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DEPENDENCE OF CAVITATION PERFORMANCE OF SUPERFICIAL IRON ALLOYS ON THE SUBSTRATE

ABSTRACT

In the work, the dependence of cavitation resistance of laser produced or electrode produced superficial iron alloys on the type of the substrate was investigated. Substrates of tested samples were made of steels 45, 2H13, 0H18N9T and Armco iron. Cavitation assays of the materials with thin surface layers alloyed with SiC or AlNi compounds or with 1–2.5 mm thick coatings deposited by means of electrodes IMP6 and IMP9 were carried out. It was found, that substrate play significant role in erosion resistance of superficially processed steels due to surface processing effects petrified in the course of the thermal cycle.

Key words: cavitation erosion, laser processing

INTRODUCTION

Cavitation wear of metallic surfaces is met in hydraulic turbines, ship propellers, pumps, valves or many other fluid-flow devices [1, 2] (Fig. 1). This results in possible damages of the machines, in operating inefficiencies, reduction of equipment service life and high maintenance and repair costs. Controlling of cavitation phenomena in field conditions by appropriate machine design and submergence setting is not always applicable. In this case, the protection of solid body against cavitation attack may consist of manufacturing of the surface layer of high cavitation erosion resistance [3]. Results of numerous works proved that alloying, cladding, melting or rapid heating of ferrous alloys by laser beam was an effective method, leading to an increase in their cavitation resistance [3-7]. The layers of high impact toughness and hardness were found highly resistant to cavitation impingements. Moreover, it was also noticed that response of superficially modified samples depends strongly on the type of core material [8]. The importance of the substrate in surface engineering was considered in [9].

It should be kept in mind that cavitation resistance of the materials is related to the specific intensity of the loading and the type of the erosion impingements, which makes it difficult to foresee the material performance on the basis of its microstructural or mechanical parameters. Hence, the search for the most resistant material should take into account the specific loading conditions. In the case of low intensity cavitation, as it usually happens in machine operating conditions, the performance of the materials in introductory – incubation period of the erosion is of paramount significance. Prolongation of the incubation time – when the shear components of applied stress of the impulses are not significant and the energy backscatter in a fluid medium is high – can be achieved by the modification or placing of thin coatings on the metallic surface.

In this work, dependence of cavitation resistance of laser produced or electrode produced superficial iron alloys on the type of the substrate during the initial stage of the erosion process

was investigated. Substrates of tested samples were made of steels 45, 2H13, 0H18N9T and Armco iron. Their surface layers were alloyed with SiC or AlNi compounds or were covered with 1–2.5 mm thick coatings deposited by means of electrodes IMP6 and IMP9 [10]. Cavitation assays with the rotating disk facility were carried out. The results of the work were assumed to be helpful in selecting the type of the protective surface layer for a fixed material.

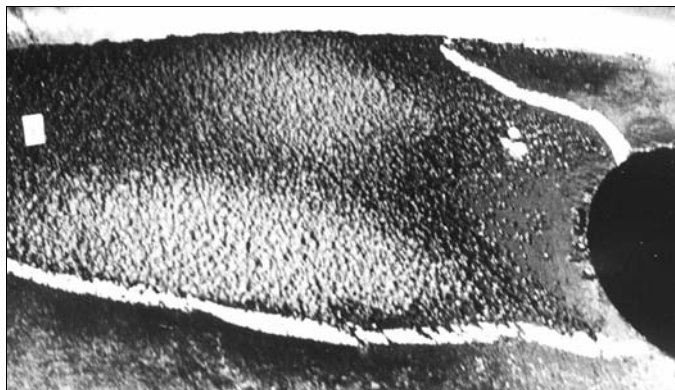


Fig.1. Surface of the water turbine runner near the joint of the blade after 1200 hours of low intensity cavitation attack. (hydro power plant Żydowo). Steel 2H13

EXPERIMENTAL PROCEDURES

Objects of investigations and processing procedures

The substrates of the investigated samples were prepared of 0.45% carbon steel (45^{*}), thermally processed in order to achieve structural uniformity (at 860°C for 20 minutes, furnace quenching), 13% chromium steel (2H13^{**}), hardened and low tempered, acid resistant chromium-nickel austenitic steel 1H18N9T^{**} subjected to quenching at 1050 °C and Armco iron.

Samples preparation consisted in depositing of the IMP6 and IMP9 electrode materials on the substrate surfaces or alloying of the attached powders by laser beam. Chemical compositions of the IMP6 and IMP9 are presented in Table 1. The thickness of each clad ranged from 1 to 2.5 mm. On the other hand, alloying of the AlNi and SiC powders attached to the core material surface by sodium chloride glass water led to manufacturing of the 0.05–0.17 mm layers. The average data on the chemical compositions of the investigated samples, defined in surface points by electron dispersive spectroscopy are included in Table 2. Continuous work CO₂ LPT1.2 laser was used as a power source [11]. The main parameters of the device as well as the conditions of the processing are presented in Table 3. The beam power on the samples surfaces was attenuated of 3% due to multiple reflections along the optical trail. During the experimental runs the specimens were moved across the laser beam along some parallel paths. The velocities of some samples subjected to laser processing were varied from 0.5 to 0.8 cm/s because of different susceptibility of various powders to melting. Before emplacing the samples into the

* designation according to Polish Standards PN-75/H-84019.

** designation according to Polish Standards PN-71/H-86020.

rotating disk, the polishing of their surfaces was done in order to leveling the roughness remained after the laser processing.

Table 1. Chemical compositions of electrode pads

Chemical compositions of the electrode pads							
	C	Mn	Si	P	S	Cr	Co
IMP6	0.35	8.31	0.26	0.069	0.012	10.93	
IMP9	0.31	0.55	0.30	0.016	0.010	16.50	6.07

Table 2. Chemical composition of the alloys produced by laser technique

Substrate and samples designation	Composition [% wt] and the thickness of the powder layers attached	The elements, which presence was identified							Average thickness of enriched layer [mm]
		Fe	Cr	Ni	Al.	Si	C	Mn	
45/1	73.0AlNi*/27.0SiC	74.47		5.17	8.22	3.57	7.86	0.71	0.056
45/2	100.0SiC	80.52				5.37	13.69	0.42	0.060
2H13/1	72.0AlNi*/27.0SiC	82.1	1.84	3.92	4.39	2.21	5.13	0.40	0.049
2H13/2	100.0SiC	73.9	8.23			4.82	12.58	0.40	0.17

Table 3. Laser beam parameters and conditions of metal surface processing

	LPT1.2
laser beam power [W]	1050
Laser beam mode	TEM 1.0 + TEM 0.1
Laser beam diameter [cm]	0.8
Laser beam divergency	1.5 – 1.7 mrad
Focussing element	ZnSe lens
Focal length [cm]	8.9
Diameter of the beam spot on the surface [cm]	0.16
Sample velocity [cm/s]	0.6
The shielding gas	Argon
Gas velocity [m/s]	47

Cavitation testing of the samples

After processing the workpieces were subjected to cavitation attack at the rotating disk rig [12]. The cavitation was generated there by cylinders situated in the disk surface on the circle which diameter equalled 300 mm. Test specimens were inlaid in the disk, downstream of

the cavitator. Their rotation speed stand for 3000 r.p.m. The resulting mean gauge pressure was 155 kPa. The water of temperature 20°C was used as an active medium. The tests were performed in runs 3-6 min long following one after another for 56 minutes in total. Duration of each run was less than the time needed to achieve the steady state cavitation intensity.

After each run the microscopic observations of the sample surfaces were done and the level of darkness caused by an increase in cavitation pits and indentations was registered. The level of darkness was automatically calculated by the programme MultiScan. The resistance of the investigated part of the material was defined with respect to the reference material by the following index: $\eta = (N_{ref}-N)/N_{ref}$, where N is the darkness of the tested part and N_{ref} refers to the darkness of the analogous area on the reference surface. 1H18N9T steel was used as the reference material. Quantifying of cavitation damage by this method gives results approximate to the results obtained by the method based on pits counting. The latter one is accepted way of defining the cavitation wear of the materials [13]. Supplementary measurements of the length of the sample surface line profiles were carried out.

Inaccuracy in assessment of η values is included in the size of the experimental points depicted in the plots. Cavitation experiments consisted of the series of runs and the conditions could differ at each series due to a possible change of fluid flow parameters and a limited time of stabilisation of cavitation wires. However, it should have had no influence on the value of η for the reference samples were subjected to the same cavitation impingements.

Methods of material investigations

A scanning electron microscope Philips 30/ESEM was used for visualisation of both the specimens surface deformations and microstructures in the plane normal to the processing path. An analysis of the chemical composition was carried out by means of electron dispersive spectroscopy EDAX at the accelerating voltage of 25 kV. The measurements of hardness were done by means of a Rockwell tester. The Vickers' microhardness within the heat-processed zone was measured at the load of 2N (HV200g).

RESULTS AND DISCUSSION

Cavitation resistance of manufactured coatings exceeded considerably the cavitation resistance of reference material up to 40 minute of intensive cavitation loading. The results obtained indicate that erosion wear of the clad depends much more on kind of the substrate than on type of the electrode used. Particularly, strong effect of the core material type on the cavitation performance of the samples was observed at the very beginning of the erosion process (Figs 2, 3). The lowest values of η were found for samples with steel 1H18N9T as the substrate. The impairment of their surfaces – defined with respect to reference material by η – was extended twice more than impairment of the samples with substrates of Armco iron. It happened in both cases of cladding: with IMP6 and with IMP9 electrodes. In case of samples covered with electrode IMP6 the erosion damage of coatings deposited on steel 1H18N9T also exceeded the erosion damage of coatings deposited on steel 45. In the advanced stage of the erosion the influence of the substrate type on the sample performance under the cavitation loading appeared to be much less meaningful (Fig. 4). In this case the damages develop temporarily in all directions within the indentations and craters and are not strongly affected by the conditions of interaction: impingement – material structure.

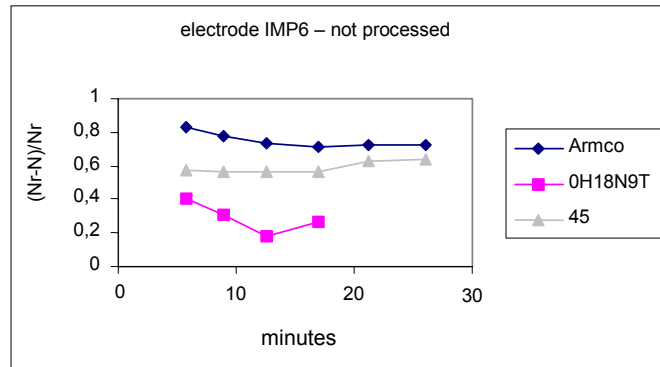


Fig. 2. Variations of the index: $\eta = (N_{ref} - N) / N_{ref}$ as a function of cavitation time for IMP6 clad deposited on different substrates

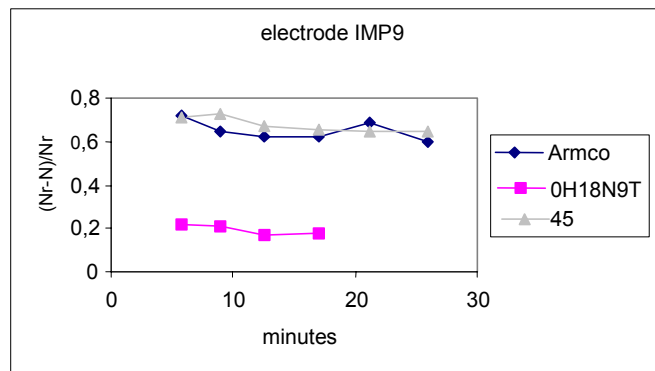


Fig. 3. Variations of the index: $\eta = (N_{ref} - N) / N_{ref}$ as a function of cavitation time for IMP9 clad deposited on different substrates

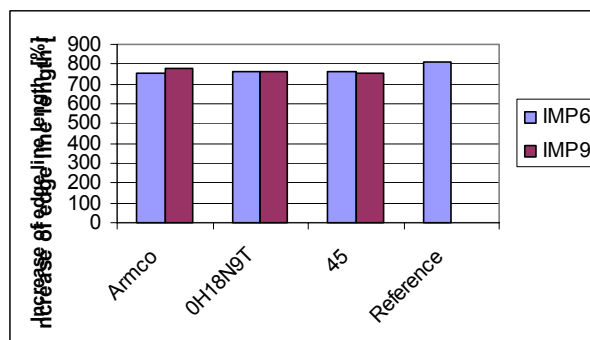


Fig. 4. An increase of the edge line length [%] (average) after 70 minutes of cavitation loading of the materials covered with electrodes IMP6 and IMP9. Values for samples with various types of the substrates are added

Comparisons of the cavitation performance of the superficial alloys made on steels 45 and 2H13 are presented in Figs 5 and 6. It is seen that alloying of the same components with different substrates led to obtaining different levels of cavitation resistance of the structures produced. During the process the convective flow of material within the melted pool and resultant difference in chemical composition of the surface layers was detected. However, in case of superficial alloying there is not usually generated a sharp step-like boundary between

the substrate and the surface layer. Instead, the transient, multiphase zone is observed (Fig. 7). It probably lets to avoid the concentration of residual stresses at the bottom of the coatings. The latter is the case of laser cladding, where very narrow bonding zone is formed (Fig. 8). It has been found, that residual compression increases the allowed loading and transfers the position of the maximum stress to a substrate location, whereas residual tension weakens the surface [9]. The nature of residual stresses depend on the material subjected to the processing [14, 15].

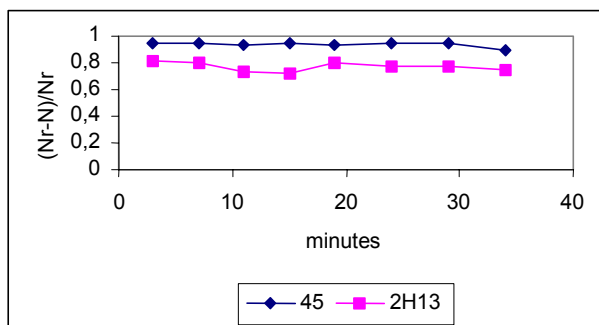


Fig. 5. Variations of the index: $\eta = (N_{ref}-N)/N_{ref}$ as a function of cavitation time for samples 45/1 and 2H13/1 containing the layers of the melted compounds of AlNi and SiC on the steels 45 and 2H13 respectively

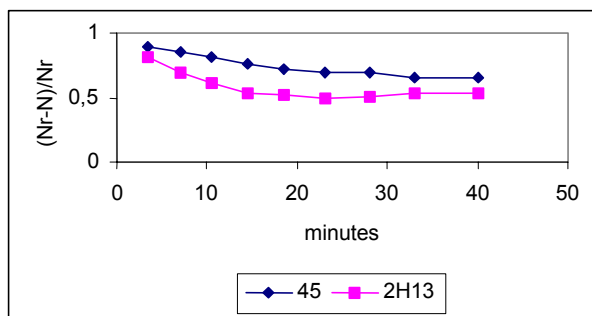


Fig. 6. Variations of the index: $\eta = (N_{ref}-N)/N_{ref}$ as a function of cavitation time for samples 45/2 and 2H13/2 containing the layers of the melted compounds of SiC on the steels 45 and 2H13 respectively

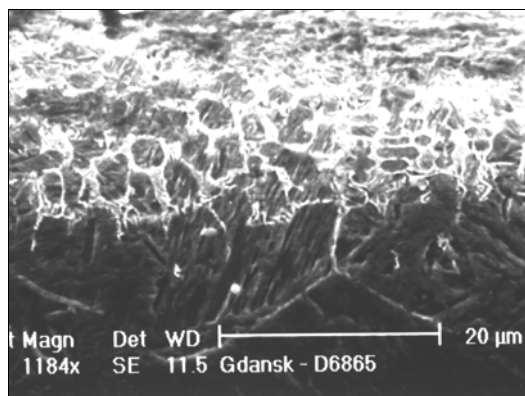


Fig. 7. Bonding zone between the surface layer of the sample 2H13/1 and the core material

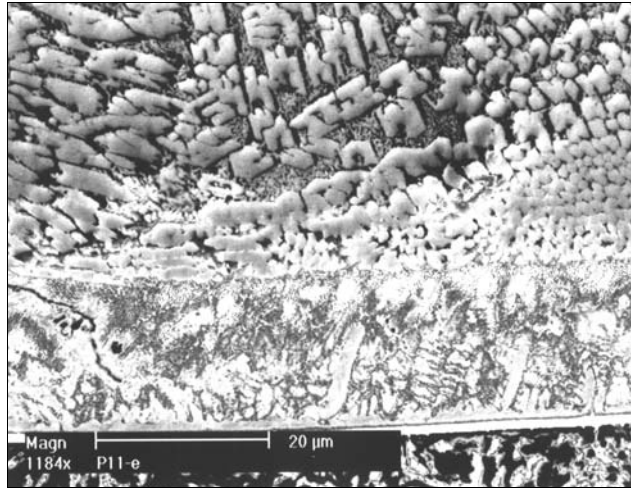


Fig. 8. Clad made of compounds FeCr and SiC supported by martensitic heat affected zone of steel 45. Visible cracking in the down part of the surface layer proves that stresses are concentrated within that layer

CONCLUSIONS

It is inferred that cavitation resistance of superficially processed steels is considerably influenced by the substrate. The following surface processing effects resultant from the thermal cycle depend substantially on the type of substrate material: (1) generation of different residual stress fields at the joint zone; (2) formation of the heat affected zones of different thickness; (3) formation of the bonding zones of different properties due to differentiated phase composition; (4) scattering of the elastic energy by various substrates with different intensity. All these effects are directly linked to the cavitation erosion resistance of the materials with modified or deposited surface layer.

It seems that prior investigations are necessary when the selection of the proper protective coatings for any kind of the material should be done.

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