Cavitation Erosion Behaviour of Cooper Base Layers Deposited by HVOF Thermal Spraying

ILARE BORDEASU[1]*, ION MITELEA[1], IOSIF LAZAR[1]*, LAVINIA MADALINA MICU[2]*, OLIMPIU KARANCSI[3],

[1] University Politehnica Timisoara, 2 Piata Victoriei Sq., 300006, Timisoara, Romania

[2] University of Agricultural Sciences and Veterinary Medicine of Banat King Mihai I from Romania, 119 Calea Aradului, 300645, Timisoara, Romania

[3]Victor Babes University of Medicine and Pharmacy Timisoara, 2 Eftimie Murgu Sq., 300041, Timisoara, Romania

The recent development in enhancing the corrosion resistance of materials by covering with powdered layers open the way to use the procedure also for cavitation erosion protection, phenomenon always present in hydraulic machinery runners as well as ship propellers. The present research analyzes the behavior of four different types copper layers, deposited with high velocity flames, HVOF upon specimens realized from cast steel for general use 270-480 W (equivalent with OT500-3 used in Romania), to cavitation erosion in a Laboratory device. Even if the powder density and the layers thickness have close values, the behavior to cavitation erosion is different and depend primarily on the powder chemical composition and the microscopic structure.

Keywords: vibratory cavitation erosion, deposition through HVOF of common steels, copper layers, powder

Thermal spraying knows, in recent time, a high applicability in the space industry, automobile industry and shipbuilding industry as the result of the multiple advantage presented [1, 2], in comparison with other procedures applied for similar purposes (immersion in molten metal, diffusion, plating, galvanic coatings [3-6], because:

- moderate heating of the underlay, so that the probability of internal tensions or even cracks is very low;
- can be done outside a specialized workshop even on large covering areas;
- can be done on every support.

The great disadvantage which creates some reservations is represented by the lack of homogeneity and the porosity of the layer. For details subjected to cavitation such as the Kaplan turbine hubs or the body of the ships in the vicinity of the propeller, the powder chemical composition is the basic element for the bound layer-sub layer with the greatest influence on the cavitation erosion resistance of those details. Because the experimental research is done on a vibratory device with high erosion capacities, in comparison with those occurring in the industrial conditions, the obtained results are overlapping with regard to the situation encountered in industrial devices.

In the same time the research results present the differences between the cavitation erosion behavior of four powders applied with high velocity (HVOF) and having different chemical composition.

Experimental part

Used materials

From a 270-480 W SR ISO 3755:1995 cast steel bar, frequently employed for realizing the runner hub for Kaplan turbines as well as ship rudders [1, 7, 8], have been manufactured cavitation erosion specimens, subsequently covered with four different powders. The chemical composition and density of these powders are given in table 1. The size of the powder granules is between 20 and 35μm.

From table 1 it can be seen that the first two powders are bronzes with tin and the last two are special brasses. Regardless of the chemical composition, all the powders have very close value of the density. The determinations made in Timisoara Polytechnic University Laboratories give the chemical composition of the steel 270-480 W as being: 0.25 % C, 1.2 % Mn, 0.6 % Si, 0.4 % Ni, 0.35 % Cr, 0.4 % Cu, 0.35 % S, 0.035 % P, 0.15 % Mo, 0.05 % Va, the rest being Fe; the mechanical characteristics are: $R_{p0.2}$ = 270 MPa, R_m = 600 MPa, A5 = 18 %, Z_{min} = 35 %, KCU = 52 daJ.

Method of layers making

The fact that a micro layer deposited through thermal spraying is characterized by adherence, structure and density/porosity [2, 9, 10]. For realizing these conditions the specimens working surfaces were turned and blasted with electro corundum particles till a roughness Ra = 18μm (fig. 1) value recommended by specific rules [1, 2]. Also, in compliance with the specific rule for spraying [4], in

Tabelul 1

CHEMICAL COMPOSITION OF THE USED POWDERS

Specimen	Component elements [% weights]										ρ [g/cm³]
	Co	Cr	Cu	Fe	Mo	Ni	Pt	Sn	Ti	Zn	
1	-	-	96	-	-	-	-	4.0	-	-	8.85
2	-	-	95.96	-	0.02	-	-	4.02	-	-	8.85
3	0.34	7.6	44.7	0.25	0.17	18.63	0.24	-	0.37	27.7	8.30
4	0.27	6.64	47.08	0.22	0.17	16.2	0.27	-	0.32	28.83	8.31

* email: ilare.bordeasu@upt.ro, ilarica59@gmail.com; office@ducodan.ro; lavimicu@yahoo.com

Fig.1 Shape of the specimen

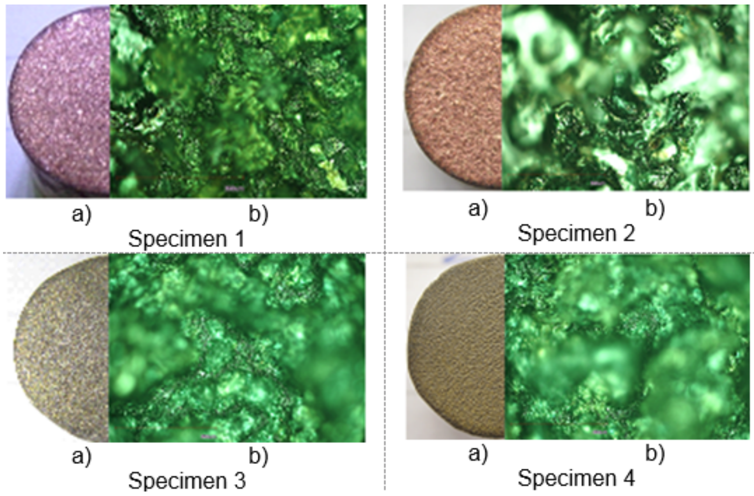

Fig.2 Surfaces sujected to thermal spraying
a) macro images;
b) microscopic images (350x)

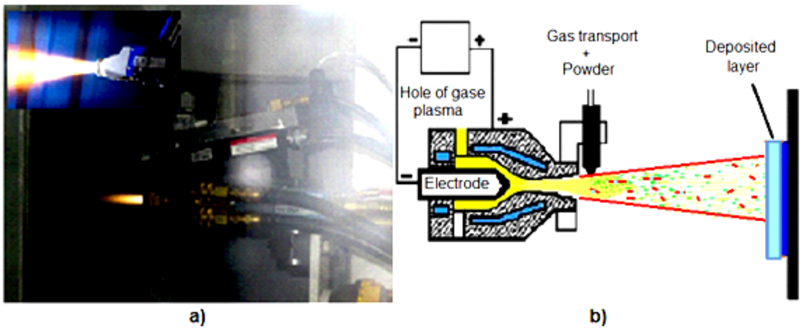

Fig.3 a) Robotic thermal spraying facility, METCO SULZER b) Principle of the HVOF spraying method [1, 2]

order to increase the adherence and compactness of the deposited layers the surfaces were cleaned and degreased, the first layer was sprayed from a distance of 80 mm, and the following from 210 mm.

The injection and acceleration of the dust in the flame towards the sub layer was realized with supersonic velocities. The procedure conducted to compact layers with the measured porosity under 2% with a fine aspect and very little oxidized, (fig. 2). The thermal spraying HVOF, described in [1, 2], was realized in the Iasi Technical University Gheorghe Asachi, on a robot spraying installation METCO SULZER which can be analyzed in figure 3.

After a few optimization steps, the chosen main parameters for the thermal spraying process were:

- temperature at piece surface ≅150°C;
- powder flow 63 g/min;
- thickness of the deposited layer approximate 0.8 mm;
- plasma genic gas, Ar+6%H_2- pressure 9 bars;
- transporting gas, Ar, pressure 4 bars;
- compressed air, pressure 2 bars.

Results and discussions

The researches concerning the behavior of the layers deposited through thermal spraying to cavitation erosions were carried out on the standard cavitation erosion device figure 4, of the Cavitation Laboratory of Timisoara Polytechnic University [11-13]. The reason of using this device, is because the cavitation effect generated by a ship propeller or by a turbine runner, figure 5, is identically with the one generated by the vibratory device, figure 6.

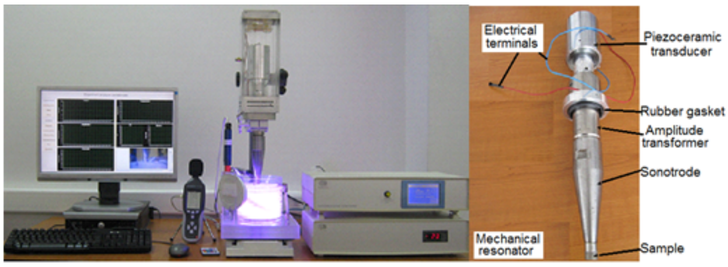

Fig.4 Standard vibratoty device (Timisoara Polytechnic University, Cavitation Laboratory)
a)General view; b) Mechanical resonator

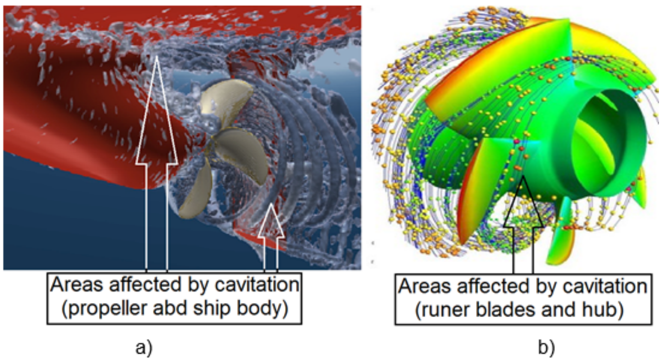

Fig.5 Images of flow with cavitation [7, 8]
a)- ship propeler; b)- Kaplan turbine runner

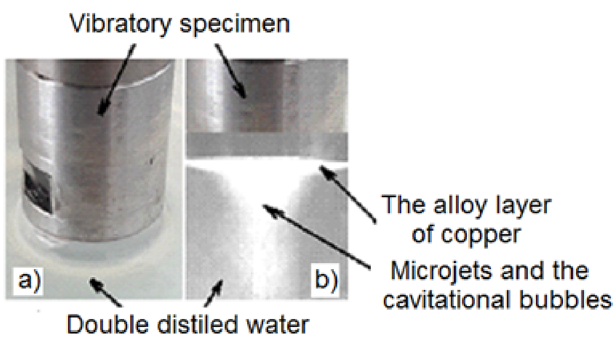

Fig.6. Vibratory specimen (recordings made in TPU Cavitation Labotarory) a) static specimen; b)vibrating specimen

Tabel 2
MACRO IMAGES OF THE EXPOSED AREA

Speci-men	Exposure time [min]				
	1	5	30	60	90
1					
2					
3					
4					

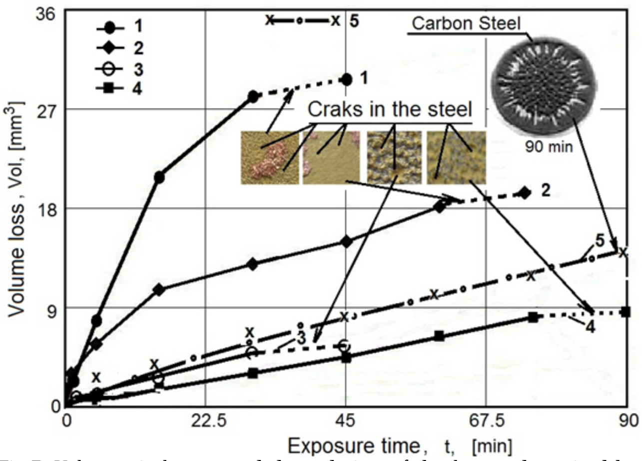

Fig.7. Volumetric losses and degradation of the layers deposited by thermal spraying exposed to vibratory cavitation

This way, the impact of the microjets generated by the implosion of the cavitation bubbles in the hydrodynamic stream of a ship propeller and of a turbine runner with the solid surfaces on their way, will generate similar erosion effect because, even they are slightly different, mechanically and hydrodynamically they are the same [1, 7, 8, 14].

Even if the laboratory has specific procedures for the cavitation tests, [15,-17], especially regarding the periods of the cavitation exposure, according to ASTM G32-2010 [18], these procedures were not integrally respected, because we wanted to put strongly into evidence only the effect of the layer, its chemical composition, the way in which it is gradually degradated, the influence of the porosities and of the adherence, excluding, as well as possible, the influence of the basic material. This is also the reason why the microscopic and macroscopic analysis, in which pictures where taken at different exposure times, is executed until some pitting corrosion appears in the base material of the specimens.

In table 2 are presented pictures with the degradation level of the covered surface at different exposure times. According to these pictures, it was found that the adhesion of the layer deposited by thermal spraying to the base material, resisted until some pittings were observed on the surface of the base material. Depending on the test duration, those pits could be seen without magnification (specimens 1 and 2) and by magnification with the electronic microscope OPLIMPUS SYX7 (specimens 3 and 4).

In figure 7, it is shown the evolution of volumetric losses which, due to approximately identical thicknesses (≅0,8 mm), represents a percentage indication of the expulsion from the surface layer exposed to cavitation. The diameter of the surface layer is 15.8 mm. In order to picture better the resistance provided by these layers, in the figure, it is also shown the volumetric loss of the base steel 270-480 W.

The dashed lines are used in order to indicate, that starting from that exposure time, the degradation strongly appears also in the base material (270-480 W), therefore starting from these times (30 min for specimen 1 and 3,.60 min for specimen 2 and 75 min for specimen 4) the behavior of the layers exposed to cavitation erosion cannot be evaluated anymore, as it is highly dependent on steel resistance.

The analysis executed on the pictures from table 1, as well as on the evolutions of Vol (t) curves (fig. 7) led to the following findings:

- After 1 min of exposure to vibratory cavitation, none of the layers presented any traces that the base material has been reached. For this short period of attack, the behavior is actually related to (density) the chemical composition of the deposited layer which contains Cr, Ni, and Zn. Specimens 3 and 4 behaves identically, as well behaves specimens 1 and 2. The only difference is, that specimens 3 and 4 have a higher resistance to cavitation erosion due to the improvements in the chemical composition, meaning that by optimizing the chemical composition, it is possible to increase the resistance of the deposited layer;
- after 5 min of exposure to cavitation, the behavior of the layers starts to diverge more and more;
- the improved behavior of the layers deposited on specimen 4, is given by the presence of molybdenum (0.17%), which improves the adhesion to the base material

by increasing the diffusion capacity [1, 2] , and by the presence of platinum (27%), which reduces the danger of decreasing the resistance of the deposited layer exposed to cavitation, by decreasing the oxidation degree of the particles form the plasma jet;

- compared to the base steel 270-480 W, just the layers of specimens 3 and 4 presented an increased resistance to cavitation erosion, and this one for short periods, due to porosity and small thickness (approximately 0.8 mm). Due to the fact that these layers have an increased resistance compared to the base steel, it is shown that by depositing them through HVOF method, was given a good adhesion and hardness which led to this behavior;

- the layers deposited on specimens 1 and 2, presents a lower resistance compared to 270-480 W steel.

Conclusions

Even tough, the resulted layers from the thermal spray treatment with constant and similar parameters had equal thicknesses, the resistance to cavitation erosion, created by axial vibrations of the vibratory device, was strongly dependent on the type of the used material.

The high content in Cr and Ni increases the resistance of the thin layer to corrosion, as well as to cavitation erosion. The presence of the chemical elements, such as molybdenum and platinum, improves the resistance to cavitation erosion, by increasing the adhesion of the layer to the sublayer and by the oxides reduction from plasma, which decreases the resistance to the shock resulted from the impact with cavitation microjets.

Comparing the resistance of the 4 layers to the resistance of 270-480 W steel, it is proven that by using the right parameters of the thermal spraying process, depending on the powder type, can be obtained layers, which can improve the resistance to cavitation erosion and the lifetime of the surfaces exposed to this kind of erosion.

References

1.MITELEA I., OANCĂ O., BORDEASU I., CRACIUNESCU C., Cavitation Erosion of Cermet-Coated Aluminium Bronzes, MATERIALS, Volume: 9, Issue: 3, Article Number: 204, MAR 2016, DOI: 10.3390/ma9030204

2.BORDEASU, I., MICU, L., MITELEA, I., UTU, I.D., PIRVULESCU, L.D., SIRBU, N.A., Cavitation Erosion of HVOF Metal-ceramic Composite Coatings Deposited onto Duplex Stainless Steel Substrate, Mat. Plast., **53**, no. 4, 2016, p. 781

3.MA, L, MENG, L., WU, G., YANG, Y., ZHAO, M., ZHANG, M., HUANG, Y., Improving, the interfacial properties of carbon fibre-reinforced epoxy composites by grafiting of branched polyethyleneimine on carbon fiber surface in supercritical methanol, Compos. Sci. Technol., vol.114, 2015, pp.64-71

4.BUNEA., M., BOSOANCA, I., BOSOANCA, R., BODOR, M., CIRCIUMARU, A., Bending an Compressive properties of Fabric reinforced Composites, Mat. Plast. **52**, no. 3, 2015, p. 368

5.BODOR, M., GRAUR, I., BRIA, V., CANTARAGIU, A., CIRCIUMARU, A., Obtaining and Analisys of ifferent Powders to be Used as Modifyind Agents in Formation of Polymers with Special Properties, Mat. Plast., **53**, no.3, 2016, p. 495

6.BEJ, A., BORDEASU, I., MILOS, T., BADARAU, R., Considerations Concerning the Mechanical Strength of Wind Turbine Blades made of Fiberglass Reinforced Polyester, Mat. Plast., **49**, no. 3, 2012, p. 212

7.*** https://www.google.ro/search?q=cavitation+ vortex&tbm =isch&source

8.***https://www.google.ro/search?ei=z5MdWoPVL8fL6ATD6riIDg&q =cavitation+in+the+Kaplan+Rotor+Turbines

9.HONG S., WU Y.P., ZHENG Y.G., WANG B., GAO W.W., LIN J.R.: Microstructure and electrochemical properties of nanostructured WC-10Co-4Cr coating prepared by HVOF spraying, Surface and Coatings Technology, vol. 235, 2013, pp. 582-588

10.HONG S., WU Y.P., ZHANG J.F., ZHENG Y.G., QIN Y.J., LIN J.R.: Ultrasonic cavitation erosion of high-velocity oxygen-fuel (HVOF) sprayed near-nanostructured WC-10Co-4Cr coating in NaCl solution, Ultrasonics Sonochemistry, vol. 25, 2015, pp. 87-92

11.BORDEASU, I., MITELEA, I., SALCIANU, L., CRACIUNESCU, C. M., Cavitation Erosion Mechanisms of Solution Treated X5CrNi18-10 Stainless Steels, JOURNAL OF TRIBOLOGY-TRANSACTIONS OF THE ASME, Volume: 138, Issue: 3, 2016, Article Number: 031102, DOI: 10.1115/1.4032489

12.BORDEASU, I., POPOVICIU, M.O., 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

13.MITELEA I., MICU L. M., BORDEASU I., CRACIUNESCU C., Cavitation Erosion of Sensitized UNS S31803 Duplex Stainless Steels, JOURNAL OF MATERIALS ENGINEERING AND PERFORMANCE, Volume: 25, Issue: 5, MAY 2016, DOI: 10.1007/s11665-016-2045-0, pp. 1939-1944

14.FRANK, J.P. MICHEL, J.M., Fundamentals of Cavitation, Grenoble Sciences, 2003

15.MICU, L.M.,BORDEASU, I., POPOVICIU, M.O., A New Model for the Equation Describing the Cavitation Mean Depth Erosion Rate Curve, Rev. Chim. (Bucharest), **68**, no. 4, 2017, p. 894

16.MITELEA I., DIMIAN E., BORDEASU I., CRACIUNESCU C., Cavitation Erosion of Laser-Nitrided Ti-6Al-4V Alloys with the Energy Controlled by the Pulse Duration, TRIBOLOGY LETTERS, Volume: 59, Issue: 2, AUG 2015, DOI: 10.1007/s11249-015-0558-6

17.MITELEA I., GHERA C., BORDEASU I., CRACIUNESCU C.M., Ultrasonic cavitation erosion of a duplex treated 16MnCr5 steel, INTERNATIONAL JOURNAL OF MATERIALS RESEARCH, Volume: 106, Issue: 4, APR 2015, DOI: 10.3139/146.111188, pp. 391-397

18. *** Standard method of vibratory cavitation erosion test,ASTM Standard G32-2020

Manuscript received: 5.06.2017