Research Article

CAVITATION EROSION RESISTANCE OF Ni-Co BASED COATINGS

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ABSTRACT

The Ni-Co based coatings were performed by means of PTA method from Ni-based and Co-based powders. The cavitation erosion resistance of Ni-Co specimens and reference sample in deionized water was determined by the ultrasonic vibration system. The microstructure, as well as mechanism of cavitation erosion of coating was examined by using SEM and LOM. The main mechanism of erosion is cracking and spalling at the boundary of dendrites and eutectics. Coatings exhibit higher cavitation erosion resistance than the reference sample. Therefore, they could be applied to repair and protect pump elements from cavitation wear.

Keywords: cavitation erosion, Ni-Co based coating, PTA deposition.

INTRODUCTION

Cavitation can be defined as the formation and subsequent collapse, within a liquid, of cavities or bubbles that contain vapor or gas, or both. It is a common phenomenon in the hydraulic components such as valves, impellers, hydraulic systems, propellers, engine cylinder sleeves and high-frequency ultrasonic devices. Cavitation erosion is a progressive loss of original material from a solid surface due to continued exposure to cavitation. Bubble collapse is a violent process that generates highly localized, large-amplitude shock waves and microjets in the fluid at the point of collapse. Cavitation bubble collapse loads act repeatedly on a material surface to produce plastic deformation, crack initiation, crack growth and material removal [1–6]. Erosion reduces the machine performance and lifetime. Figure 1 presents pump impeller with the cavitation erosion damage located at the edge of impeller blades.

According to the data included in [6–9], modern materials, such as PTA, deposited coatings based on Ni and Co matrix are applied for regeneration and protection of machines and their components against cavitation erosion wear. In addition, application of coatings is usually easy and fast, a wide variety of materials can be deposited and minimal surface preparation is needed [10]. In the literature, cavitation erosion resistance of Ni-Co based coatings is not so widely presented as for Co [11] or Ni [12] based ones. Hence the cavitation damage mechanism of Ni-Co coatings is not recognized and scarce information is available in contradiction to those relating to Co or Ni. This paper describes the results of research into the cavitation wear behavior of Ni-Co coatings. The presented results of investigations will

Fig. 1. Radial impeller worn by cavitation

be useful in elaboration of protection technology and repair technology of pump elements damaged by cavitation.

The aim of the present study was to determine the cavitation erosion resistance of Ni-Co based coatings PTA deposited on a steel substrate combined with the research into wear mechanism.

MATERIALS AND METHODS

In the present work, the Ni-Co based coatings were deposited by means of NP1250 PTA deposition unit from the mixtures of Ni and Co based powders (Table 1). The substrate was made of a steel plate grade S235JR (C = 0.22%; Si = 0.35%; Mn =1.1%; Cr = 0.3%; Fe = bal.). Coating 1 (Table 2) was deposited by using only PMNi50p powder. Coatings 2–10 were synthesized from the PMNi50p and PMCo45 powders mixed in various proportions. The chemical compositions of the 2 layered coatings (1, 5, 6 and 8) were determined by weight percentage of powders used for coatings deposition whereas chemical compositions of the 1 layer coatings (24, 7, 9, 10) were identified by using EDS (energy-dispersive X-ray spectroscopy) method on scanning microscope Zeiss Ultra Plus. Results of chemical analysis are given in Table 2. Microhardness HV0,05 was measured by means of the Hanemann microhardness head. The head was mounted on the Neophot

2 optical microscope. Sixty indentations were performed on the coating cross-section at accidental locations.

From the padded steel plates, the samples were cut off with dimensions of 8×30×30 mm. The reference sample was made of normalized carbon steel, grade C45 (C = 0.42–0.5%; Mn = 0.5–0.8%; Si = 0.10,4%; P = max. 0.4%; S = max. 0.4%; Cr = max. 0.3%; Ni = max. 0.3%; Cu = max. 0.3%; Fe = bal.). Before the cavitation tests, surfaces of samples were grinded and polished with 1µm oxide suspension.

Cavitation erosion tests were carried out for different coatings by using the stationary specimen method with a vibratory apparatus, shown in Figure 2. Tests were conducted in accordance with the procedure described in ASTM G32 standard [2]. An acoustic power output equaled 500 W. The distance between the horn tip and the sample was 1.5 mm. The resonance frequency of the oscillator was 20 kHz and the amplitude of the tip was 50 µm. Deionized water was used as test liquid, which was kept at 25±4°C with a temperature

Table 1. Nominal chemical composition of powders

Powder	Nominal chemical composition, weight %
PMNi50p	Ni = 87%, Cr = 6%, Fe = 2.1%, Si = 3.5%, B = 1.8%, C = 0.1%
PMCo45	Co = 63.2%, Cr = 30%, W = 4%, Si = 1.3%, B = 0.8%, C = 0.7%

Fig. 2. Schematic diagram of the ultrasonic equipment

Table 2. Chemical composition of coatings

Coating number	Chemical composition, weight %							
	Co	Ni	Cr	W	Fe	Si	C	B
1	–	87.00	6.00	–	2.10	3.50	0.10	1.80
2	3.84	48.45	14.12	0.22	29.88	2.27	0.15	0.97
3	10.97	38.12	14.05	0.73	33.22	1.74	0.22	0.86
4	24.91	5.64	11.52	3.10	51.16	2.84	0.38	0.41
5	27.09	38.18	10.28	1.89	18.21	2.55	0.40	1.35
6	32.12	42.58	18.98	2.15	–	2.46	0.39	1.27
7	33.26	41.06	19.40	2.22	–	2.36	0.40	1.25
8	34.76	39.30	20.01	2.27	–	1.96	0.42	1.23
9	44.21	7.39	24.47	2.93	17.58	2.17	0.50	0.66
10	48.67	20.66	25.80	3.25	–	–	0.54	1.00

control device. Total test time for each sample was equal to 120 minutes (tests were termineted after 2 hours because of the detachment of some coatings). After each test step, which last 30 minutes, the specimen was weighed by means of the analytical balance with the accuracy of 0.2 mg to determine mass loss.

A quantitative assessment of cavitation erosion resistance of samples based on the evaluation of mean depth of erosion (MDE) parameter, in accordance with [2]. MDE is calculated by dividing the measured mass loss by the product of material density and the tested area. To assess qualitatively cavitation erosion and to study the mechanism of cavitation erosion, SEM microscope VEGA 3XMH TESCAN as well as light optical microscopes Nikon MA200 and Nikon SMZ1500 were used.

DESCRIPTION OF RESULTS

Typical microstructures of Ni-Co based coatings are illustrated in Figure 3. According to literature [13–15], at first stage of solidification dendrites are formed from the liquid phase at the boundary substrate/coating (Figure 3A), and then eutectics solidifies. The basic microstructure of coatings contains dendrites (γ phase) and interdendritic eutectic regions (dark area). The eutectic regions consisted of γ phase – boride eutectics as well as other eutectics. The γ phase is composed of alloying austenite based on cobalt which incorporated elements such as chromium, nickel, iron, tungsten and molybdenum.

Diagram with the MDE parameters of coatings and the reference sample is presented in Figure 4. The highest values of MDE parameter were for coatings 6 and 1, whereas the lowest ones were for coatings 4 and 9. Ni-Co based coatings compared to reference mild steel sample reveal higher cavitation erosion resistance (Figure 4) which is in agreement with literature, e.g. [6, 16].

In the works [16–18] it was stated that the presence of Co in metal matrix lowered the stacking-fault energy, resulting in planar slip, high strain-hardening and enhanced strain-induced martensitic transformation, all of which favored an increase of resistance to cavitation erosion. In the presented work no evident relationship between Co content in matrix of coatings and cavitation erosion resistance was found (Figure 5). Moreover, some influence of nickel
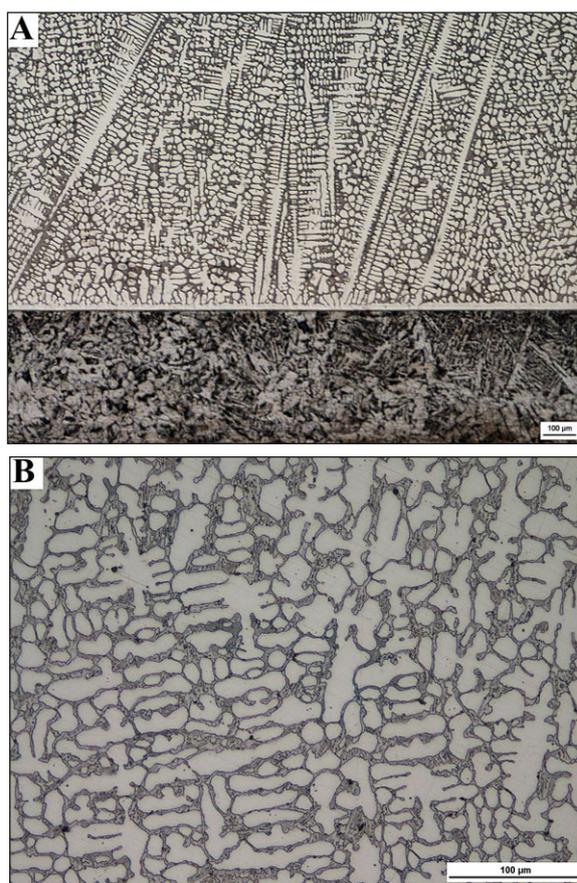
Fig. 3. LOM micrographs. The cross-section of sample 3 (A) and microstructure of coating 9 (B)
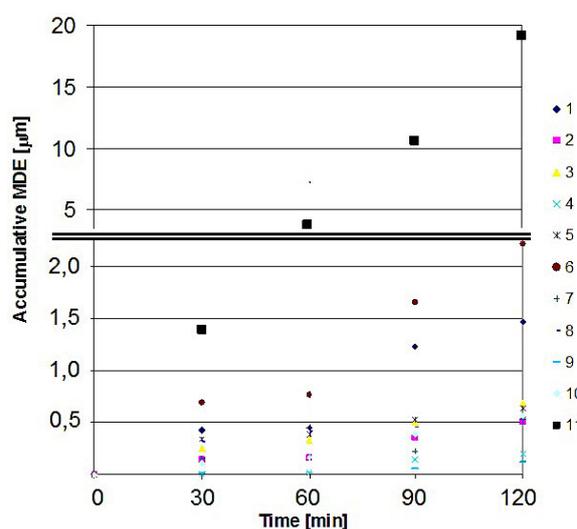
Fig. 4. Cavitation erosion resistance of coatings (1–10) and reference sample (11)

on cavitation erosion wear was observed. Ni-Co based coatings (4 and 9) that contain the smallest amount of nickel (according to Table 2) exhibit lower values of MDE parameter and relatively higher cavitation erosion resistance than nickel rich coatings (Figure 5).

After 120 minutes of test, coatings 3, 1 and 6 show relatively high values of MDE parameter equal 0.69; 1.49 and 2.22, respectively. Their cavitation wear mechanism was mainly the detachment of the whole coating grains. Coating 6 surface with pits after 30 minutes of cavitation is presented in Figure 6A. After 120 minutes of cavitation these worn regions increased and produced higher mass loss, Figure 6B. In contrast, coating 5 after 30 minutes exhibits relatively low value of MDE parameter, 0.34. However after 120 minutes of cavitation the matt-surface area increased and small pits occurrence was observed (Figure 7). Matt-surface appearance is a typical
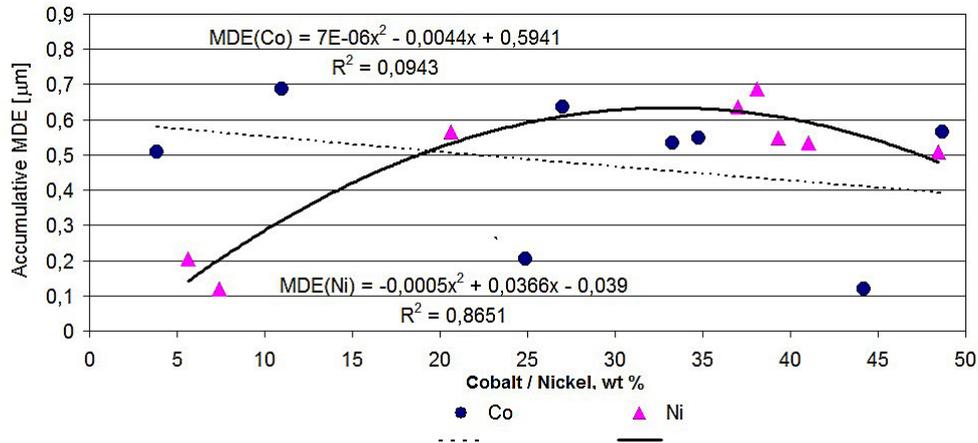
Fig. 5. Accumulative MDE parameters of coatings 2–5, 7–10, after 120 minutes of cavitation, with relation to their main matrix elements

In figure: $MDE(Co) = 7E\text{-}06x^2 - 0{,}0044x + 0{,}5941$, $R^2 = 0{,}0943$; $MDE(Ni) = -0{,}0005x^2 + 0{,}0366x - 0{,}039$, $R^2 = 0{,}8651$
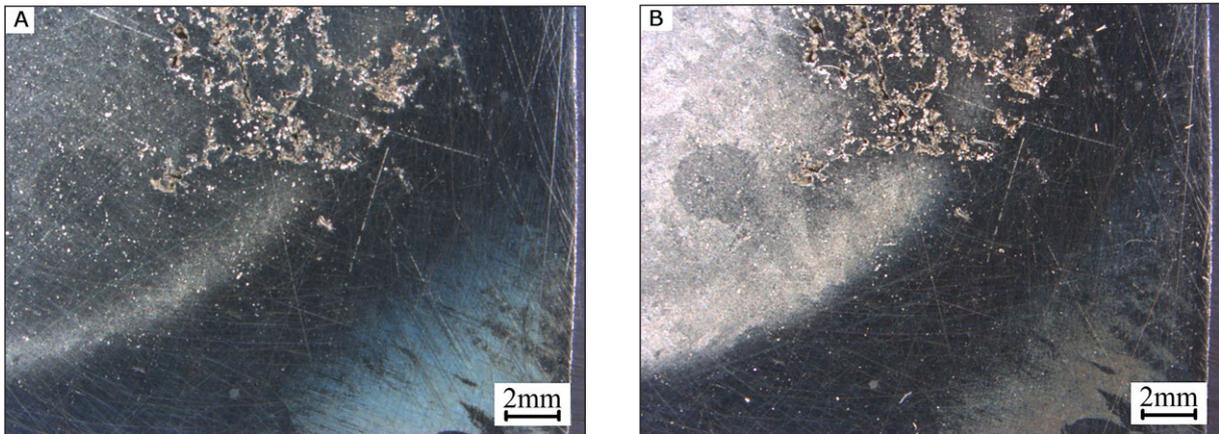
Fig. 6. Coating 6: A – after 30 minutes and B – after 120 minutes of cavitation test
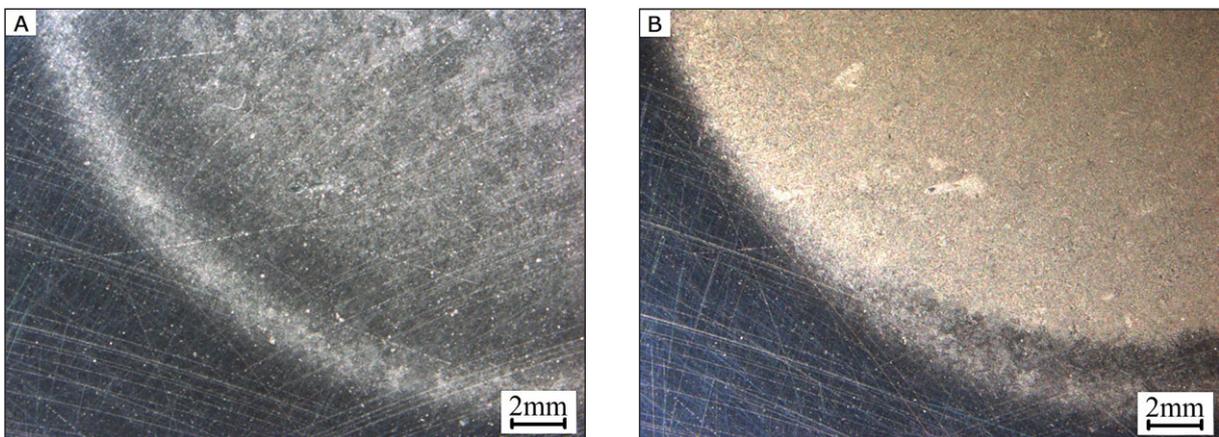
Fig. 7. Coating 5: A – after 30 minutes and B – after 120 minutes of cavitation test

phenomenon observed for polished surface of metals and alloys in incubation period of cavitation wear. Some coatings reveal matt-areas and very little mass loss even after 120 minutes of cavitation (coatings 9 and 4; MDE = 0.12 and 0.20, respectively). The genesis of matt-effect is a plastic deformation of surface and it is clarified in literature [19, 20]. In Figure 8A, the areas of cavitation damage of coating 3 are clearly visible. Figure 8B presents matt-surface area of coating 2. Surface particle detachments may be accelerated by coating non-uniform structure (occurrence of cracks and pores). The presence of pores in coatings was revealed in microscopic examinations. Surface areas with inhomogeneities are less resistant to brittle fracture and to plastic shearing caused by a repeated collapse of cavitational bubbles [16].

Table 3. Results of microhardness measurements

Coating	Microhardness, HV 0.05	
	Average	Range
1	791	380 – 1356
2	946	535 – 1357
3	660	471 – 954
4	1015	855 – 1261
5	606	447 – 885
6	500	357 – 771
7	839	575 – 1274
8	935	588 – 1357
9	676	498 – 954
10	539	413 – 885
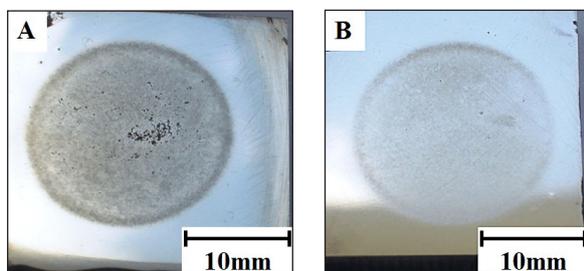
Fig. 8. Specimen surface after 120 minutes of cavitation: A – coating 3; B – coating 2

The results of the microhardness measurements are given in Table 3. Some of researchers [11, 21, 22] assert that mechanical properties such as hardness influence the cavitation resistance of coatings. The range of microhardness (Table 3) confirmed the presence of hard phases (carbides, borides and silicides) in austenitic matrix. However, the influence of hard phases presence in coating microstructure on cavitation erosion resistance after 120 minutes was not recognized. In our investigation, relationship between mi-

crohardness and MDE parameter was not found, which is presented in Figure 9. This is rough agreement with previous work [19] in which, after 90 minutes of cavitation no effect of C or B content on cavitation resistance of Ni-Co coatings was found.

Micrographs of the less (Figure 10) and the most worn (Figure 11) surfaces of coatings at different magnifications are presented. Generally cavitation pits arose close to the regions of surface defects such as micro-scratches (Figure 10A and B), also at the interfaces between hard and soft phases. Thus in our case the mechanism of erosion of Ni-Co based coatings depends on cracking that starts at the borders of dendrites with interdendritic eutectics which incorporated hard phases. Some coatings demonstrate advanced cavitation (Figure 11) so in that case arrays of dendrites are clearly visible. The observed mechanism of cavitation erosion of the Ni-Co based coatings was similar to the already published in the literature for Co-, Ni- and Fe- based coatings [11, 22, 23]. Hard phases are the areas which act as initiating site for erosion damage, whereas the matrix was
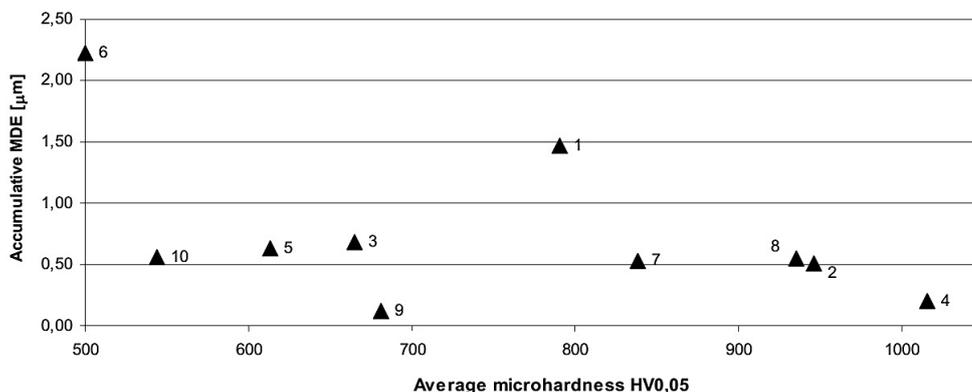
Fig. 9. Accumulative MDE after 120 minutes of cavitation versus the range of microhardness of coatings (1-10)
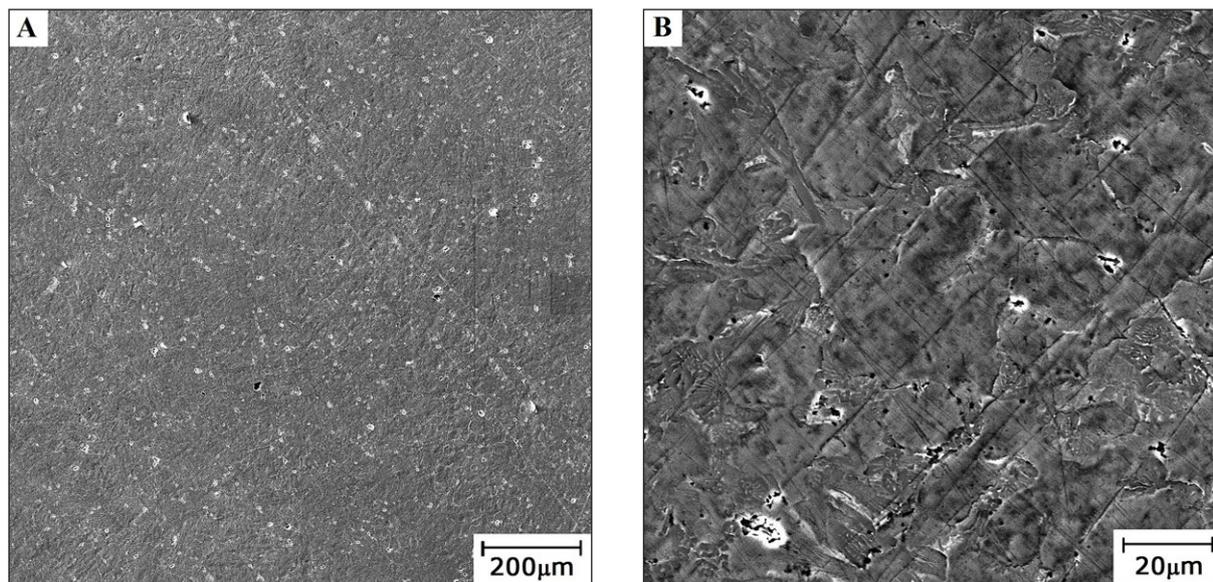
Fig. 10. SEM micrographs of coating 9, after 120 minutes of cavitation test
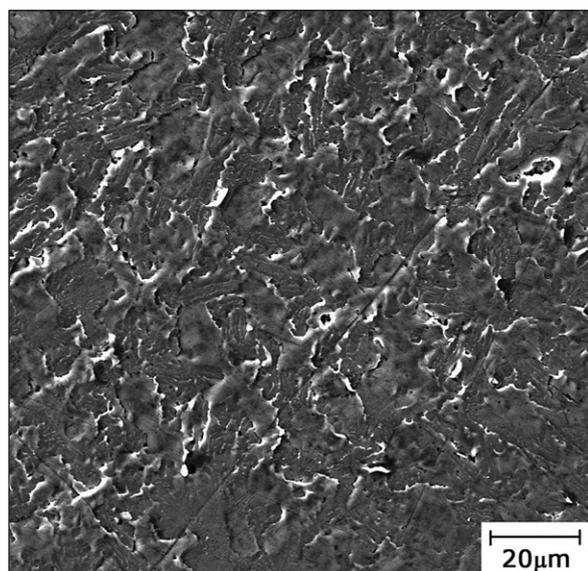
Fig. 11. SEM micrograph of coating 6 after 120 minutes of cavitation test

plastically strained which could be accompanied by strain-induced transformation.

After 2 hours of test, cavitation erosion wear of some coatings (9, 4) may be classified as incubation period of the cavitation erosion [1, 4, 16]. This period of erosion is characterized by a very little mass loss. Coatings 1, 3, 6 exhibit high mass losses. They could experienced accelerated period of erosion [1, 4, 16]. After 2 hours of cavitation, the reference sample reveals considerably higher value of MDE parameter compared with Ni-Co coating (Figure 4). Cavitation wear of reference carbon steel may by allocated to a stationary period of cavitation erosion wear [1, 4, 16].

CONCLUSIONS

Ni-Co based coatings exhibit nearly 10 times higher resistance to cavitation erosion than reference sample made of mild steel, therefore, they could be suitable to protect and repair machine parts applied under conditions of cavitation erosion.

The main mass removal mechanism observed in Ni-Co overlay coatings in cavitation tests was cracking and spalling of phases located at the boundary of dendrites and eutectics.

The influence of microhardness on cavitation erosion resistance of coatings was not stated. Ni-Co based coatings that contain relatively high percentage of nickel in their matrix exhibit relatively lower cavitation erosion resistance.

The presence of inhomogenities at the coating surface reduced the resistance of coatings to cavitation erosion.

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