www.czasopisma.pan.pl PAN www.journals.pan.pl

ARCHIVES of FOUNDRY ENGINEERING

ISSN (2299-2944)
Volume 18
Issue 4/2018

31 – 34

DOI: 10.24425/123628

6/4

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

A Possibility to Improve Resistance of Cast-iron Hydraulic Valves to Cavitation Wear

A.W. Orłowicz, M. Tupaj *, M. Mróz, B. Kupiec, M. Jacek, M. Radoń
Rzeszow University of Technology,
Al. Powstańców Warszawy 12, 35-959 Rzeszów, Poland
* Corresponding author. E-mail address: mirek@prz.edu.pl

Received 02.03.2018; accepted in revised form 30.04.2018

Abstract

A common problem encountered in hydraulic valves is a progressing deterioration of tightness of their water flow cutting-off seats. The seats are provided usually with a copper-alloy insert joined mechanically with cast-iron valve housing. The problem of unreliability of such joints can be solved by providing surface of the seat with a coating, deposited with the use of HVOF method and resistant to abrasive and cavitation wear. The tests were carried out for a sealing-draining seat insert made of CuZn39Pb2Al brass used to date and a specimen taken from the cast-iron valve housing which was the substrate for a plasma-sprayed coating of powder containing 86.1% Cr, 7.2% Ni, and 6.7% C. The coating, 345 ± 15 μm thick, was characterized with good quality of bonding with cast-iron substrate and high compactness of the material. The cavitation wear test on materials used in the study were carried out with the use of Vibra-Cell ultrasonic liquid processor (Sonics) equipped with a piezoelectric probe operating at the frequency of 20 kHz. Based on profilograms taken along a line crossing centers of cavitation craters, measurements of the height parameter R_t, and microscopic observations of surfaces it has been found that the coating plasma-sprayed onto substrate of nodular cast iron demonstrated higher resistance to cavitation compared to copper-alloy inserts used so far in cast-iron hydraulic valves. Cavitation craters on the material used typically for valve seats to date were more distinctly outlined and deeper compared to craters observed on the coating. Larger were also sizes of local tear-outs which resulted in larger difference between the peaks line and the valleys line.

Keywords: Cast-iron hydraulic valves, Cavitation wear, Plasma-sprayed coating, Sealing ring

1. Introduction

The issue of cavitation wear is of special importance for users of hydraulic components surfaces of which are exposed to contact with fast water flows [1], such as e.g. rotors or blades of water pumps [2]. Areas particularly exposed to cavitation wear are also narrow orifices of full-port valves, constrictions in conduits, or inner surfaces of pipe fittings diverting direction of liquid flows; these are typical areas of occurrence of turbulent flows with local irregular water flow rate increases. These areas of liquid stream are subject to strong and abrupt pressure drops. Once the water boiling pressure is reached, cavitation bubbles appear filled with steam and gases dissolved in water. If the liquid pressure continues to drop, volumes of cavitation bubbles increase and so does the liquid volume affected by cavitation [3]. When the local pressure value increases above the water evaporation point, then the cavitation bubbles disappear (implode). This results in occurrence of a shock wave caused by sudden increase of pressure in micro-areas of the liquid and local cyclically varying pressure pulses on the surface with peak values of up to 1000 MPa [4, 5]. The pulses cause nucleation and development of fatigue cracks in superficial layer of hydraulic fittings carrying fast flows of water.

Requirements applicable to water supplying systems in scope of admissible flow rates and pressures become nowadays more and more demanding. For this reason, numerous research centers deal with the issue of making hydraulic fittings more resistant to cavitation wear.

The methods used to extend service life of fittings and protecting them against destructive effect of cavitation include application of overlays and coatings of materials showing resistance to cavitation higher than this of the substrate material [6–8].

To this end, a number of welding methods are employed such as GTAW, MIG-MAG, plasma, or gas overlaying welding. Recent years have seen an increased interest in plasma-based coating methods, such as VPS (Vacuum Plasma Spraying), HVOF (High Velocity Oxygen Fuel), and APS (Air Plasma Spraying).

The interest in these methods is reflected in literature of the subject which offers reports on studies concerning application of coatings e.g. on turbine components made of austenitic steel to increase their resistance to cavitation wear [9–11].

Less attention was devoted to the problem of improving resistance of cast-iron components of fittings to cavitation wear. Cast-iron components of water system fittings exposed to cavitational action of the medium are sometimes protected by paint coatings. Because of low resistance of such coatings to cavitation wear, surfaces of cast-iron valve housings cooperating with components cutting off water flows are provided by inserts made of copper alloys. These inserts are joined with valve housings by mechanical means. The practice shows that such joints are unreliable. Loosening of insert in the retaining seat results in leakage of a valve.

The use of welding techniques for fixing inserts to valve housing or providing them by overlaying welding is connected with a hazard of occurrence of welding cracks as a result of crystallization of brittle cementite eutectic in the remelted areas and creation of martensitic microstructure in the heat-affected zone [12, 13]. Such problem does not occur in case of forming coatings with the use of APS or HVOF method.

The objective of the present study was to demonstrate the possibility to replace copper-alloy inserts used to date in cast-iron valves with a cavitation-resistant coating sprayed with the use of HVOF method.

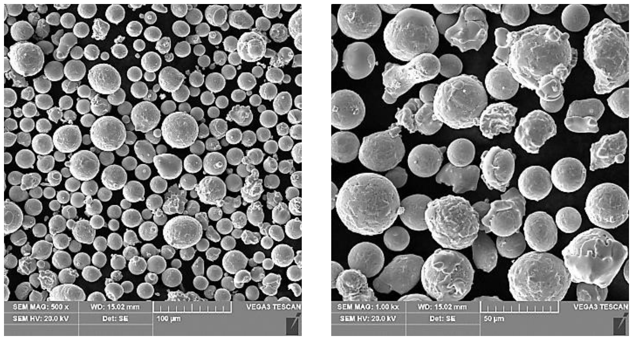
2. Research material and methodology

From a valve seat insert made of CuZn39Pb2Al alloy and from a valve housing made of nodular cast iron, specimens with dimensions 20 mm × 20 mm × 5 mm were cut out. Surfaces of the specimens were first ground and then polished on a polishing wheel with diamond suspension. The copper alloy test specimens prepared this way were characterized with the surface profile height parameter R_t = 0.5 µm. The parameter quantifies the difference between the peaks line and the valleys line. Values of the surface profile height parameter were measured with the use of T8000 roughness measurement system (HOMMEL-ETAMIC).

Surfaces of the cast-iron specimens, just before start of the coating application process, were degreased with acetone and then subjected to blasting with abradant (EFK930 alumina with grain size 125–180 µm) in a stream of air supplied at pressure of 6 bar. The process was carried out manually by positioning the front face of nozzle at a distance of about 100 mm from plate surfaces. The used apparatus was KCW-1200-1150+FCPd abrasive blasting machine.

The value of the profile height parameter R_t for surface of plates prepared that way for application of coating was R_t = 10.5 µm.

The material used for coating was CRC-410 powder (PRAXAIR). Results of examination of shape, size, percentage share, and chemical composition of powder particles are given in Figure 1.



Shape	Size, µm	Share, %
Spherical	36–49	60
	10–36	20
Globular	26–60	20
Composition: 86.1% Cr, 7.2% Ni, 6.7% C		

Fig. 1. A view of CRC-410 powder particles and their shapes, sizes, percentage share, and chemical composition

The process of plasma-spraying the coating onto cast iron substrate was realized in premises of the company Thermisches Beschichtungs Center Uskovic GmbH, with the use of Thermico C-CJS-N HVOF apparatus equipped with CPF-2 powder feeder with gravimetric control of feed rate and K 5.2 burner with accelerating nozzle with diameter of 140 mm. The value of the height parameter R_t for the deposited coating was R_t = 15.6 µm.

From plasma-sprayed cast-iron plates, a number of specimens were cut out to assess thickness of the coating, quality of its bonding with substrate, and susceptibility to exfoliation. For this purpose it was necessary to prepare metallographic sections in the plane perpendicular to the coating deposition surface. Thickness of the coating was determined with the use of microscopic method. The quality of the coating-substrate bonding and susceptibility of the system to exfoliation was assessed with the use of scratch test, in combination of results of observation of the scratch trace with the use of the electron scanning microscope. Scratch tests were performed on Revetest RST macro scratch tester (CMS Instruments) using C-281 Rockwell indenter loaded with force of 10 N.

The next stage of the study concerned the cavitation wear of copper alloy used so far for water valve seat inserts and a coating plasma-sprayed onto a cast-iron substrate.

The cavitation wear resistance tests were carried out with the use of Vibra-Cell Ultrasonic Liquid Processor (SONICS) equipped with a piezoelectric transducer probe. The used vibration frequency was 20 kHz. In the course of testing, the specimens were immersed in distilled water. The distance from ultrasonic probe face to specimen surface was 0.5 mm. The time of exposure to cavitation was 120 minutes.

A view of the cavitation mist area generated above specimen surface in the course of the cavitation wear test is shown in Figure 2.

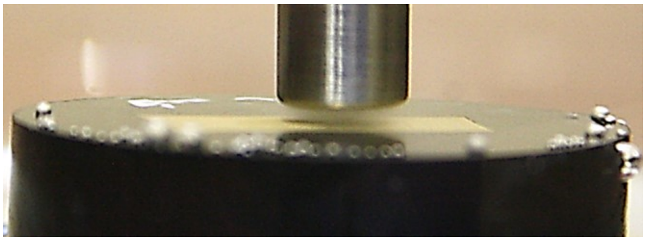


Fig. 2. A view of the cavitation mist area above specimen surface in the course of the cavitation wear test

The degree of cavitation wear of the materials used in the test was assessed based on profilograms taken along lines crossing centers of cavitation craters and measurements of values of the profile height parameter R_t as well as on microscopic observations.

3. Research results and analysis

Figure 3 shows a view of the deposited coating and a scratch made in direction from substrate to outer surface of coating.

(a) (b)

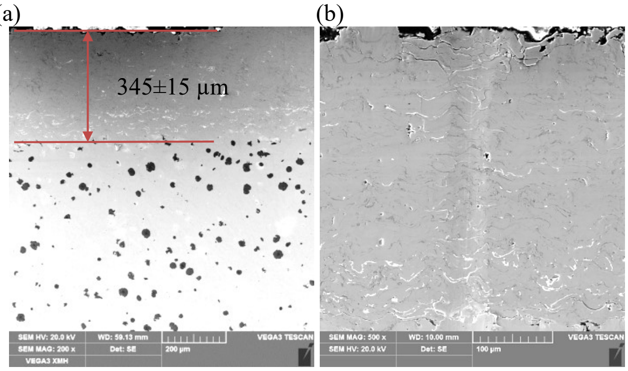
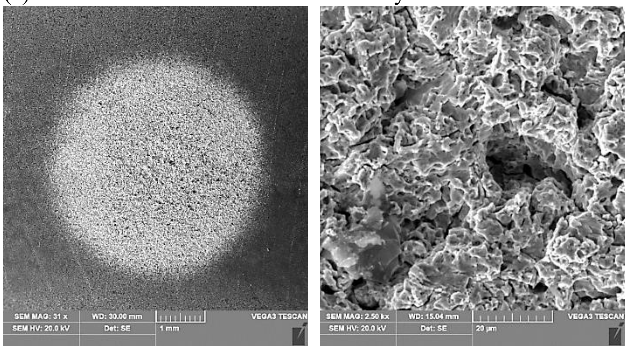


Fig. 3. (a) A view of coating made of powder containing 86.1% Cr, 7.2% Ni, and 6.7% C deposited on nodular cast iron substrate with the use of HVOF method and (b) a view of a test scratch made in direction from substrate to outer coating surface

The obtained results indicate good quality of the substrate-coating bonding. On the border line separating the materials, there are no signs of bonding discontinuities. The scratch test confirms good quality of the bonding and high compactness of the coating material which are evidenced by absence of exfoliation on surface and around the scratch path. Further, the scratch test results prove that the substrate is much more susceptible to scratching than the coating material, as the scratch width is less on the latter.

Figure 4 presents example views of cavitation craters and views of surfaces of the tested materials after exposure to cavitation.

(a) CuZn39Pb2Al alloy



(b) a coating containing 86.1% Cr, 7.2% Ni, 6.7% C

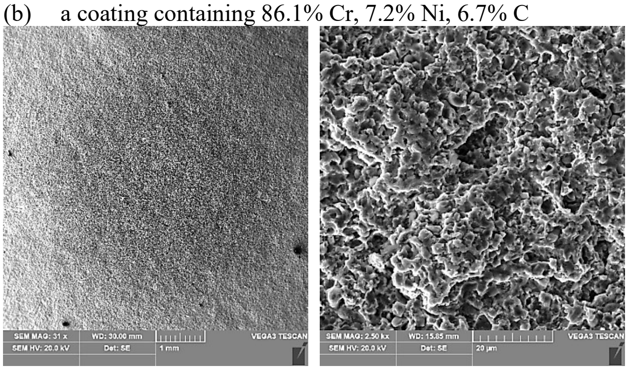


Fig. 4. Example views of cavitation craters and surfaces of the compared materials after exposure to cavitation in water

The obtained results indicate that a crater with a distinctly defined outline was formed in the material of the tested valve seat sealing insert used typically to date. Observation of surface of the crater indicates that individual components of microstructure of CuZn39Pb2Al alloy are characterized with different susceptibility to cavitation damage which results in development of extensive local cavities.

On the surface of plasma-sprayed coating, a cavity without clearly defined edges was formed. Microscopic observation of the cavity surface reveals inhomogeneous susceptibility to cavitation damage. In case of the material used typically for valve seat inserts, dimensions and depths of tear-outs are much larger compared to those occurring on the coating surface.

Figure 5 shows example profilograms of surfaces of the two compared materials after cavitation tests, with said profilograms being taken along lines crossing centers of respective cavitation craters.

The obtained results weight in favor of decidedly higher susceptibility of the material used earlier for valve seat sealing inserts to cavitation wear compared to the coating material used in the tests. It has been found that the cavitation crater occurring on the coating was less deep and less wide.

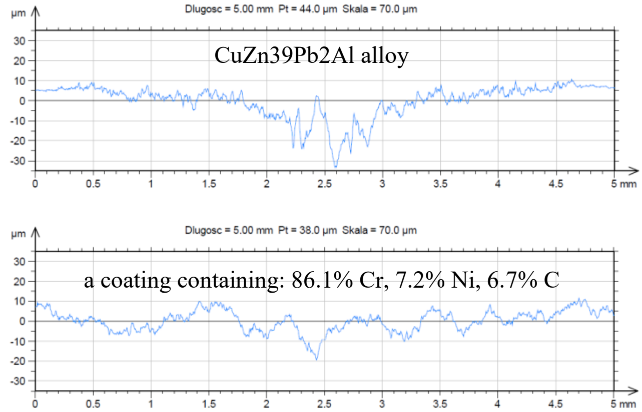


Fig. 5. Example profilograms of specimen surfaces in areas exposed to cavitation taken along a line crossing centers of cavitation craters

Table 1 summarizes results of measurements of the parameter R_t taken on surface of specimens of the material used so far for valve sealing seats and the coating material, before and after cavitation caused by water.

Table 1.
Results of cavitation wear tests assessed by means of measurements of values of the height parameter R_t for the material used to date for sealing valve sealing seats and the proposed coating material

Material type	**R_t parameter value, µm**		**ΔR_t, µm**
Insert material	initial condition	0.5	31.6
	condition after cavitation wear test	32.1	
Coating applied onto nodular cast iron substrate	initial condition	15.6	4.3
	condition after cavitation wear test	19.9	

The obtained results indicate that the plasma-sprayed coating demonstrates, compared to the material used commonly for sealing inserts in water valve seats, distinctly higher resistance to cavitation wear which manifested itself in less difference of peak and valley heights on its surface.

4. Conclusions

The obtained results prove that the coating plasma-sprayed onto a substrate of nodular cast iron is characterized with higher resistance to cavitation wear compared to the material of sealing water valve seat inserts of CuZn39Pb2Al alloy used typically to date in cast-iron hydraulic valves.

It seems to be appropriate to undertake further research on cavitation resistance of coatings made of other plasma-sprayed materials, including their behavior in such media as drinking water, seawater, and contaminated water in view of their application in cast-iron hydraulic valves.

Acknowledgements

The study presented in this paper was carried out in cooperation with Fabryka Armatury Jafar S.A. and Thermisches Beschichtungs Center Uskovic GmbH, within the framework of project POIR 01.01.01-00-0636/15, jointly with CEBAPO.

References

[1] Kumar, P. & Saini, R.P. (2010). Study of cavitation in hydro turbines – A review. *Renewable and Sustainable Energy Reviews*. 14, 374-383.
[2] Dorji, U. & Ghomashchi, R. (2014). Hydro turbine failure mechanisms: an overview. *Engineering Failure Analysis*. 44, 136-147.
[3] Adamski, M. (2003). How to avoid cavitation — circulation pumps. *Rynek Instalacyjny*. 11. (in Polish).
[4] Bagiński, J. (1998). *Cavitation in water supply and heat engineering systems*. Poznań: Wyd. Politechniki Poznańskiej. (in Polish).
[5] Jamróz, S. (2015). Critical flow-related phenomena and ways to suppress them. *Armatura i Rurociągi*. October-December 10,12. (in Polish).
[6] Romo, S.A., Santa, J.F., Giraldo, J.E. & Toro, A. (2012). Cavitation and high-velocity slurry erosion resistance of welded Stellite 6 alloy. *Tribology International*. 47, 16-24.
[7] Kwak, C.F., Man, H.C. & Cheng, F.T. (2001). Cavitation erosion–corrosion behaviour of laser surface alloyed AISI 1050 mild steel using NiCrSiB. *Materials Science and Engineering*. A303, 250-261.
[8] Hattori, S. & Mikami, N. (2009). Cavitation erosion resistance of Stellite alloy weld overlays. *Wear*. 267, 1954-1960.
[9] Stella, J., Schüller, E., Heßing, C., Hamed, O.A., Pohl, M. & Stöver, D. (2006). Cavitation erosion of plasma-sprayed NiTi coatings. *Wear*. 260, 1020-1027.
[10] Bitzer, M., Rauhut, N., Mauer, G. Bram, M., Vaßen, R., Buchkremer, H.P., Stöver, D. & Pohl, M. (2015). Cavitation – resistant NiTi coatings produced by low pressure plasma spraying (LPPS). *Wear*. 328-329, 369-377.
[11] Wang, Y., Stella, J., Darut, G., Poirier, T., Liao, H. & Planche, M.P. (2017). APS prepared NiCrBSi-YSZ composite coatings for protection against cavitation erosion. *Journal of Alloys and Compounds*. 699, 1095-1103.
[12] Malek Ghaini, F., Ebrahimnia, M. & Gholizade, Sh. (2011). Characteristics of crack in heat affected zone of ductile cast iron in powder welding process. *Engineering Failure Analysis*. 18, 47-51.
[13] Ebrahimnia, M., Malek Ghaini, F., Gholizade, Sh. & Salari, M. (2012). Effect of cooling rate and powder characteristics on the soundness of heat affected zone in powder welding of ductile iron. *Materials and Design*. 33, 551-556.