ARCHIVES of FOUNDRY ENGINEERING

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

ISSN (1897-3310)
Volume 14
Special Issue
1/2014
181-186

37/1

Methods of Geometric Surface Structure Measurement of AW-2017A Alloy after Cavitation Wear

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Received 17.03.2014; accepted in revised form 31.03.2014

Abstract

Evaluation of the cavitation erosion resistance of structural materials is based on selected measurement method. Destruction of the sample surface caused by cavitation phenomenon can be evaluated in laboratory conditions by measuring few quantitative parameters e.g. loss of mass of sample, quantity or weight of detached particles, the area of the worn material, the average and the maximum depth of cavitation erosion, the change of surface roughness or the number of cavities on the surface. In this paper optical and profilometry methods of geometric surface structure measurement of AW-2017A alloy after cavitation wear, were presented and compared. The optical method was carried out on Nikon Eclipse MA200 light microscope and profilometry method was performed using TOPO 01P v3D profilometer.

Keywords: Cavitation, Cavitation Wear, Geometric Structure of Surface.

1. Introduction

Cavitation erosion is a one of the form of destruction of materials. The basic reason of cavitational destruction process are sudden changes in flowing liquid pressure. The course of process takes place in several repeated stages. Initially, liquid pressure is decreased below its critical value (which is close to liquid evaporation pressure). This stage is followed by formation of vapour-gas bubbles and finally, implosion of these bubbles in the zone of higher pressure. The repeated implosion of cavity bubbles induces destruction of the material by large plastic strain, material losses, microstructure changes and surface micro- and macrogeometry changes [1-4].

Results of previous research conducted on many different types of laboratory stands and various materials shown that the process of cavitation damage is complex and there is no one proper measurement method of this phenomenon. The most often used form of cavitation erosion measurement is the analysis of mass or volume changes as a function of exposure time. Obtained curves contain four characteristic periods: incubation period, increase of mass loss rate period, decrease of mass loss rate period and constant rate of mass loss period [5-8].

Other measurements methods of cavitation erosion included: quantitative analysis of the worn area of the material, the average the maximum depth of cavitation erosion, the change of surface roughness and the number of cavities on the surface. Evaluation of the surface changes during cavitation wear is made by photo-recording of material surface and specify the number of cavities on the surface as a function of time. On the basis of the observed number of cavities or assessment of the tested material surface actual stage of destruction can be determined. In order to define

the characteristic periods of cavitation erosion, changes of the surface area may be compared with some other parameters e.g. kinetics of mass loss [9].

Assessment of surface geometry changes is typically carried out by profilometry method, which allows to specify selected roughness parameters. The basic roughness parameters include [10]:

R_a – arithmetical mean deviation of assessed profile along the measured distance, expressed by the formula:

$$R_a = \frac{1}{n}\sum_{i=1}^{n}|y_i| \tag{1}$$

R_q – mean square deviation from the roughness profile line measured along the assesed distance, expressed by the formula:

$$R_q = \sqrt{\frac{1}{n}\sum_{i=1}^{n} y_i^2} \tag{2}$$

$R_{z(ISO)}$ – arithmetical mean roughness value taken from 10 roughness profile value, expressed by the formula:

$$R_{z(ISO)} = \frac{1}{n}\left(\sum_{i=1}^{n} p_i - \sum_{i=1}^{n} v_i\right) \tag{3}$$

R_v – maximum depth of valleys of a roughness profile along the measured distance;

R_p – maximum height of peaks of a roughness profile along the measured distance.

The average line of roughness profile necessary to calculate the above parameters is described by the following equation:

$$\sum_{i=1}^{n} y_i^2 = \min \tag{4}$$

The course of roughness changes as a function of time of cavitation erosion process is inconstant. Surface roughness increases in linear manner starting from the beginning of cavitation test. In order to correct interpretation of cavitation erosion course, the change of surface roughness should be compared with change of sample mass. The rise of roughness value without simultaneous prominent increase of mass loss suggest large plastic deformation of the tested material.

The aim of this work was to compare the two methods of geometric surface structure analysis of AW-2017A alloy after cavitation wear. The first method is based on optical analysis with Nikon Eclipse MA200 light microscope, held at Institute of Basic Technical Sciences, Maritime University in Szczecin. The second method is an analysis of geometrical structure of surface by profilometry method with TOPO 01P v3D profilometer located at Faculty of Advanced Technology and Chemistry, Military University of Technology in Warsaw.

2. Material and research methods

AW-2017A alloy was subjected to evaluation of cavitation erosion resistance using the flux-impact device. AW-2017A aluminium alloy has good mechanical properties with high tensile and fatigue strength. The alloy is weldable and has medium corrosion resistance. However, investigated material has a lower cavitation erosion resistance compared to other metals and alloys. The rapid mass loss period begins after only 60 minutes of exposure, and formation of cavitation pitts with 1 mm depth on the surface of the material takes place. AW-2017A alloy samples were examined for 90 minutes, and then the geometric surface parameters were analyzed by two considered methods.

In this study geometrical surface structure analysis after cavitation wear was limited to the primary surface, because surface waviness was a non-eliminated obstacle in optical method approach.

The first method to determine the primary surface profile was carried out using Nikon Eclipse MA200 optical microscope with NIS - Elements image analyzing software (Fig 1). The microscope used in present work was equipped with motorized table and additionally, allows to structure examination in bright and dark field, what provide a possibility of precise and automatic analysis of sample in three axes. Basic technical parameters of Nikon Eclipse MA200 microscope are presented in table 1.

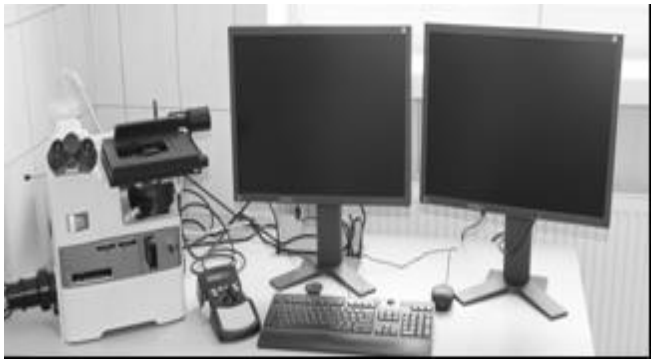


Fig. 1. Nikon Eclipse MA200 optical microscope

Table 1.
The basic technical parameters of Nikon Eclipse MA200 microscope

Parameter	Value
Optics	CFI60
Observation method	Bright/Darkfield/Simple Polarizing/DIC/Epi-Fluorescence
Scale	MA2-MR Scale Reticle (5-100x)
Range in axis x [mm]	115
Range in axis y [mm]	75
Range in axis z [mm]	1,8

Analysis of geometrical surface structure was performed using TOPO 01P v3D profilometer (Fig. 2).

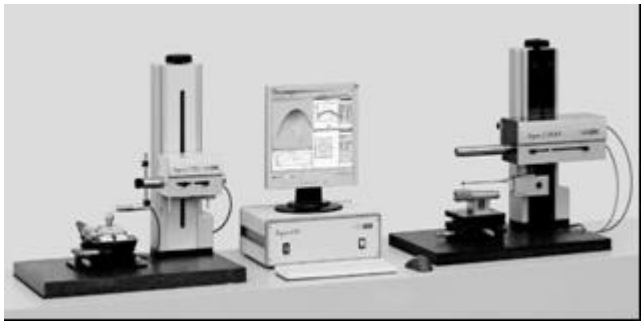


Fig. 2. Profilometer TOPO 01P v3D

The TOPO 01P system allows to measure of roughness, waviness and primary profile of studied surface (both in 2D and 3D arrangement). Software device provide a results in form of 3D isometric maps or contour maps as well as allows to determine parameters of geometric spatial structure of the surface. Basic technical details of TOPO 01P v3D profilometer are presented in table 2:

Table 2.
The basic technical data of TOPO 01P v3D profilometer

Parameter	Value
Measurement range pickup [μm]	1000 – 1 with BS1000 pickup
Measurement lengths [mm]	0.4; 1.25; 4; 12.5; 40
Measurement speed [mm/s]	0.1; 0.2; 0.5; 0.8
Measuring pickup	mapping edge: diamond, vertical angle: 90°, rounding radius ± 0,5 μm
Measuring accuracy [%]	5

Geometric surface structure examination was conducted on three selected AW-2017A alloy samples. This analysis included surface roughness measurements in order to determine Pa, Pq, Pp, Pv, Pp parameters of primary profile. The following samples were used in the study: taken from material in initial state (sample 1), and material after 15 and 90 minutes of cavitation erosion test (marked as sample 2 and sample 3, respectively). Analysis of geometrical surface structure was carried out with 5x magnification lens, by taking series of photographs along Z axis from 3.02 mm^2 area. The Pa, Pq, Pp, Pv, Pp height parameters were calculated according to equations (1-3) for each eleven surface profiles. The average values of that results were treated as the final ones obtained by optical method and were compared to the results received from TOPO 01P v3D profilometer.

3. Study results and their analysis

3D surface profiles and example 2D profile taken from samples subjected to optical method observation are presented in Figure 3-5.

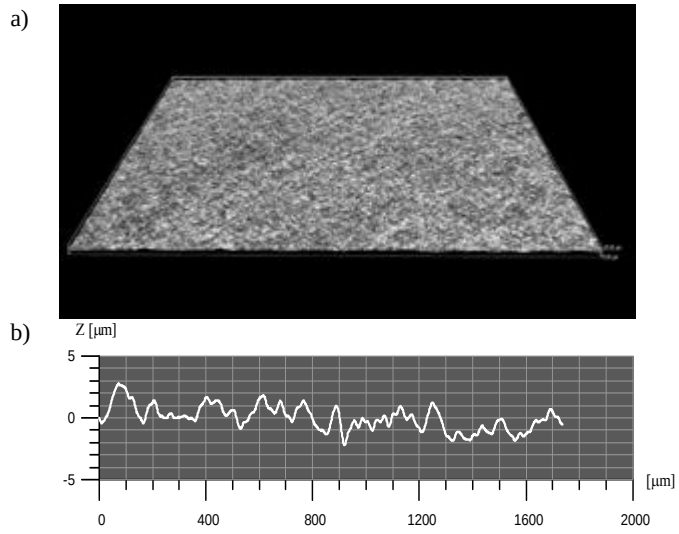


Fig. 3. Surface profile of sample 1: a) primary 3D profile, b) example primary 2D profile

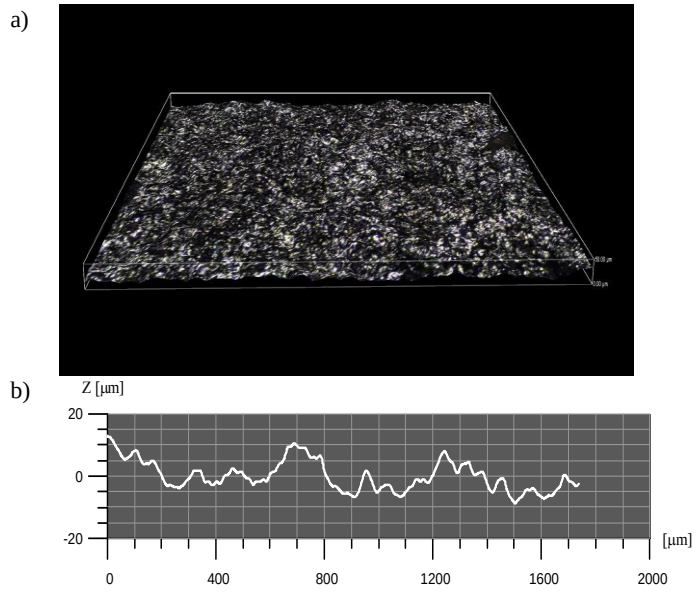
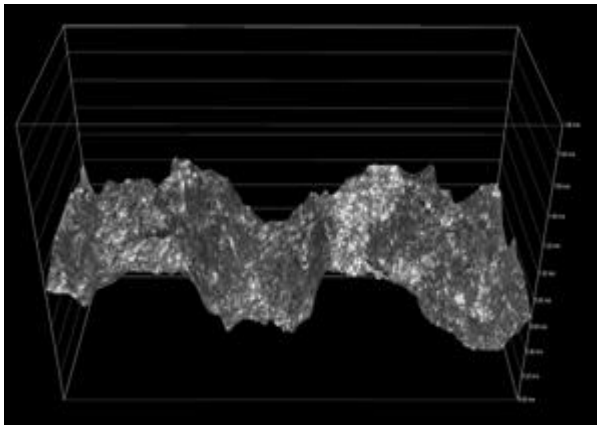


Fig. 4. Surface profile of sample 2: a) primary 3D profile, b) example primary 2D profile

a)



b)

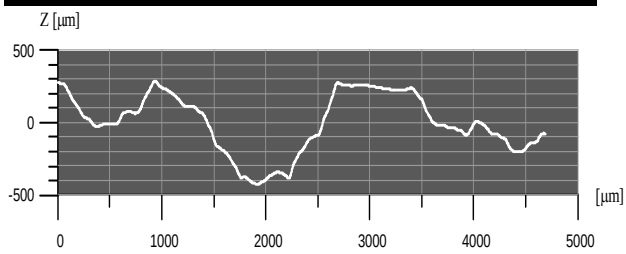
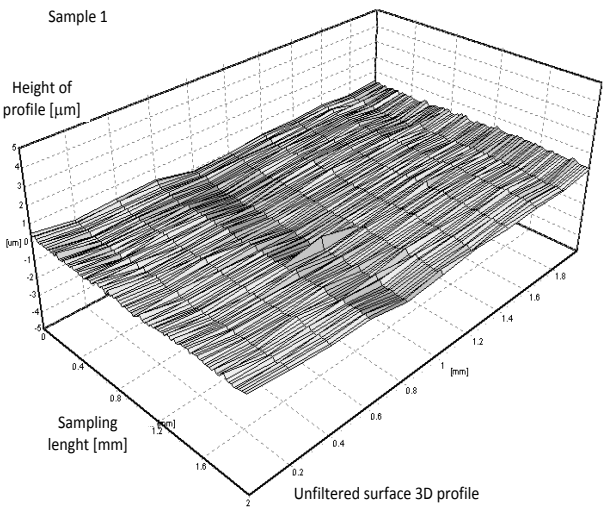


Fig. 5. Surface profile of sample 3: a) primary 3D profile, b) example primary 2D profile

Measurements with TOPO 01P v3D profilometer were carried out with BS 1000-10-01 WAT head with 1000 mm measurement range in the direction perpendicular to the tested surface (which was 2mm x 2mm area), with a v=0,5 mm/s speed. The primary profile area taken from samples 1 and 2 by profilometry method are presented in Figure 6 and 7, respectively. Deep pitting in sample 3 did not allow to perform the 3D measurements, due to the limited measurement range of applied head. Figure 8 shows primary 2D profile of the sample 3 surface recorded during the first scan on TOPO 01P v3D profilometer.

a)



b)

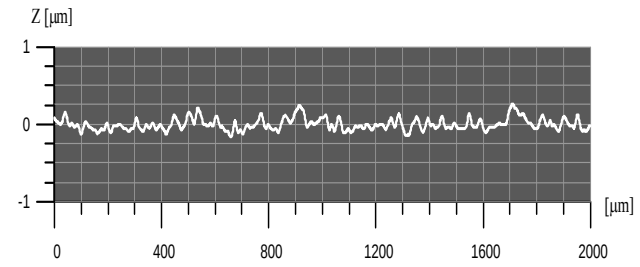
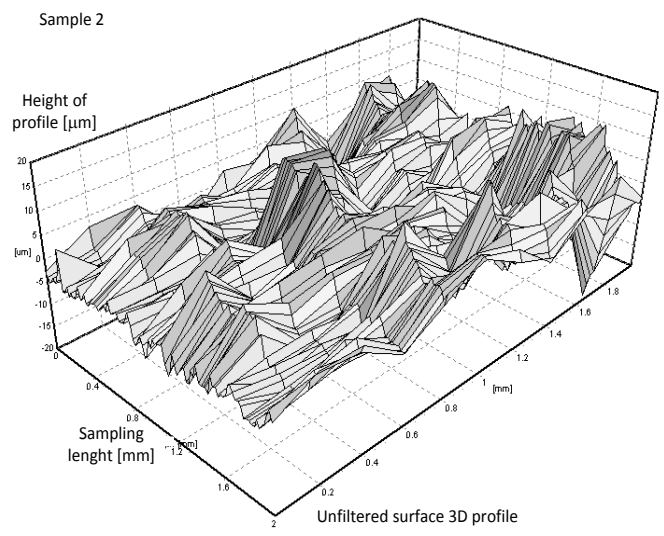


Fig. 6. Surface profile of sample 1: a) primary 3D profile, b) example primary 2D profile

a)



b)

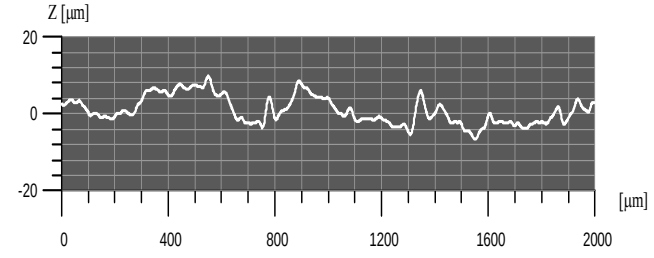


Fig. 7. Surface profile of sample 1: a) primary 3D profile, b) example primary 2D profile

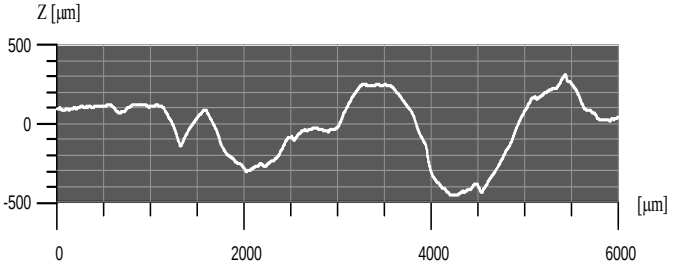


Fig. 8. 2D profile of the sample 3 surface recorded during the first scan on TOPO 01P v3D profilometer

The height parameters values for primary profiles obtained by two considered methods are summarized in table 3-5. In order to compare presented results, the ϖ parameter, define as the ratio of results obtained by using Nikon Eclipse MA200 microscope to results obtained from TOPO 01P v3D profilometer, was calculated.

Table 3.
Results of geometrical surface structure measurements for sample 1

Parameter	Sample 1		
	Nikon	TOPO	ϖ
Pa [μm]	0.779	0.143	5.45
Pq [μm]	0.977	0.182	5.37
Pz [μm]	4.548	1.048	4.34
Pv [μm]	2.15	0.500	4.30
Pp [μm]	2.77	0.548	5.05

Table 4.
Results of geometrical surface structure measurements for sample 2

Parameter	Sample 2		
	Nikon	TOPO	ϖ
Pa [μm]	3.926	2.435	1.61
Pq [μm]	4.764	2.977	1.60
Pz [μm]	21.248	11.351	1.87
Pv [μm]	8.61	4.969	1.73
Pp [μm]	12.76	6.382	2.00

Table 5.
Results of geometrical surface structure measurements for sample 3

Parameter	Sample 3		
	Nikon	TOPO	ϖ
Pa [μm]	166.37	168.978 [1]	0.98
Pq [μm]	202.20	199.425 [1]	1.01
Pz [μm]	546.73	499.209 [1]	1.09
Pv [μm]	428.28	211.267 [1]	2.02
Pp [μm]	290.41	287.943 [1]	1.01

[1] results of the only one TOPO 01P v3D profilometer scan.

Summary

In order to investigate cavitation erosion resistance of structural materials, a proper measurement quantities should be established. In present paper, cavitation erosion resistance was evaluated by analysis of change of primary surface profile determined by two methods – optical microscopy observation and profilometry surface analysis. The optical method allows to qualitative analysis. It is a quick and easy way to observe the effects of surface damage and quantitative assessment of emerging cavities. However, observation with Nikon Eclipse MA200 microscope does not allow to determine roughness parameters of analyzed surface, due to its substantial waviness. Optical method gives 3D presentation of cavitation erosion progress into the material. The measurements of the primary profile by TOPO 01P v3D profilometer allow to quantitative examine of geometric surface structure with very high accuracy. This method is however limited to the measurements of the cavities with depth not greater than 500 μm. In the case of surface cavities above 500 μm depth, the use of optical method seems to be more reasonable (due to similar value of ω parameter). The discrepancies in results of primary surface profile measurements between the samples 1 and 2, tested by the two methods can result from the lack of technical capabilities of the Nikon Eclipse MA200 microscope to obtain a series of sharp photos of surface with little roughness parameter or from incorrect selection of the Z axis scan parameters.

Acknowledgements

Scientific work is funded by the Ministry of Education and Science in the years 2011 ÷ 2014 as a research project No. N N507 231 040.

Literature

[1] Brennen, C. E. (1995). *Cavitation and Buble Dynamics*. Oxford University Press.
[2] Briggs, L. J. (1970). The Limiting Negative Pressure of Water, *Journal of Applied Physics*. Vol. 21, 721-722.
[3] Trevena, D. H. (1987). *Cavitation and tension in liquids*, IOP Publishing Ltd, 1987.
[4] Plesset, M. S. & Chapman, R. B. (1971). Collapse of an Initially Spherical Vapour Cavity in the Neighbourhood of a Solid Boundary, *Journal of Fluid Mechanics*. Vol. 47, Part 2, 283-290.
[5] Thiruvengadam, A. & Preisner, H. S. (1964). On testing materials for cavitation damage resistance, *Journal of ship research*. Vol. 8, No 3, 39-56.
[6] Tichler, J.W. & W de Gee, A. (1970). *Time Dependence of Cavitation Erosion and Effect of Some Material Properties*. Farnborough, England, 847-879.
[7] Plesset, F. J. & Devine, R. E. (1966). Effect of Exposure Time on Cavitation Damage, *Journal Basic Eng*. Vol. 68, No 4, 691-705.
[8] Steller, K. (1982). *Cavitation Basic concepts, with particular emphasis on the concepts of hydraulic machines*,Zeszyty Naukowe Instytutu Maszyn Przepływowych PAN w Gdańsku, Nr 140/1057/82, Gdańsk.

[9] Jasionowski, R., Przetakiewicz, W. & Zasada D. (2011). The method for determination of the beginning of cavitational wear through comparison of mass decrement and destroyed surface increment on the example of FeAl36 alloy,*Archives of Foundry Engineering*. Vol. 11, Special Issue 2, 103-107.

[10] [10] Gadelmawla, E. S., Koura, M. M., Maksoud, T. M. A., Elewa, I. M. & Soliman H. H. (2002). Roughness parameters.
Journal of Materials Processing Technology. Vol. 123, 133-145.