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EBSD Strain Analysis of CuZn10 Cast Alloy During Cavitational Wear

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Abstract

Microstreams of liquid formed during the implosion of cavitation bubbles and the effects of pressure waves coming from disappearing bubbles are the main causes of damage of the washed surface, leading to loss of material (the cavitation erosion). Repeated cavitation implosions cause non-uniform stress state resulting in the strengthening of the surface layer, change of micro-geometry and surface cracks leading to detachment of the material particles. Course of cavitation erosion process depends on the effects of plastic deformation at the beginning of the destruction. The aim of this study was analysis of plastic deformation by EBSD method of CuZn10 cast alloy at the beginning of the cavitation destruction process.

Keywords: EBSD, Cavitation, Cavitational erosion, Strain analysis

1. Introduction

Cavitation is the process of formation, growth and implosion of bubbles containing steam, gas or steam-gas mixture due to cyclic pressure changes in the flowing liquid [1-3]. The implosion of cavitation is an effect of pressure change from the area of its low value to a region of elevated pressure, causing condensation of steam which fills the cavitation bubble. Implosion phenomenon occurs at very high velocity (exceeding 100 m/s), and in such case time of growth and decay of cavitation bubble is in the order of milliseconds. According to Plesset and Chapman [4], the dynamics of the formation and sealing of bubble is dependent on the physicochemical properties of the liquid, the distance between the wall and the interaction of bubbles. The neighborhood of the wall creates a bubble in imploding microstream, which can reach a velocity of 300 to 500 m/s [5].

Microstreams formed during the implosion of cavitational bubbles transmit on the wall pressure pulses in the order of 1÷4 GPa. Multiple repetitive cavitation implosion causes vibration of walls, and then elastic and plastic deformation of the surface (as schematically shown in Fig. 1).

According to Hickling and Plesset [6] only that microstream of bubbles which are located away from the wall at a distance no greater than the radius of the largest bubble have the pressure that causes destruction of the material. Results of study by Krause and Mathias [7] carried out on a impact beam stand shown that, in place of the impact of the water stream very high compressive stresses are formed in a short time (30 seconds) in the surface layer area, causing a change in the surface microgeometry.

The aim of this study was analysis of plastic deformation by EBSD method of CuZn10 cast alloy at the beginning of the cavitation destruction process.

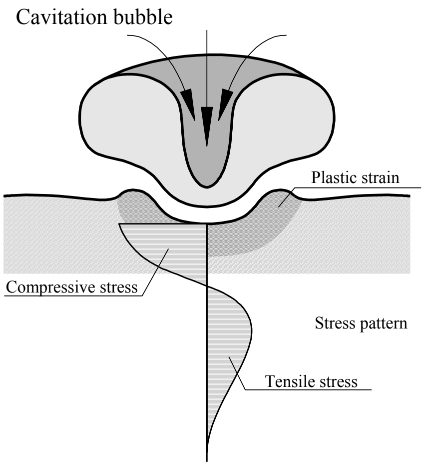

Fig. 1. Stress distribution during the implosion of cavitation beam near the wall

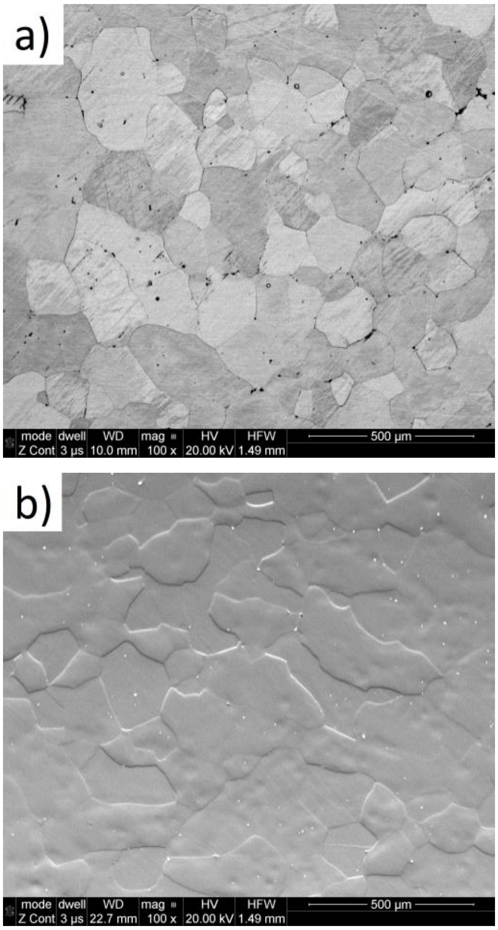

Fig. 2. Microstructure of CuZn10 alloy in initial state: a) BSE, b) topography

2. Material and experimental details

The research was carried out on CuZn10 alloy in as-cast state. This material has single-phase structure of α solid solution of zinc in copper. Investigated material was obtained by melting and casting of pure elements in PIT 10 induction furnace. Microstructure of CuZn10 alloy in initial state is presented in Fig. 2.

Surface of the brass sample before wear experiment was prepared with normal metallographic routine, which include grinding with SiC abrasive papers (with granulation up to 1200), mechanical polishing with diamond suspension and then final polishing with silica suspension. Such prepared surface of investigated alloy was subjected to cavitational erosion on a jet-impact device (Fig. 3).

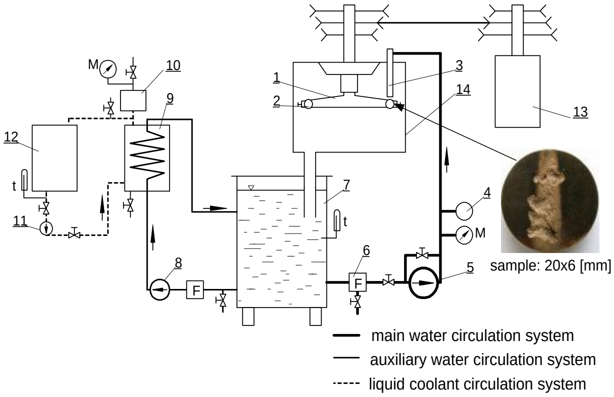

Fig. 3. A scheme of jet-impact measuring device: 1-rotor, 2-sample, 3-nozzle, 4-flow-meter, 5-pomp, 6-self-rinsing filter,7-circulating tank, 8-pomp of the cooling system, 9-cooler, 10-equalizing tank, 11-coolant pomp, 12-refrigerator, 13-elektric motor, 14-rotor casing

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. After 30, 60, 120, 180 and 300 seconds of exposition change of surface was measured by electron backscattered diffraction (EBSD) method.

EBSD system coupled with field emission gun scanning electron microscopy (FEG SEM) was applied to analyze microstructure changes upon cavitational wear but also to estimate lattice strain introduced by action of cavitational beam. Area of 1200 x 1200 μm was scanned with 6 μm step size. Collected data was then analyzed with TSL OIM Analysis 5 commercial software.

3. Results and discussion

EBSD assessment of lattice strain was conducted by local misorienation approach [8]. Previously presented data [9] clearly indicates that change of values of average local misorientation angles may be closely related with lattice quality (e.g. defects density). It was previously presented in works by Hansen et al [10], that introducing of plastic deformation is strictly related with development of dislocation substructure. Since it is well known, that strain induced introduction of geometrically necessary dislocations cause rotation of ”microvolumes” (cells, subgrains) inside each grain, some mathematical parameters that describes point-to-point misorientations may be used to assess local changes of lattice straining. In present paper, local misorientation changes were expressed by Grain Orientation Spread (GOS) and Kernel Average Misorientation (KAM) parameters. According to their definitions these parameters should be delineated as:

- GOS - in this method 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 – 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).

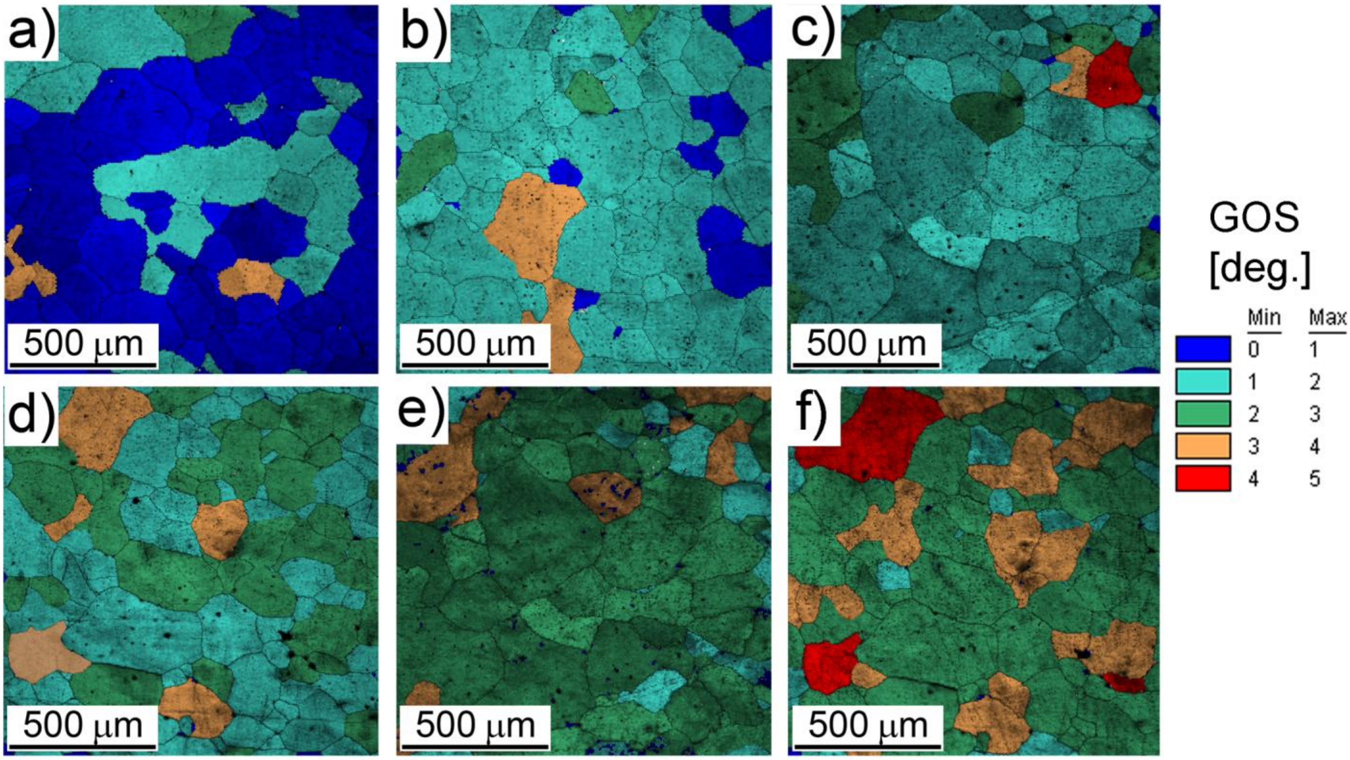

Fig. 4. Grain orientation spread (GOS) maps obtained for investigated brass in as cast state after different time of cavitatational exposure. a) initial state and after b) 30 seconds, c) 60 seconds, d) 120 seconds, e) 180 seconds, f) 300 seconds.

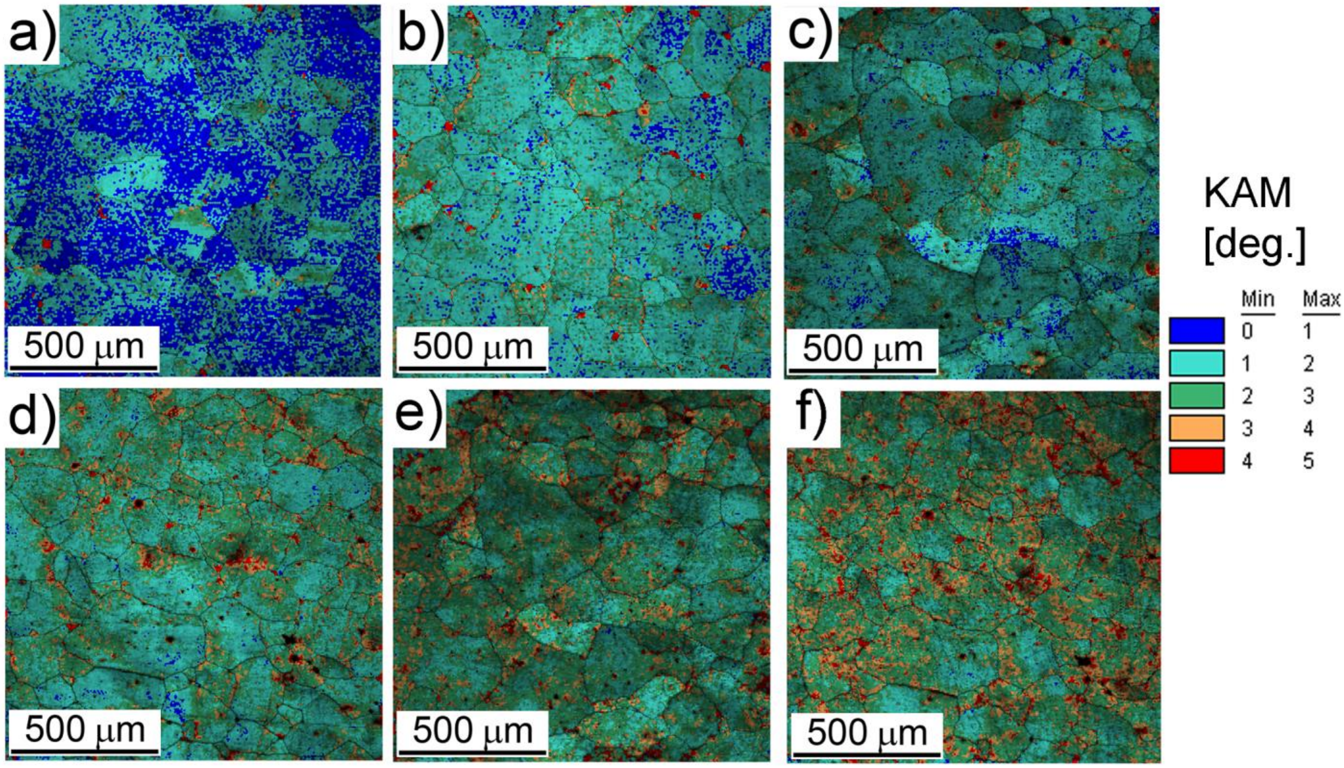

Fig. 5. Kernel Average Misoreination (KAM) maps obtained for investigated brass in as cast state after different time of cavitatational exposure. a) initial state and after b) 30 seconds, c) 60 seconds, d) 120 seconds, e) 180 seconds, f) 300 seconds.

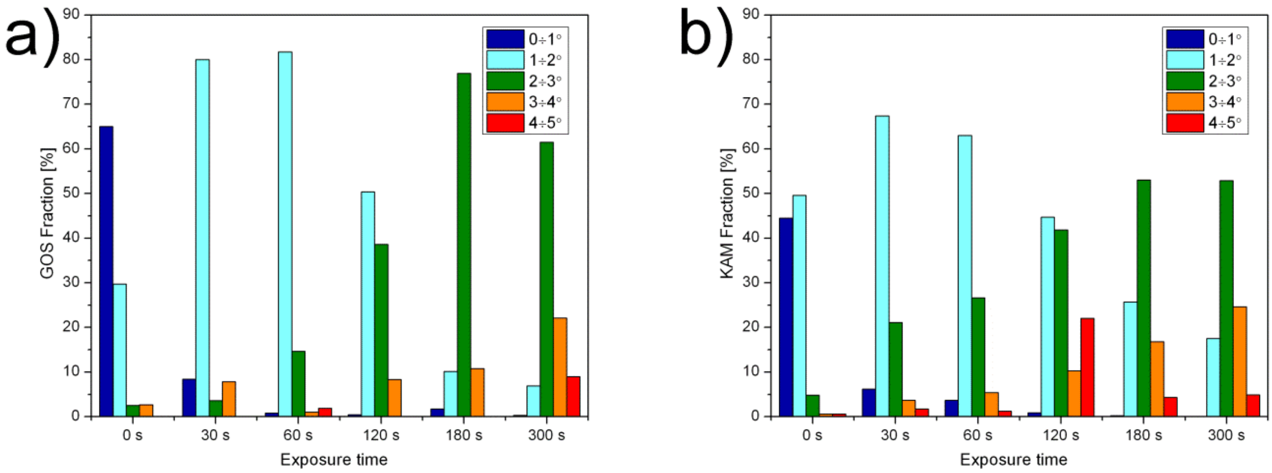

Fig. 6. a) GOS and b) KAM fractions in particular misorientation angle ranges as a function of cavitational exposure time.

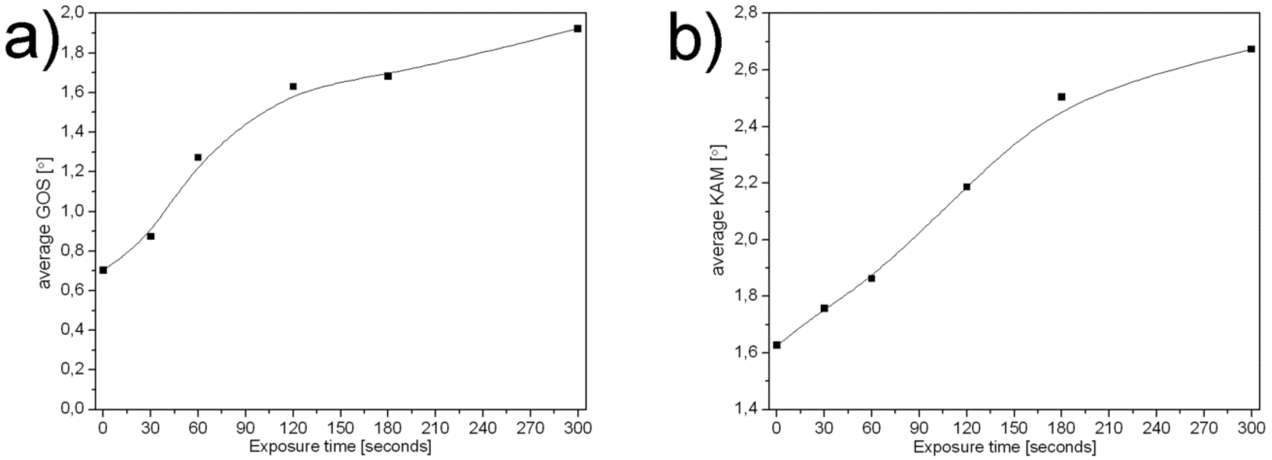

Fig. 7. a) Average GOS and b) average KAM plots as a function of cavitational exposure time.

Results of EBSD strain analysis are presented in Fig. 4-7. Fig. 4 and 5 show microstructure maps of GOS and KAM parameters after different cavitational exposure time, since Fig. 6 shows color key consistent with these maps as well as fraction of particular ranges of misorientation angles. As it may be found, elongation of exposure time leads to gradual increase of values of both considered parameters. Analysis of surface distribution of KAM parameter presented in Fig. 5 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. 8), where effect of material uplifting in boundary area was distinctly visible.

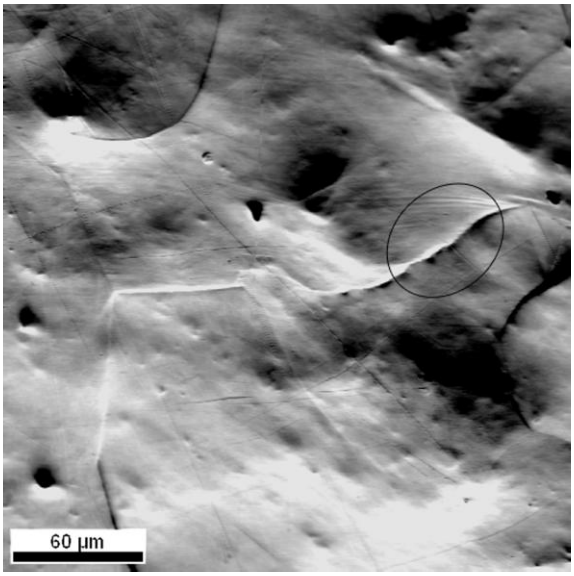

Fig. 8. SEM microphotograph of the CuZn10 brass surface after 180 second of cavitational test showing effect of material uplifting in near grain boundary area.

Additionally, course of average KAM and GOS values as a function of exposure time presented in Fig 4a and 4b show high increase of estimated lattice strains up to 120 seconds (for GOS) or 180 seconds (for KAM) of exposition time. After that, some stabilization effects may be observed. However, it should be noted, that calculated average KAM values were also affected by presence of cavitational micropits, surrounded by highly strained areas.

4. Conclusion

The cavitation erosion laeds to the material destruction, which consists of plastic deformation, material losses, changes in the microstructure as well as micro- and macrogeometry of surface. The diversity of this process makes it difficult to predict its exact course, and that is why study of initial stage of destruction are especially important. In present paper, EBSD estimation of strain introduced during cavitational erosion, has been carried out by local misorientation approach. Results of analysis of GOS and KAM parameters as a function of cavitation time indicates on prominent rise of strain up to 120 seconds of exposition. After that, rate of strain increase is substantially reduced. Additionally, analysis of KAM maps revealed strain localization in near grain boundary area confirmed also by SEM observation of worn surface.

Results obtained in present paper show that EBSD method may be efficiently applied in assessment of strain introduced during cavitation wear. In the future, it is planned to perform similar experiments for other materials.

Acknowledgements

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