Study on the Use of Elastomeric Coatings for Protection of Hydraulic Turbine Components Against Cavitation Erosion

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In order to find alternative solutions for protection of hydraulic turbine components against cavitation, a fluid elastomer layer, curing at room temperature, was deposited onto a martensitic stainless steel substrate. The resistance of the coating to cavitation erosion was determined by the vibratory indirect method, using ultrasonic equipment with piezoelectric converter and the microstructure of the polymer was investigated using scanning electron microscopy (SEM) and energy dispersive X-ray analysis (EDX). The authors compared the cavitation erosion resistance of the elastomer layer with that of the base material (martensitic stainless steel) as well as that of protective cold hardening austenitic stainless steel coatings, deposited by overlay welding onto the base material. The experimental results revealed that the elastomer coating ensures better resistance to cavitation erosion than both stainless steel types.

Keywords: cavitation, cavitation erosion resistance, elastomer, stainless steels, hydraulic turbines

Due to their excellent mechanical properties and low price, stainless steels are widely used as main materials for manufacturing of hydraulic turbine components. However, it is well known that the cavitation resistance of stainless steels is relatively low [1-2]. In order to enhance the cavitation resistance of steel components, scientists have studied various techniques such as overlay welding or thermal spraying of protective layers, as well as thermochemical treatments [3-5, 19]. Up to now, the best results regarding the protection against cavitation of turbine runner blades were obtained by overlay welding of cold hardening austenitic stainless steels [6-7]. The main problems in case of repair welding in situ are connected to the residual stresses and to the important structural modifications which appear during the welding process [8]. These effects, especially when extensive welding is applied, can lead to the damage of the repaired components during following operation. Neither the coatings obtained by thermal spraying lead to acceptable results in case of exposure to cavitation, because of the insufficient adhesion of the deposited layers to the substrate and high porosity [9]. As many researches indicate that elastomeric materials present very good physical and mechanical characteristics [10-13, 18], the authors of this paper aimed to investigate if the use of a protective elastomer coating with inserts of calcite and sand particles can prevent or at least decrease the undesirable effects produced by cavitation erosion.

Experimental part

Testing method

The cavitation tests were carried out in the Center for Research in Hydraulics, Automation and Thermal Processes of the Eftimie Murgu University of Resita, using the ultrasonic equipment with piezoelectric converter and applying the indirect vibratory method with fixed specimen, fully immersed in the liquid (fig. 1). The resonance frequency of the oscillator was set at 20 ± 0.5 kHz and the double (peak to peak) amplitude of the vibrating sonotrode was 50 μm. The test liquid consisted of de-ionized water, maintained at 25±2 degrees Celsius by a temperature control device and a cooling system with water.

The distance between the vibrating sonotrode and the test specimen (stand-off work) was adjusted at 0.6 mm. The test specimen was removed periodically after predetermined time intervals and weighed with a precision balance after cleaning with acetone and drying in hot air flow. The test results were expressed by the mean depth of erosion (MDE), using the mass loss divided by the density of the material and the eroded area, according to ASTM G32-10. The results were graphical represented after calculating the equation (1).

$$MDE = \frac{10^6 \cdot \Delta m}{\rho \cdot A_e} \qquad (1)$$

In the eq.1, the following abbreviations were used:
Δm[mg] – mass variation;
A_e [mm^2] – area of the eroded surface;
ρ [kg/m^3] – density of the material exposed to erosion.

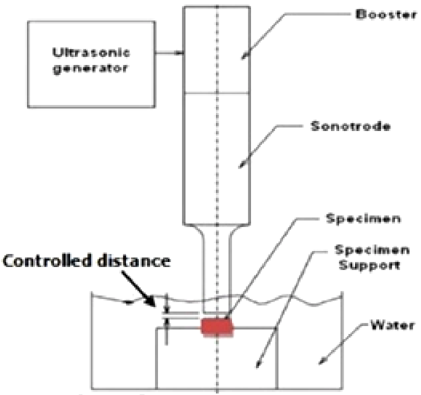

Fig.1 The principle of the indirect cavitation method

Materials and specimens

The fluid elastomer layer was applied onto 16 mm diameter cylindrical samples made of martensitic stainless steel. In the first stage, the surfaces were covered with a primer layer after a very thorough blast cleaning. In the second stage, the fluid elastomer curing at room temperature was applied with a paintbrush, eliminating the need for hot work. Figure 2 shows the cross section of the sample, revealing that the deposited elastomer layer is well anchored to the base material and has a thickness around 900 μm.

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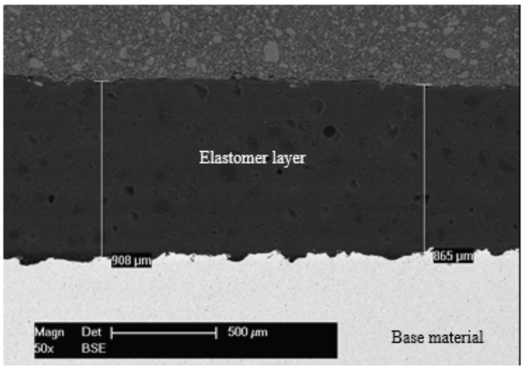


Fig.2 Elastomer layer deposited onto the base material. Cross section of the sample

Table 1
PHYSICAL AND MECHANICAL PROPERTIES OF THE ELASTOMER

Density [g/cm^3]	1.06 - 1.09
90^0 Peel adhesion [N/mm]	31.52
Tensile strength [MPa]	15.2
Tear strength [N/mm]	66.55
High elongation [%]	530
Shore A Hardness	87

Table 2
CHEMICAL COMPOSITIONS OF THE STAINLESS STEELS

Materials	**Chemical elements [%]**							
	C	**Si**	**Mn**	**Cr**	**Ni**	**Mo**	**P**	**S**
Martensitic stainless steel (base material)	0.03	0.46	0.71	12.64	3.63	0.53	0.025	0.001
Austenitic stainless steel (welding wire)	0.24	2.02	9.49	15.56	12.00	0.36	0.014	0.003

In table 1 are listed the physical and mechanical properties of the elastomer, as specified by the manufacturer. In order to point out the efficiency of the elastomer, the experimental results were compared with those obtained by testing under same conditions of a martensitic stainless steel type, that is widely used as base material for manufacturing of hydraulic turbine components, as well as those performed by a cold hardening austenitic stainless steel type, applied by overlay welding, which led to the best results up to now regarding the protection of turbine runner blades against cavitation. The chemical compositions of the martensitic and the austenitic stainless steels are presented in table 2.

Results and discussions

In order to evaluate the resistance to cavitation erosion of the coating realized from the fluid elastomer with inserts of calcite and sand particles, three specimens were tested for a period of 3000 min under the same conditions. The average value of the total eroded mass [Δm] for the samples is graphically represented in figure 3. As one can observe, the slope of the curve climbs constantly up to 2500 min. The tested specimens lost an average weight of 0.38 mg because of the detachment of insertion particles from the deposited coating surface (fig.4). After complete removal of these particles, the weight of the samples remained constant and the curve has stabilized. Figure 4 shows the time evolution of the elastomeric surface appearance.

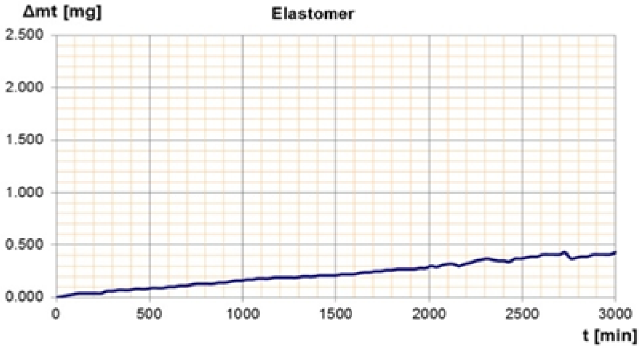
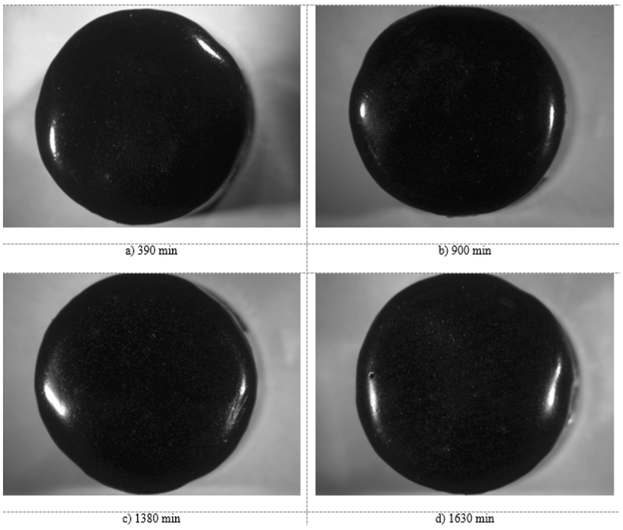


Fig.3 Mass loss curve of the elastomer layer

After the total time of exposure to cavitation, the surface of the elastomer layer has been evaluated by scanning electron microscopy (SEM) and energy dispersive X-ray analysis (EDX). Figure 5 shows a SEM-capture of the elastomer coating after exposure to cavitation, as well as the EDX-analysis of the detached inserts (points 1 and 3) and the matrix (point 2).

The results obtained during 50 h testing of the elastomer coating were compared with those previously determined



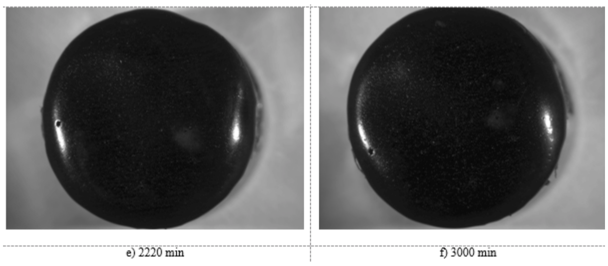


Fig.4. The appearance of the elastomer surface exposed to cavitation at succesive testing intervals

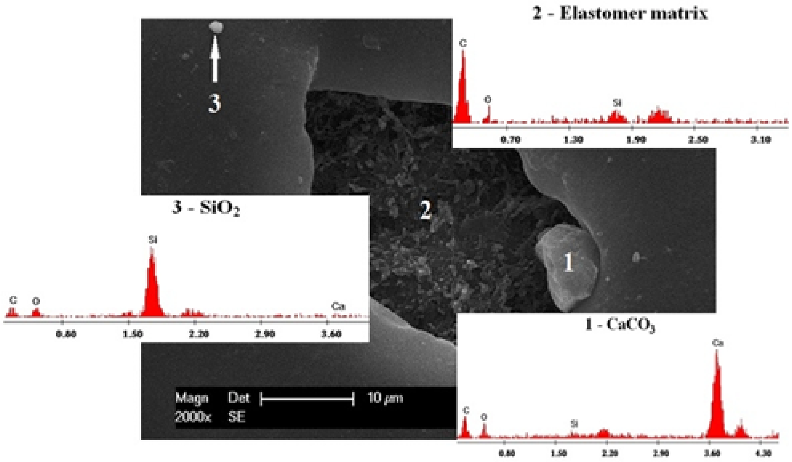


Fig.5 SEM-micrograph of the sample surface and EDX-analysis of the matrix and the inserts

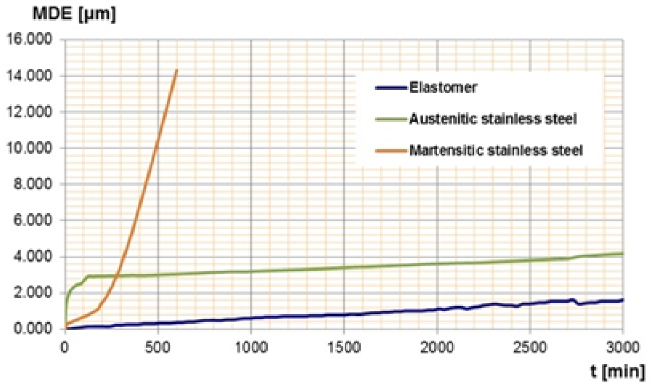


Fig.6 Resistance to cavitation of the elastomeric coating, the martensitic stainless steel and the cold hardening austenitic stainless steel

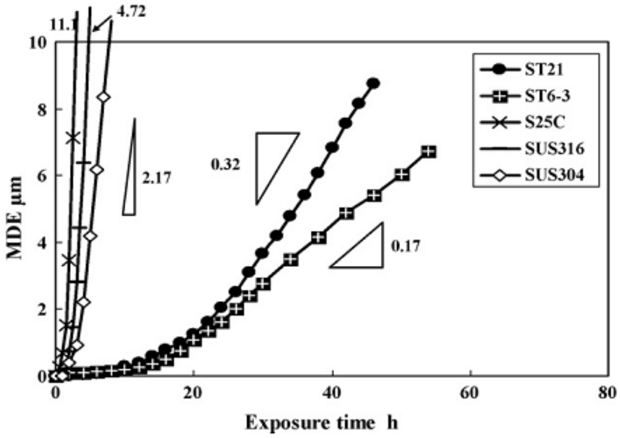


Fig.7. Mean depth of erosion determined by Hattori for different types of materials using the vibratory indirect method [14]

by the authors, under the same experimental conditions, for the martensitic stainless steel and the cold hardening austenitic stainless steel. Therefore, according to ASTM G32-10, the variation in time of the mean depth of erosion (MDE, µm) was used (fig. 6).

As one can see, figure 6 reveals that, throughout the complete testing interval of 3000 min, the elastomeric layer assured the slightest mean depth of erosion, even lower than that of the cold hardening austenitic stainless steel, thereby providing a very good protection against cavitation to the martensitic substrate. Meanwhile, the time evolution of the MDE for the martensitic stainless steel explains why protection is needed.

Comparing the mean depth of erosion rate (MDER) obtained for the elastomer with values encountered in the scientific literature for materials considered having good resistance to cavitation erosion, the behaviour of the elastomeric layer can be appreciated as excellent. For example, cobalt base alloys are used in all industrial areas due to their excellent wear resistance. A lot of literature concerning state of the art in respect to the cavitation resistance of Stellite 6 reports about welded [14-15] or high velocity oxy fuel sprayed Stellite 6 coatings [16-17]. In this regard, it has to be considered that for welded Stellite 6 coatings, tested to cavitation erosion by the vibratory indirect method, Hattori [14] achieved in the stabilization area a value of 0.17µm/h MDER (fig. 7), whereas for the elastomer layer, tested by the authors in this study, the MDER was only 0.036 µm/h.

Conclusions

The investigations presented in this paper are part of a comprehensive research program conducted under the Research Center for Hydraulics, Automation and Thermal Processes (CCHAPT) of the *Eftimie Murgu* University of Resita, aiming to develop alternative repair techniques and materials for hydraulic turbine components working under cavitation.

In this regard, one of the methods than can offer a solution worthy to be considered for enhanced protection against cavitation is the use of paint brushed elastomer layers. Within this study, the authors have tested an elastomer with insertion particles to cavitation resistance by the vibratory indirect method, using ultrasonic equipment with piezoelectric converter. The experimental investigations carried out revealed that the elastomer layer was more resistant to cavitation than the base material (martensitic stainless steel) and also than the cold hardening austenitic stainless steel, widely used for repair welding in situ of cavitation eroded surfaces. Furthermore, the elastomer coating showed much better resistance to cavitation erosion than welded Stellite 6 layers, considering the data reported by the scientific literature.

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References

1. SANTA, J.F., BLANCO, J.A., GIRALDO, J.E., TORO, A., Cavitation erosion of martensitic and austenitic stainless steel welded coatings, Wear, 271, 2011, p. 1445;
2. HATTORI, S., ISHIKURA, R., Revision of cavitation erosion database and analysis of stainless steel data, Wear, 268, 2010, p. 109;

[3] FRUNZAVERDE, D., CAMPIAN, C.V., COJOCARU, V., MARGINEAN, G., BARAN, M., CIUBOTARIU, R., Influence of welded layers thickness on the cavitation erosion resistance, Proceedings of 6th WSEAS International Conference on Energy, Environment, Ecosystems and Sustainable Development (EEESD TO), 2010, p. 316;

4. SHENG, HONG, YUPING, WU, JIANFENG, ZHANG, YUGUI, ZHENG, YUJIAO, QIN, JINRAN, LIN, Ultrasonic cavitation erosion of high-velocity oxygen-fuel (HVOF) sprayed near-nanostructured WC-10Co-4Cr coating in NaCl solution, Ultrasonics Sonochemistry, 26, 2015, p. 87;

5. WINCK, L.B., FERREIRA, J.L.A., ARAUJO, J.A., MANFRINATO, M.D., DA SILVA, C.R.M., Surface nitriding influence on the fatigue life behaviour of ASTM A743 steel type CA6NM, Surface & Coatings Technology, 232, 2013, p. 844–850;

6.FRUNZAVERDE, D., CAMPIAN, V., NEDELCU, D., GILLICH, G.R., MARGINEAN, G., Failure analysis of a Kaplan turbine runner blade by metallographic and numerical methods, Proceed. WSEAS Inter. Conf. on Fluid mechanics, 2010, WSEAS Press, p. 60-67;

7. BORDESAU, I.,Eroziunea cavitationala a materialelor, Ed. Politehnica Timisoara, 2006;

8. FRUNZAVERDE, D., CAMPIAN, V., MARGINEAN, G., Metallographic Investigations on Anti-Cavitation Lips of Kaplan Blades, 23rd IAHR SYMPOSIUM on Hydraulic Machinery and Systems, Yokohama, Japan, October 17th - October 21st 2006;

9. COJOCARU, V., FRUNZAVERDE, D., CAMPIAN, V., MARGINEAN, G., CIUBOTARIU, R.C., PITTNER, A.M., Cavitation erosion investigations on thermal spray coatings, Proceed. WSEAS Inter. Conf. on Engineering Mechanics, Structures, Engineering Geology, Grecee, 2010, p. 177-180;

10. NEDELCU, D., GILLICH, G.R., CZIPLE, F., CIUCA, I., PADUREAN, I., Considerations about using polymers in adaptive guardrails construction, Mat. Plast., **45**, no. 1, 2008, p. 47

11. GHITA, E., BORDEASU, I., CERNESCU, A., BALASOIU, V., CIUCA, I., On the behaviour of elastic elements belonging to the elastic tram wheel at particular loading, Mat. Plast., **45**, no. 1, 2008, p. 97

12. LAZAR, M., FIAT, D., BACIU, V., HUBCA, G., Researches Regarding the Influence of Some Concrete Protection Polymeric Products, Mat. Plast., **49**, no. 1, 2012, p. 9

13. KORKA, Z., I., GILLICH, G., R., MITULETU, I., C., TUFOI, M., Gearboxes Noise Reduction by Applying a Fluoropolymer Coating Procedure, Environmental Engineering and Management Journal, **14**, no. 6, 2015, p. 1433-1439;

14. HATTORI, S., MIKAMI, N., Cavitation erosion resistance of Stellite alloy weld overlays, Wear, **267**, 2009, p. 2033–2038;

15. KUMAR, A., BOY, J., ZATORSKI, R., STEPHENSON, L., D., Thermal spray and weld repair alloys for the repair of cavitation damage in turbines and pumps: A technical note, Journal of Thermal Spray Technology, **14,** Issue 2, 2005, p. 177-182;

16.SINGH, SIDHU, H., SINGH, SIDHU, B., PRAKASH, S., Performance of HVOF Sprayed NiCr and Stellite-6 Coatings under Pin on Disc Wear Testing, Materials science forum, **701**, 2012, p. 21-29;

17. CIUBOTARIU, C., R., FRUNZAVERDE D., MARGINEAN G., SERBAN, V., A., BÎRDEANU A., V., Optimization of the laser remelting process for HVOF-sprayed Stellite 6 wear resistant coatings, Optics & Laser Technology, **77**, 2016, p. 98-103

18. MITELEA, I, VARZARU, N, BORDEASU, I, POPESCU, M, The High Frequency Welding Aptitude of Thermoplastic Polymers, Mat. Plast., **46**, no. 1, 2009, p. 101

19. BORDEASU, I, POPOVICIU, MO, MITELEA, I, BALASOIU, V, GHIBAN, B, TUCU, D, Chemical and mechanical aspects of the cavitation phenomena, Rev. Chim. (Bucharest), **58**, no. 12, 2007, p. 1300

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