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PROCEEDINGS

Editors:
Ljubiša Balanović
Dejan Tanikić

18-21 October 2023, Bor Lake, Serbia

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PREFACE

On behalf of the Organizing Committee, it is a great honor and pleasure to welcome all esteemed participants of the 54th International October Conference on Mining and Metallurgy (IOC 2023), scheduled to take place at the picturesque Bor Lake, Serbia, from October18th to 21st 2023.

The collaborative efforts of the University of Belgrade, the Technical Faculty in Bor, and the Mining and Metallurgy Institute Bor have meticulously organized this year's IOC. Our focus remains unwavering on showcasing the latest research findings and advancements in geology, mining, metallurgy, materials science, technology, environmental protection, and other engineering disciplines. Our primary objective is to foster a dynamic environment where academics, researchers, and industry professionals can come together to share their knowledge, experiences, and innovative ideas while exploring opportunities for collaborative research endeavors.

Our conference agenda is rich and diverse, encompassing plenary sessions, engaging invited lectures, technical presentations, enlightening oral and poster sessions, informative technical tours, a diverse exhibition, and memorable social gatherings. At the heart of this event lies our strong commitment to sustainable development within the mining and metallurgy sector. We are dedicated to exploring ecologically conscious methodologies, responsible resource extraction practices, and cutting-edge technologies that reduce the industry's environmental impact and enhance the well-being of local communities.

The conference proceedings comprise 129 papers authored by individuals from universities, research institutes, and industries in 22 countries. We are proud to welcome participants from Bosnia and Herzegovina, Bulgaria, Canada, China, Croatia, Germany, Greece, India, Iran, Kazakhstan, Libya, North Macedonia, Montenegro, Morocco, Romania, Russia, Slovakia, South Africa, Spain, Turkey, United States, and, of course, Serbia.

We are excited to host the 8th International Student Conference on Technical Sciences (ISC 2023) as part of IOC 2023. This event offers students from Serbia and the wider region a unique chance to showcase their research and discuss the future of their fields with experts.

We sincerely thank the Ministry of Science, Technological Development, and Innovation of the Republic of Serbia for their generous financial support. In addition, we express our profound gratitude to all our sponsors, exhibitors, and friends of the Conference for their contributions and unwavering support for playing a pivotal role in ensuring the success of IOC 2023.

We would like to express our heartfelt thanks to all authors, committees, reviewers, speakers, and chairpersons for their invaluable contributions in shaping IOC 2023.

We look forward to welcoming you to the 55th International October Conference on Mining and Metallurgy (IOC 2024), which will be held in October 2024.

On behalf of the 54th IOC Organizing Committee,

Prof. dr Ljubiša Balanović

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APPLICATION OF IMAGE ANALYSIS FOR CVITATION EROSION RESISTANCE MONITORING OF SOME ENGINEERING MATERIALS

Tatjana Volkov-Husović[1], Sanja Martinović[2], Ana Alil[2], Milica Vlahović[2]

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Abstract

Engineering materials are often used in various operating conditions including high temperatures, pressure, aggressive solutions, or cavitation erosion. The phenomenon of cavitation erosion is expected when fluid flow is present, which contains equipment such as turbine blades, high-speed propellers, or pump parts. Cavitation erosion usually causes surface degradation of material with defects that appear in the form of pits and fractures. Such loss of material leads not only to surface degradation but usually also to strength deterioration with the potential risk of failure and therefore also to shortening of material lifetime, thus requiring additional costs for failure analysis, repair, and replacement of parts. This paper will present the results regarding the resistance of various engineering materials to cavitation erosion. As materials, austenitic stainless steel 316L and CuAlNi shape memory alloy are selected and studied. The comparison of the behavior between these two materials in cavitation erosion conditions will be shown based on the results of mass loss and morphology analysis of the pits formed at the surface over time. Image analysis tools will be applied in order to quantify the surface damage level and to analyze selected morphology descriptors.

***Keywords**: Cavitation erosion, 316L steel, CuAlNi SMA, Image analysis*

1. INTRODUCTION

The behavior of various engineering materials in different operating conditions is of great interest since the lifetime of the material and/or part of equipment can be monitored and predicted, taking into account material degradation during exposure to temperature, pressure, aggressive solutions, or other conditions over time. One of the parameters that should be studied is cavitation erosion. Hammitt noted in early 1960 that the erosive aggressiveness of cavitating flows can be assessed through a consideration of energy conversion predicting the instantaneous surface impact power of collapsing cavities from the potential energy hypothesis, not on the cavitation type. The cavitation erosion model is based on partly theoretical and partly empirical considerations. The empirical approaches are derived from the knowledge that was achieved in previous studies by various authors, and that continues to this day [1-3].

Through experimental investigations and statistical calculations, an obvious connection between the cavitation structures and cavitation erosion was established. There are four different phases of the cavitation erosion process that ultimately lead to pit formation [1-3]:

- Collapse of the cavitation cloud that causes a shock wave radiating into the fluid;
- The magnitude of the shock wave is attenuated as it travels toward the solid surface;
- Single bubbles present near the solid surface begin to oscillate producing a micro-jet phenomenon if the bubble is close enough to the wall;
- The damage (single pit) is caused by a high-velocity liquid jet impacting the solid surface.

Numerous studies have shown the existence of four different time periods that can be correlated to the different erosion mechanisms [4]:

I. An incubation period that is characterized by negligible loss of material, elastic or plastic deformation of the material, and the formation of some microcracks;
II. An accumulation zone is a period of time associated with increasing material loss due to the propagation of cracks in exposed materials;
III. An attenuation period in which the rate of material loss decreases;
IV. A stable period or steady-state zone in which the erosion rate is substantially constant.
Image analysis has various tools that offer a simple and reliable quantification of visual information (optical or SEM microphotographs). In this paper, Image Pro Plus, as a software program, will be applied to monitor the levels and characteristics of damages.

Metallic materials such as stainless steel and shape memory alloys (SMAs) are widely used in the fields of electronics, machinery, energy, aerospace, civil engineering, automotive, medicine, and everyday life [4,5].

2. EXPERIMENTAL

2.1 Samples preparation

Stainless steel: Powder of commercial austenitic stainless steel (SURFIT TM 316L) with a diameter from 45 to 90 μm was used. The spherical shape steel powder was obtained by gas atomization with a particle size below 45 μm. The samples were pressed at approximately 150 MPa and then sintered at a temperature of 1200°C for 60 minutes in a vacuum furnace.

The polycrystalline Cu-12.8Al-4.1Ni (wt.%) SMA was prepared using pure raw materials of copper, aluminum, and nickel in a vacuum induction furnace at a temperature of 1240°C. Using a vertical continuous casting device connected to a vacuum induction furnace, a solid bar of 8 mm was produced directly from the melt. The bar was continuously cast at a casting speed of 320 mm/min (as-cast state). After the casting, the heat treatment procedure was performed by a solution annealing at 885°C for 60 minutes and then quenching in water [6].

2.2 Methods

Cavitation erosion was performed using standard ultrasonic vibratory testing with a stationary sample [8]. Samples were dried between the tests, then measured in order to monitor specimen weight change, and photographed in digital form for further image analysis.

3. RESULTS AND DISCUSSION

According to the standard procedure, degradation of the samples exposed to cavitation erosion is monitored using mass loss results. Obtained measurements of mass loss for studied samples are given in Figure 1. Based on the obtained results, it was found that both samples exhibited excellent cavitation resistance. However, the SMA sample showed better results with minimal mass loss after over 7 hours of testing (420 minutes).

The levels of surface degradation for both tested samples, stainless steel and SMAs, are given for different times of exposure. The results for the samples based on steel are given during an exposure time of up to 60 minutes, while the exposure time for the SMA samples time was 420 minutes. Calculated values of surface degradation level and microphotographs of the damaged surfaces presenting the morphology of degradation are given in Figure 2. Based on the total area of formed pits level of degradation was calculated, and the obtained results are presented. The level of degradation for both samples is low, but better values are related to the SMA sample, especially in the case of a very long time of exposure to cavitation erosion (420 minutes).

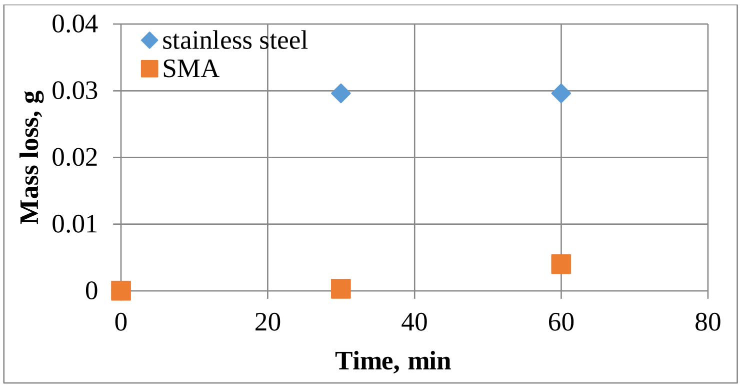

Figure 1 - Mass loss of the samples during cavitation testing

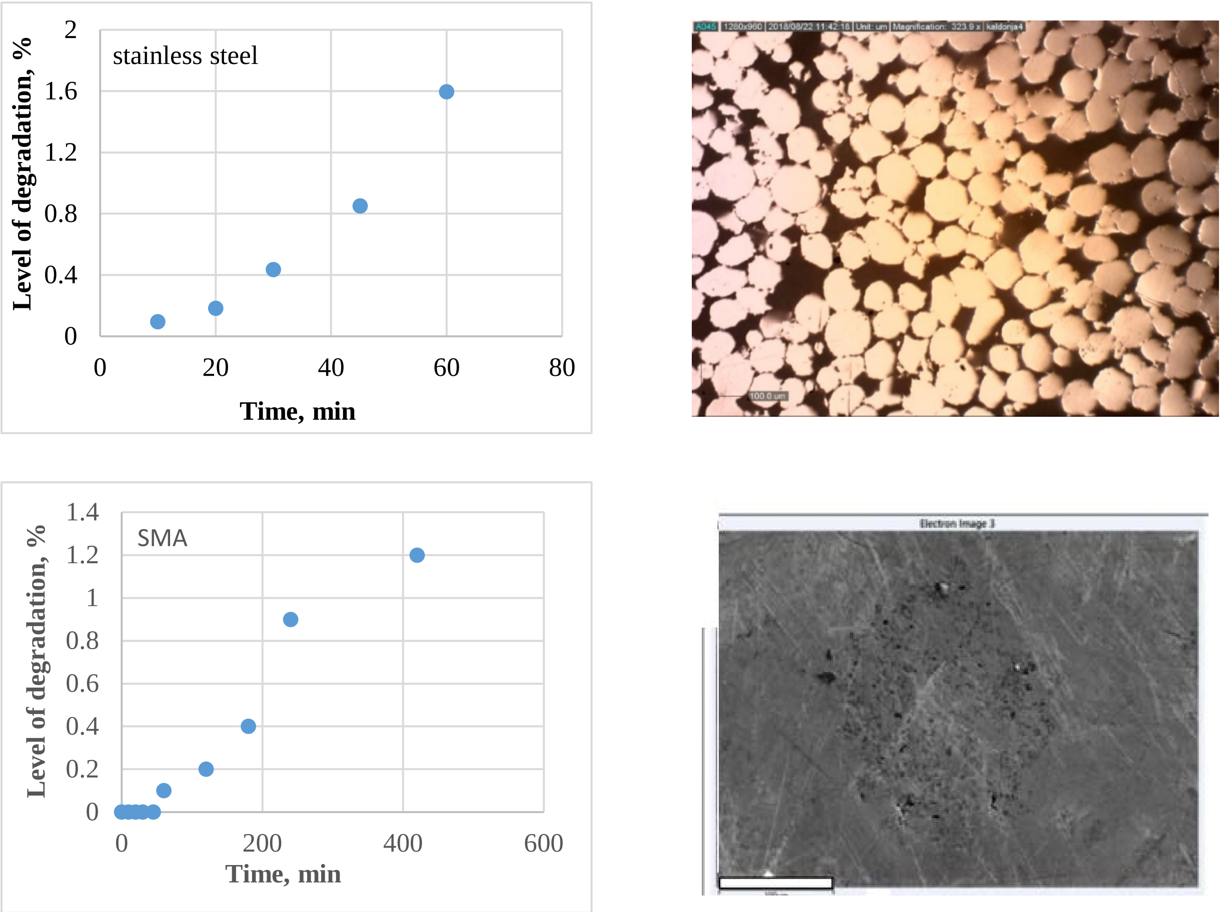

Figure 2 - Level of degradation during testing and microphotographs of the sample surfaces at the end of testing

Besides the above-presented results, the morphology parameters that are characteristical for the formed pits (damages) are also quantified and given for the stainless steel and SMA samples after 60 and 420 minutes, respectively. Selected morphological parameters that best depict the formed pits and therefore used in further image analysis are as follows: *Area*, *Diameter (max)*, *Diameter (mean)*, *Diameter (min)*, *Radius ratio*, and *Roundness*. The average values of measuring selected morphological parameters regarding formed pits are shown in Table 1.

Table 1 - Analysis of morphological parameters for the SMA's and steel 316L.

Parameter	**SMA**	**Steel 316L**
	420 minutes	**60 minutes**
Area, µm^2	36.17	1.8
Diameter (max), µm	9.55	1.7
Diameter (min), µm	3.25	0.8
Diameter (mean), µm	6.28	1.2
Radius (min), µm	0.72	1.5
Roundness	1.25	1.65

The obtained results confirmed that characteristics of the formed pits related to the SMA samples also exhibited better values considering the time of exposure. However, steel samples also showed very good cavitation erosion resistance.

4. CONCLUSION

The behavior of two metallic engineering materials, stainless steel and SMAs, was analyzed with the aim of monitoring their resistance during exposure to the cavitation resistance. In addition to measuring mass loss over specific time periods of exposure to cavitation erosion, the overall levels of surface degradation were calculated, and characteristic morphological parameters for formed pits and damages were quantified.

The obtained results can point out the following conclusions:

- Results indicated that SMAs exhibited superior resistance to cavitation erosion;
- Stainless steel was quite good, but not as good as in the case of SMAS, as expected.

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