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Destruction Mechanism of Z10400 Zn-based Alloy Subjected to Cavitational Erosion

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Abstract

Z10400 zinc-based alloy has a very good casting properties and high resistance to corrosion. These two advantages make that Z10400 zinc-based alloy is commonly used for cathodic protection of hulls of ships. Cathodic anodes made of Z10400 zinc-based alloy in the propeller and flap rudder areas are also additionally exposed to the cavitation erosion. The aim of this work was to determine the cavitation erosion resistance of Z10400 zinc-based alloy, which is applied as protectors in cathodic protection of hulls of ships. The examination of cavitational erosion was carried out on a jet-impact measuring device. Study of the mechanism of the destruction of Z10400 alloy based on analysis was performed with scanning electron microscope Quanta 3d FEG and electron back scattered diffraction (EBSD) method.

Keywords: Zinc alloy, Cavitation, Cavitational wear, Electron back scattered diffraction (EBSD)

1. Introduction

Zinc-based cast alloys are characterized by good castability, good corrosion resistance and the dimensions invariability upon aging treatment. Zinc alloys can be cast into sand and permanent moulds and under pressure. Depending on type of addition elements, alloyed zinc alloys can be divided into Zn-Al, Zn-Al-Cu and Zn-Mn-Cu based alloys. Zn-Al alloys due to their high dimensional accuracy during casting, high-strength and corrosion resistance and good castability and machinability are mostly prevalent. Zn-Al cast alloy containing up to 6 wt. % Al shall be applied on the cover, enclosures, parts, printing machines, cameras and industrial fittings (handles, levers). Zinc alloys with higher amount of aluminum (6-11% Wt) are actually used for casting moulds and dies, carburetors as well as bearings and bushings. Zn-Al zinc alloys due to their low electrochemical potential (approx. -1,1 V) are used as protective anodes in seawater environment. Anode plating made of cast Zn-Al alloys are placed on the hull of the ship, providing good protection for the entire structure. Cathodic anodes in the propeller and flap rudder areas are also additionally exposed to the cavitation erosion. Formation of vortical cavitation phenomenon in propellers area accelerates the destruction of ship's hull protectors installed on these parts. In order to properly protect surrounding of the stern of ship against corrosion, it is recommended to install more cathodic anodes [1-4].

The aim of this work was to determine the cavitation erosion resistance of Z10400 zinc-based alloy, which is applied as protectors in cathodic protection of hulls of ships.

2. Material and experimental details

Z10400zinc-based alloy is investigated material in this paper. This alloy is commonly used as pressure casts with high dimensional accuracy for precision industry, automotive, electrical and mechanical engineering. The structure of ZnAl4 alloy is characterized by η solid solution dendrites and $\eta+\alpha$ eutectic located in inter-dendrite spaces [5] (Fig.1).

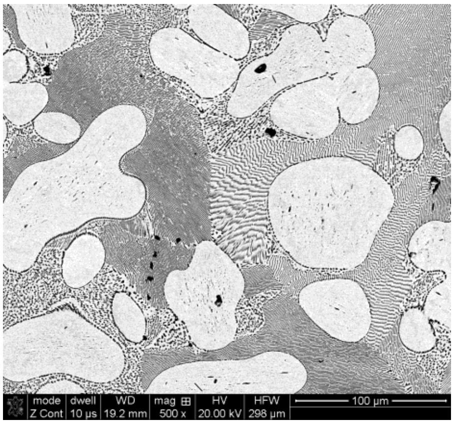


Fig. 1. Microstructure of Z10400 zinc-based alloy

Chemical composition and selected mechanical properties of tested Z10400 alloy are shown in Table 1.

Table 1.
Chemical composition and mechanical properties of Z10400 alloy [5]

Chemical element and mechanical properties	Z10400
Al	3,80 ÷ 4,20
Mg	0,045
Zn	bal.
Fe	0,020
Cu	0,030
R_m min [MPa]	280
$R_{e0,2}$ min [MPa]	200
A_5 min [%]	10,0

3. Methods of investigation

Polished alloy samples Z10400 were subjected to cavitational wear test on a jet-impact device (Fig. 2).

Examinated samples had cylindrical shape with 20 mm diameter and 6 ± 0,5 mm height. Surface roughness of samples before tests, measured by PGM-1C profilometer, was in range of 0,010÷0,015 μm. The samples were vertically mounted in rotor arms, parallel to the axis of water stream pumped continuously at 0,06 MPa through a 10 mm diameter nozzle located 1,6 mm away from the sample edge. The rotating samples were hitting by the water stream. Water flow of 1,55 m^3/h was constant during entire experiment. The samples were examined up to 120 minutes. After 5, 15, 30, 60, 90 and 120 minutes samples were taken out from rotor arms, degreased in an ultrasonic cleaner for 10 minutes at 30°C, dried in a laboratory drier for 15 minutes at 120°C and finally weighted as well as observed on microscope. After that, specimens were mounted again in the rotor arms with maintaining their initial position in relation to the water stream.

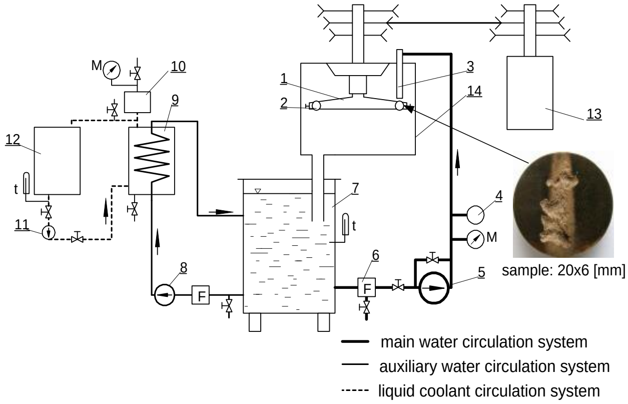


Fig. 2. A scheme of jet-impact measuring device: 1-rotor, 2-sample, 3-nozzle, 4-flow-meter, 5-pomp, 6-self-rinsing filter,7-circulating tank, 8-pomp of the cooling system, 9-cooler, 10-equalizing tank, 11-coolant pomp, 12-refrigerator, 13-elektric motor, 14-rotor casing

Electron backscattered diffraction (EBSD) system coupled with field emission gun scanning electron microscopy (FEG SEM) was applied to estimate lattice strain introduced by action of cavitational beam after 5 minutes. For each sample EBSD data were taken from 250 x 250 μm (for fine-grained alloy), or from 1200 x 1200 μm (for coarse-grained alloy) area. Assessment of lattice strain was conducted by local misorienation approach [6]. This method assumes that strain induced dislocation structure development is associated with rotation of "microvolumes" (cells, subgrains) leading to increase of local misorientation between adjacent points [7]. There are few metrics that may be use for quantitative analysis in this approach [8]. In present paper, following parameters were chosen:

- GOS (Grain Orientation Spread) - the average orientation of the grain is calculated, and then the misorientation between this average orientation and the orientation of each individual measurement point within the grain is calculated.
- KAM (Kernel Average Misorientation) – for a given data point the average misorientation between the data point and all of its neighbors is calculated (exclude misorientations greater than some prescribed value - 5° in this case).

4. Results and discussion

The process of destruction initiates on phase boundaries between η solid solution dendrites and $\eta+\alpha$ eutectic. First single losses of material are visible after 5 minutes of the water stream hitting (Fig. 3), after 15 minutes marks of plastic deformation are visible on the surface of sample (Fig. 4).

a) b)

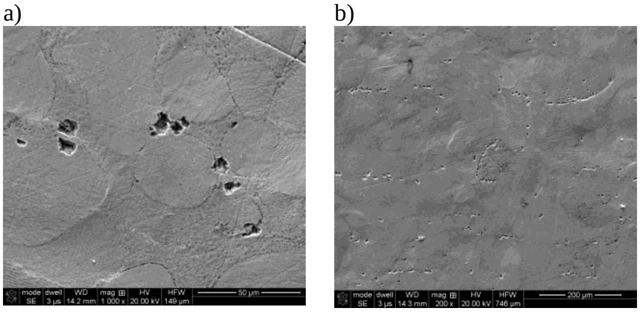


Fig. 3. a,b. Effects of cavitational erosion of Z10400 zinc-based alloy after 5 minutes of test

Presence of plastic deformation is also confirmed by EBSD strain analysis with GOS and KAM parameters (Fig 5-7). Analysis of surface distribution of GOS and KAM parameter presented in Fig. 2 clearly indicates on strain localization in near grain boundary areas - where the highest KAM values (marked with orange and red colors) were observed. This finding was also confirmed by SEM observation of worn surface of alloy (Fig. 5), where effect of material uplifting in boundary area was distinctly visible.

a) b) c)

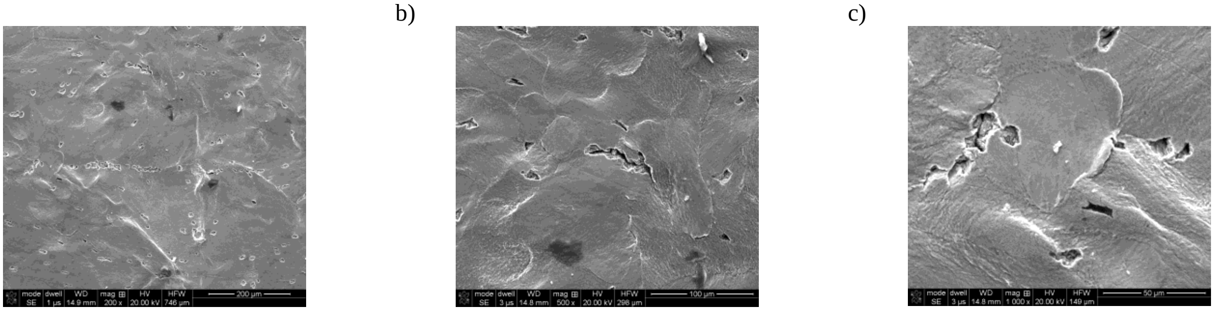


Fig. 4. a,b,c. Effects of cavitational erosion of Z10400 zinc-based alloy after 15 minutes of test

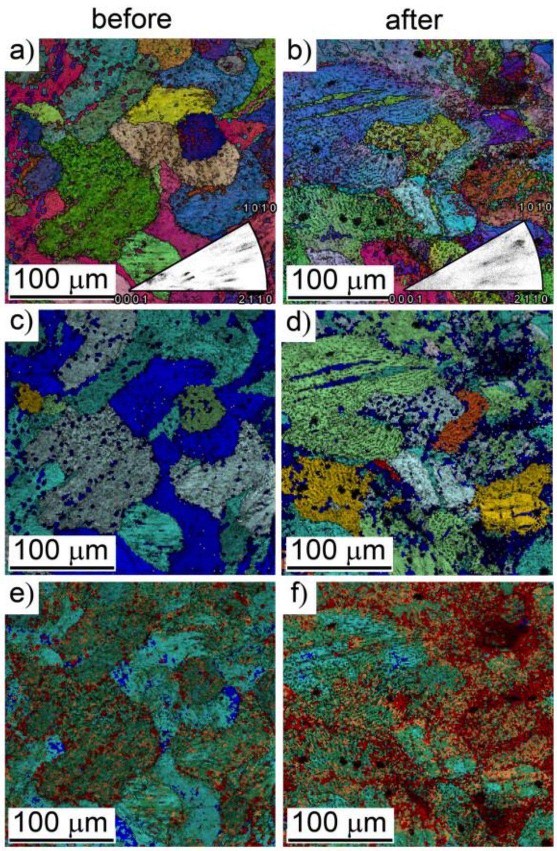
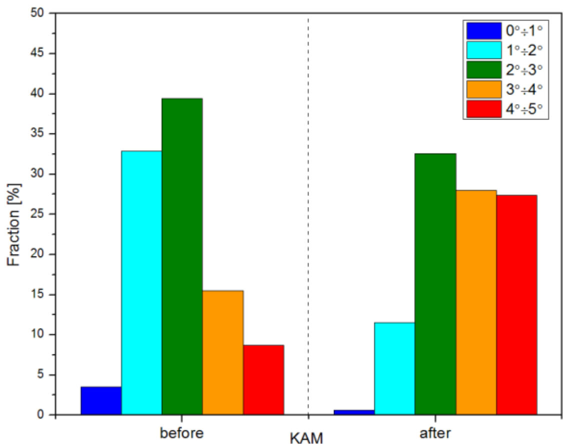
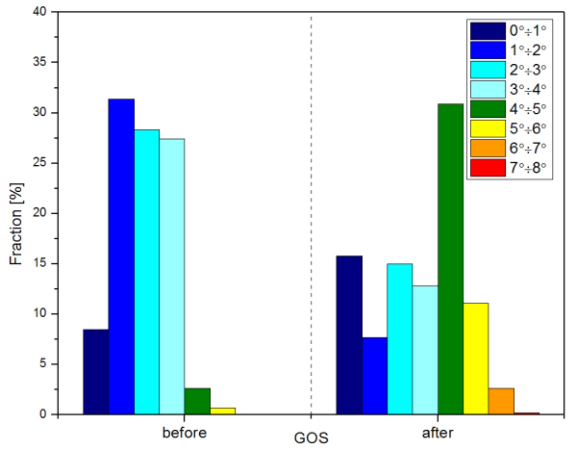


Fig. 5. EBSD maps taken from Zn sample surface before and after 5 minutes of cavitation test:
a-b) Inverse Pole Figure maps, c-d) Grain Orientation Spread maps, e-f) Kernel Average Misorientation maps



a)



b)

Fig. 6. a) KAM and b) GOS fractions in particular misorientation angle ranges before and after 5 minutes of cavitation test

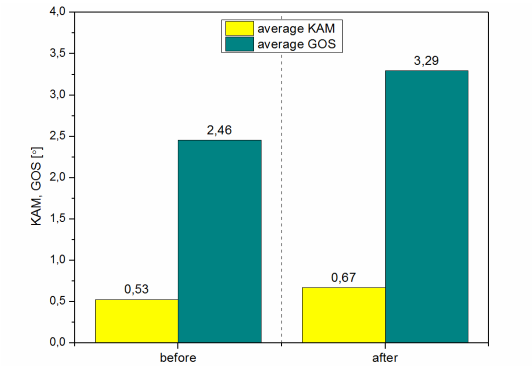


Fig. 7. Average KAM and GOS values before and after 5 minutes of cavitation test

Further exposition on liquid stream leads to coalescence of individual pits and thus formation of craters located in phase boundaries, as well as prominent plastic deformation of the surface (Fig. 8a). Depth of the craters is subsequently increased during the accelerated erosion period, through a process of gradual destroying of whole grains or their crushing (Fig. 8b).

a) b)

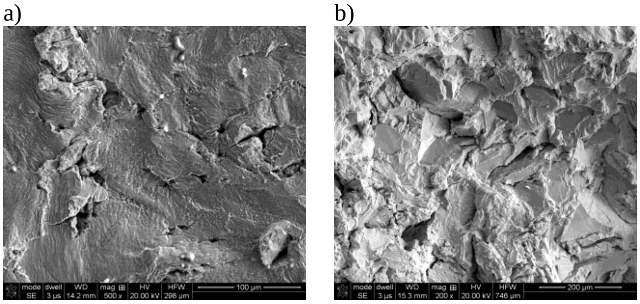


Fig. 8. Effects of cavitational erosion of Z10400 alloy after: a) 30 minutes, b) 60 minutes of test

After 60 minutes of testing, surface fatigue striations were observed on craters walls, what confirms the presence of fatigue stresses in the material.

Analysis of obtained results of resistance to cavitational wear of the Z10400 zinc-based alloy, allows separating two destruction stages: incubation period and volume decrement rate increase period. The incubation period takes 30 minutes, and after this time, rapid erosion of Z10400 zinc-based alloy takes place (Fig. 9).

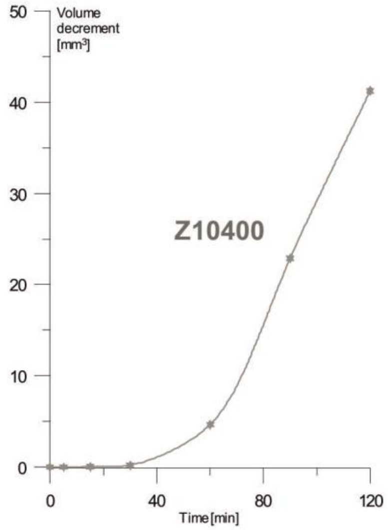


Fig. 9. The curve of the volume loss as the function of time obtained for Z10400 zinc-based alloys

5. Conclusion

Cathodic protection is an effective prevention method which has been applied in this area for many years. In this method, potential of the ship's hull is reduced by using galvanic anodes (so-called protectors), which are additionally exposed to cavitation erosion. Z10400 zinc-based alloy is a material with the good mechanical properties, but with the lowest resistance on cavitation erosion. Due to the low resistance to cavitation erosion of Z10400 zinc-based alloy, in order to ensure effective protection of the hull of the ship, it is necessary to deploy a larger number of zinc protectors in the places most sensitive to this type of erosion.

Acknowledgements

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