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CAVITATION EROSION MONITORING OF 42CrMo4 STEEL SAMPLES USING THE IMAGE AND MORPHOLOGICAL ANALYSIS

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Abstract: *The choice of steel depends on environmental factors like temperature, pressure, and chemical exposure. Steel components in machinery often face varying conditions that can lead to damage, such as cavitation erosion. In this study, steel 42CrMo4 samples were chosen to represent a common and widely used steel. Application of this type of steel is often related to the statically and dynamically stressed components for vehicles, engines, and machines, where corrosion or cavitation can occur. The behavior of steel samples under conditions of cavitation erosion in distilled water was the focus of this paper. Testing was performed using a standard cavitation vibratory setup using a stationary specimen, according to the ASTM G-32 procedure. Image and morphological analyses were implemented to quantify the level of sample degradation caused by cavitation. The observed changes in the monitored parameters during testing are linked to the degradation mechanism of cavitation erosion. The results showed that pits began forming within 60 minutes, and afterward, the growth and merging of these pits significantly impacted the degradation process.*

Keywords: *Cavitation erosion, Image analysis, Degradation level, Morphology analysis*.

1. INTRODUCTION

A thorough understanding of the material's behavior during cavitation is essential for engineers and researchers to evaluate its performance and durability. The objective of this approach is to provide the development of more reliable and long-lasting steel components for industrial use. Steel 42CrMo4 is selected because of its exceptional mechanical properties, such as strength, toughness, and wear resistance. It is commonly used in applications where durability and resistance are crucial, including the automotive, aerospace, and hydraulic sectors [1]. Steel 42CrMo4 is essential in marine engineering, hydraulic systems, and power generation [2]. In marine equipment parts, it is used for producing propellers and other underwater components that are constantly exposed to cavitation and corrosion. In hydraulic systems, it is essential for components like pumps and valves that experience high-pressure fluctuations. In power generation, it is crucial for turbine blades and other parts that are subjected to intense cavitation forces [1-3]. However, the marine equipment parts made of 42CrMo4 steels are very susceptible not only to corrosion but also to cavitation erosion due to their synergistic effect. The subject of some investigations was based on the synergistic effect of cavitation erosion-corrosion, but mainly focusing on non-ferrous metals [4,5]. Thus, the purpose of this study was to examine the effects of cavitation and corrosion on steel 42CrMo4 first separately, and then in simultaneous action.

The term "cavity" originates from the Latin word ‘cavus’, meaning hollow [6]. Cavitation refers to the dynamic process involving the formation, growth, and collapse (implosion) of bubbles within a liquid. The beginning of cavitation is closely related to liquid pressure [7-15]. When implosion happens in close vicinity of a solid surface, material can detach from a surface inducing surface erosion and resulting in cavitation damage. This damage is observed in various hydraulic constructions including ship propellers, hydrofoils, dam overflows, valves, tunnels, hydraulic pumps, and turbines [7,12,15-18]. Numerous studies have been extensively conducted by researchers like Hofmann et al. (2022) [19] relating the cavitation erosion of martensitic stainless steel X3CrNiMo13-4 QT780. Gao et al. (2019) [20] conducted cavitation erosion tests on stainless steels 316L and 420 to predict damage. Raami et al. (2023) [21] improved the cavitation erosion resistance of AISI 420 stainless steel through quenching and partitioning heat treatment. Building on the work of Lloyds Register, Basumatary (2017) [6] investigated the cavitation erosion of various materials including duplex stainless steel (DSS) and as-cast nickel aluminium bronze (NAB), 13/4 martensitic

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stainless steel, 42CrMo4 low alloy steel, carbon fibre reinforced composites, and LRAH32 low carbon steel. Basumatary et al. observed the response of these materials to cavitation erosion in laboratory prepared ASTM standard seawater in a NaCl solution (3.5%) and found that DSS and NAB exhibit superior resistance [22] thus focusing their subsequent research on these materials.

Additionally, Bărbulescu et al. (2023) [23] investigated brass corrosion under cavitation conditions in seawater, while Vuksanović et al. (2021) [24] examined the cavitation resistance of aluminum-zirconium composites. These studies provide valuable insights into materials' behavior under cavitation, however, there is a lack of research specifically focused on the cavitation resistance of 42CrMo4 steel. To assess cavitation resistance in annealed 42CrMo4 steel, Bordeas et al. (2017) [25] proposed utilising the roughness parameter Rz, which would complement the findings of Dojčinović's (2013) [26] study on quenched and tempered 42CrMo4 steel.

The main aim of this study is to analyze cavitation erosion in 42CrMo4 steel samples using image and morphological analysis.

2. EXPERIMENTAL

The samples for cavitation testing were prepared by cutting in the form of rectangular prisms with dimensions of width and length of 20 mm × 20 mm. To obtain standardized samples, a 10 mm thick plate was processed on a milling machine and reduced to a thickness of 4 mm. The prepared samples were subjected to a cavitation erosion test using the ultrasonic vibration method (with a stationary sample), following ASTM G32-16 standard. An ultrasonic generator with a frequency of 20 ± 0.2 kHz created cavitation bubbles. The ultrasonic horn had a 16 mm diameter, and the working distance between the horn tip and the specimen was set to 0.5 mm. Test samples were placed on a platform in a beaker of distilled water at 22 ± 1°C. The specimens were weighed before and after each cavitation exposure period. An optical microscope monitored surface damage morphology. Mass measurements were taken using an analytical balance with 0.1 mg accuracy.

To evaluate surface erosion, the samples were inspected with a trinocular metallurgical microscope (EUME, EU Instruments, Gramma Libero, Belgrade) at different magnifications. Additionally, SEM images were captured using a JEOL JSM-5800 to observe changes during cavitation erosion. Defects from cavitation erosion can be described using morphological descriptors and quantified with image analysis tools in the Image Pro Plus 6.0 software (IPP) package (Media Cybernetics, 2006, Rockville, MD). The sample surface was scanned at 1200 dpi resolution after each cavitation erosion period and processed with IPP. Morphological features that best characterize the surface defects (pits) were selected after segmenting the defects.

3. RESULTS AND DISCUSSION

The results that are most commonly used for degradation monitoring represent the mass loss during testing and are presented in Figure 1. Different periods of cavitation were marked. The Incubation period (I) is very short, indicating that the sample is most sensitive to pit formation, and the energy for pit formation is rather low. The accumulation period (II) lasted for 30 min (10-40 min), followed by an attenuation period lasting 20 min (40-60 min). The steady-state period began after 60 min. As the exposure time was 120 min, further experiments will provide the results for the duration after this period.

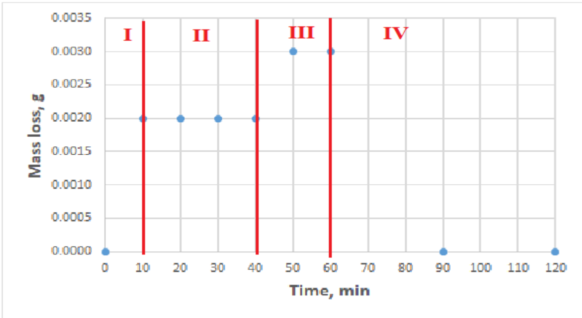

Figure 1. Mass loss during cavitation testing

Samples images using optical (OM) and scanning electron (SEM) microscopy before and after testing for 120 minutes are presented in Figure 2.

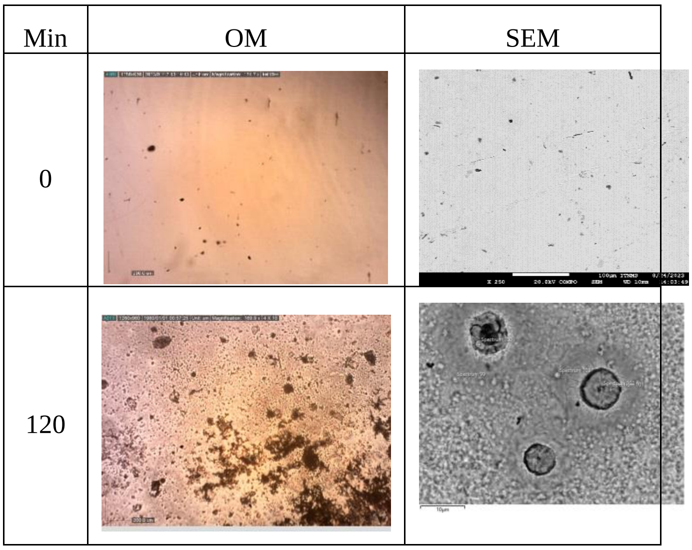

Figure 2. Image of the samples using OM and SEM before and after 120 minutes of testing

Morphological analysis was performed using Image-Pro Plus software, which enables the quantitative analysis of selected morphological parameters. The parameters that were selected and monitored were the average pit area, total pit area, and the number of formed pits. The results are shown in Figure 3.

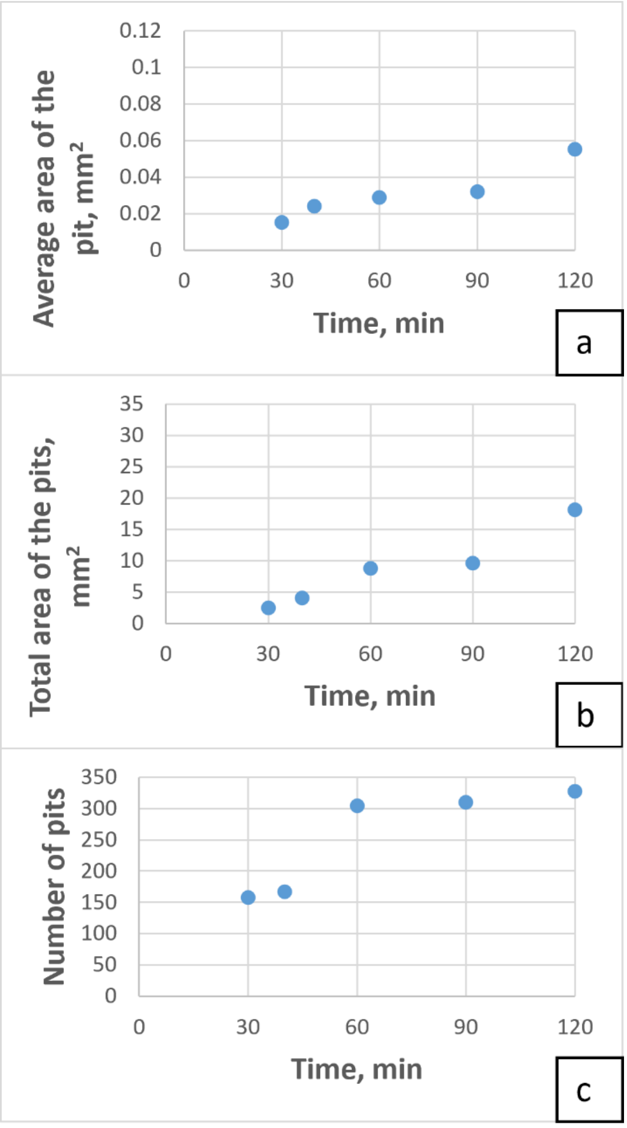

Figure 3. Monitoring of morphological parameters during testing (average values): a) single pit area, b) total pit area, and c) number of formed pits

The total area of the formed pits and the average area of the formed single pit increased during the experiment, as expected (Figure 3a and 3b). These results are in correlation with the increasing number of pits (Figure 3c), thus leading to the conclusion that forming pits is the dominant mechanism during cavitation testing. After 60 min, this increase slowed, which suggests that pit growth and merging of the smaller single pits also have a significant influence on the degradation mechanism.

4. CONCLUSION

The cavitation erosion of 42CrMo steel sample was monitored using mass loss and morphological analysis. Mass loss results were used to divide the cavitation erosion into four periods as well as the duration of each period. Quantitative morphological analysis was performed using selected parameters such as the average area of the single pit, the total area of the pits, and the number of formed pits. These changes in the monitored parameters during testing could be related to the degradation mechanism during cavitation erosion. The results indicated that pit formation occurred over 60 min, after which pit growth and merging of the formed pits had a significant influence on the degradation mechanism.

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