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CAVITATION EROSION DEGRADATION OF BELZONA® COATINGS

ABSTRACT

In hydrocarbon and maritime industry there is a constant need of materials and coatings withstanding severe conditions. One of adverse phenomena present there is cavitation erosion. The paper presents evaluation of cavitation resistance of three different steel coatings. Belzona 2141 (ACR-Fluid Elastormer), 1321 (Ceramic S-Steal) and 5831 (ST-Barrier) were deployed on P110 steel and subjected to ultrasound cavitation in distilled water and drilling mud environment. According to mass loss measurements Belzona 2141 shows superior performance comparing to two other coatings and bare p110 steel surface. This is due to its high elasticity comparing to steel.

Keywords: *cavitation erosion, P110 steel, coating, Belzona*

INTRODUCTION

The paper presents the study on cavitation erosion resistance of three composite materials. The tested materials were Belzona® 2141 (acr-fluid elastomer), 1321 (ceramic s-metal) and 5831 (st-barrier). All of those materials were commonly used in hydrocarbon exploration systems and maritime to protect equipment surface from harmful effects of environment. Below in Fig. 1 presents examples of protection marine propulsion and pump elements on effects of cavitation erosion.

In recent years can be seen a huge increase in the global demand for energy resources. A significant reduction of fossil fuels draw attention to more accurate and safer processes and used materials in oil and gas. For this purpose, special attention was paid to the borehole protection casing. During the injection of drilling mud can form various types of damage caused by erosion. Erosion can be generated by a number of phenomena [4]:

- Particulate erosion,
- Liquid droplet erosion,
- Erosion-corrosion,
- Cavitation erosion.

Fig. 1. Examples of use Belzona products in Maritime [1]

The transportation of petroleum products is often accompanied by sand particles and water which adversely affect the pipelines and casing. Erosion of the oil and gas pipeline has been an increasing problem in petroleum industry. The control of erosion-corrosion problems can be expensive and time consuming due to the unplanned nature of stoppages and high maintenance costs. This paper draws attention to the phenomenon of cavitation erosion. Cavitation can be very damaging to pipework and piping components, e.g. valves. When liquid passes through the restriction, low pressure areas can be generated, for example downstream of the sudden step. If the pressure is reduced below the vapor pressure of the liquid, bubbles are formed. These bubbles then collapse generating shock waves. These shock waves can be of sufficient amplitude to damage pipework. Cavitation is rare in oil and gas production systems as the operating pressure is generally much higher than liquid vaporization pressures. The evidence for cavitation is sometimes found in chokes, control valves and pump impellers, but is unlikely to occur in other components [4,3].

The P110 steel is one of API 5CT standard most used material for casing equipment and pipes in drilling industry [18]. The chemical composition of steel P110 is shown in Table 1. In oil and gas exploitation, the petroleum tube is an important structure member of the well, which accounts more than half of the cost in the whole oil and gas well. The casing tubes are exposed to aggressive and adverse work conditions in the high temperature, high pressure and multiphase flows during applications. The casing pipes are used to protect the borehole and ensure safe exploitation of hydrocarbons. One of the biggest destructive threats from borehole environment for casings are corrosion and erosion [4,5]. Those hazards are potentially associated with oil and gas production transportation facilities damage. Almost every aqueous environment can promote corrosion and erosion. The test will be performed in two aqueous environments of water and drilling mud.

The casing is put into the borehole with use of drilling fluid (mud). After the end of the casting process pipes are isolated and joined with rock by cementing. The wide use of drilling fluids and cement slurry may cause degradation of wall thickness of pipes caused by solid particles erosion and cavitation erosion. The pressure decrease in fast flowing liquid is the main reason for cavitation phenomenon. The dissolved gas is the source of cavitation nuclei [14]. The dynamic load at the moment when cavitation bubble collapses lasts for a few microseconds or nanoseconds [15]. Also the borehole environment is very favourable for formation of different types of corrosion outbreaks [7].

Over the last few decades, considerable efforts have been devoted to enhance the erosion resistance of steel by depositing protective coatings on its surface. The drilling equipment producers are frequently applying coating by fusion bonded epoxy (FBE) for corrosion protection of casing alloys. The coatings can be easily formed on the surface of steel, which can exhibit smooth surface and good mechanical properties such high hardness high elastic modulus or high oxidation resistance [16].

Therefore, in order to verify the cavitation erosion resistance, the samples were made of steel P110 coated with composite materials 2141 (acr-fluid elastomer), 1321 (s ceramic-metal) and 5831 (st-barrier).

Below will be presented description of materials, testing method and results.

Table 1. *Chemical compositions of P110 steel [12]*

Element	C	Si	P	S	Mn	Cr	Ni	Cu	Mo	Ti	Nb	V	Fe
Content (wt. %)	0.26	0.19	0.009	0.004	1.37	0.148	0.028	0.019	0.013	0.011	0.006	0.06	balance

EXPERIMENTAL

Company Belzona is specializing in the design and manufacture of repair composite materials and protective coatings for machinery, equipment, buildings and structures. The materials produced by Belzona are applied in variety of industrial issues, including erosion, corrosion, chemical attack, abrasion and wear, water and weatherproofing.

In order to test resistance to cavitation erosion, by courtesy of Belzona the three types of coatings 2141, 1321 and 5831 were obtained. The coatings were prepared and applied according to the instruction on six probes. Probes were prepared with dimensions conforming ASTM G32-10. The front side of probes were prepared with regards to roughness for relevant coating. The suggested roughness of surface stated by the producer was R_z = 75 µm [8-10]. Samples before and after surface treatment are shown in the Fig. 2. The probes were cleaned in acetone before coating. The instruction for each coating require different time to achieve full mechanical strength of material. The following paper describes applied material in tests and examples of their applications.

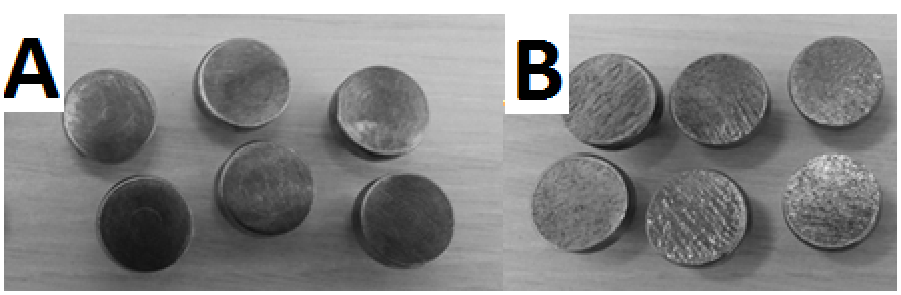

Fig. 2. P110 steel probes according to ASTM G32-10. A) Before surface treatment. B) After surface treatment to roughness Rz=75 um Belzona® 2141 - ACR-Fluid elastomer

The material with marketing mark 2141 is elastomer coating used to preform anti-cavitation security. The 2-part polyurethane resin was designed for the coating of metal and rubber components. This material is appropriate for coating localized in high pressure areas where abrasion, cavitation, erosion and corrosion resistance are required. This fluid material is applied without the need for specialist tools and it cures at room temperature eliminating the need for hot work. The probes with applied 2141 coating are shown in Fig. 3. The example of applications for Belzona 2141:

- Coatings of cooling water pump impellers, wicket gates and stay vanes,
- The anti-cavitation coating on Kaplan and Francis turbines,
- The creation of a protective coating on ship propellers and Kort nozzles to provide long-term cavitation, erosion and corrosion protection,
- The protective coating on shafts, valves and filters to prevent the effects of erosion and cavitation [1,8].

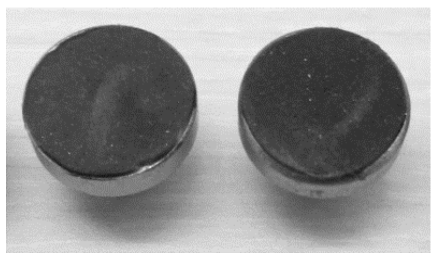

Fig. 3. Belzona 2141 applied on P110 probes; Belzona® 1321 - Ceramic s-metal

The 2-part ceramic filled epoxy coating designed to provide erosion and corrosion resistance of metal surfaces. This solvent free epoxy coating has high chemical resistance and bonds to any rigid surface. Due to its high compressive strength it can be also used to create a perfect shim. This material is applied without the need for specialist tools in room temperature. The material after cavitation erosion impact is shown in Fig. 4. Examples of applications for Belzona 1321 (Photo 3):

- The internal coating for centrifugal and positive displacement pumps,
- Long-term erosion and corrosion resistance for heat exchangers, water boxes and tube sheets,
- The protection of butterfly and gate valves, fans and kort nozzles from erosion, corrosion and cavitation,
- Impingement protection of pipe elbows,
- The high strength structural adhesive for metal bonding,
- The creation of irregular load bearing shims [1,9].

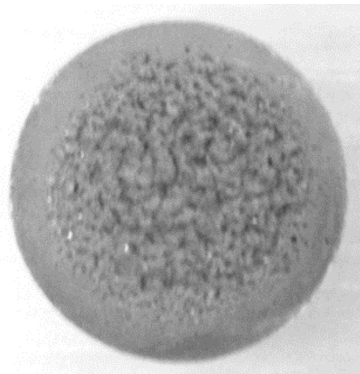

Fig. 4. Belzona 1321 applied on P110 probes after cavitation test; Belzona® 5831 - St-barrier

The 2-part epoxy coating which once cured forms a barrier coating for the protection of equipment operating under immersed conditions or in contact with aqueous solutions. This solvent free epoxy coating bonds strongly to steel and other metallic and non-metallic surfaces such as concrete or brick. Belzona 5831 (ST-Barrier) is formulated for application to wet and oil contaminated surfaces that cannot be dry for application, as well as for underwater applications. The coating displaces water from the surface ensuring maximum adhesion to damp or wet surfaces, even underwater. Examples of applications for Belzona 5831 (Fig. 5.):

- The prevention of corrosion and deterioration of metallic substrates in splash zones, pipework, tanks, bunds and clarifiers,
- The protecting submersible pumps, valves and transformers from the effects of galvanic corrosion,
- Long-term repair and coating of oil and water leaks,
- The sealing of joints and flanges [1,10].

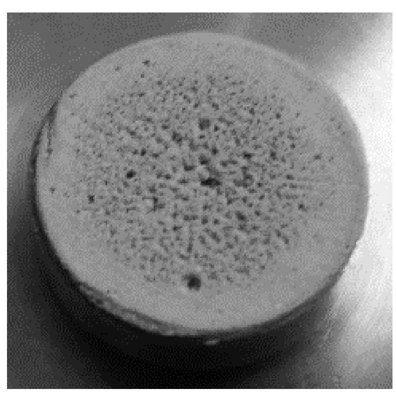

Fig. 5. Belzona 5831 applied on P110 probes at counter probe stand

Cavitation erosion tests were performed on the ultrasonic cavitation test rig to explore the coatings' cavitation erosion resistance according to most of ASTM G32-10 tests method recommendations. The vibratory cavitation apparatus Hielscher UP400s is shown in Fig. 6. This equipment with ultrasonic processor generates longitudinal mechanical vibrations. The medium is subjected to compression and decompression subsequently, which causes it to tear in weakest points, form cavitation bubbles, and then collapse. The power output of the processor can be steplessly adjusted between 20% and 100% of the maximum output. The vibrations are amplified by the sonotrode fitted to the horn and formed as a λ/2 vibrator and transferred via its end face to the medium to be sonically irradiated. The UP400s device can be used to irradiate liquids and granulates. The sonotrode H14 has 14 mm dimeter tip and provides maximum of 110 µm peak to peak amplitude in water. The acoustic power density on its tip is about 106 W/cm^2. An integrated PC interface with special control enables the PC aided monitoring and control of all the important parameters of the ultrasonic processor and the connection of additional sets (e.g. temperature probes) [6].The vessel used for the tests has a cooling bath, through which an ultra-thermostat circulates cooling agent. The temperature can be set between -10 to 100°C [18].

Fig. 6. Cavitation test stand

In the work, the cavitation erosion test of three coatings were presented. A raw P110 sample was used as a reference. The surface was polished with 600 grit emery cloth. Six samples were made of P110 steel and prepared using most of recommendations from ASTM G32-10 Standard Test Method for Cavitation Erosion Using Vibratory Apparatus [11]. The samples were obtained from P110 casing pipe, which was acquired with the courtesy of Exalo drilling S.A.

The three kinds of coatings were investigated in distilled water and drill mud under the same cavitation intensity. Epoxy coatings with thicknesses between 200-300 µm where brushed on alloy steel P110. The coatings were prepared and applied according to the instruction on six probes with suggested roughness by producer. Tested samples were treated with cavitation in counter stand with ultrasonic apparatus. The liquids were irradiated with a 24 kHz frequency and amplitude of 0.05 mm. The vibratory apparatus for all tests was set to maintain amplitude of 50% which for this configuration stands for 0.05 mm peak to peak. The device maintained this amplitude in both mediums by regulating output power. The average power needed was 45 Watts. The probes were inserted into the counter stand in 0.5 mm distance from ultrasonic horn. The counterpart test configuration is shown on Fig. 7. The test was prepared in an environment of distilled water and drilling mud at constant temperature of 22^{o}C. The composition of used drilling fluid are shown in Table 2. After a fixed period of time samples were removed, dried and weighed. The evaluation parameter of cavitation erosion resistance is the cumulative mass loss versus exposure time determined for each sample and showed in the Fig. 8.

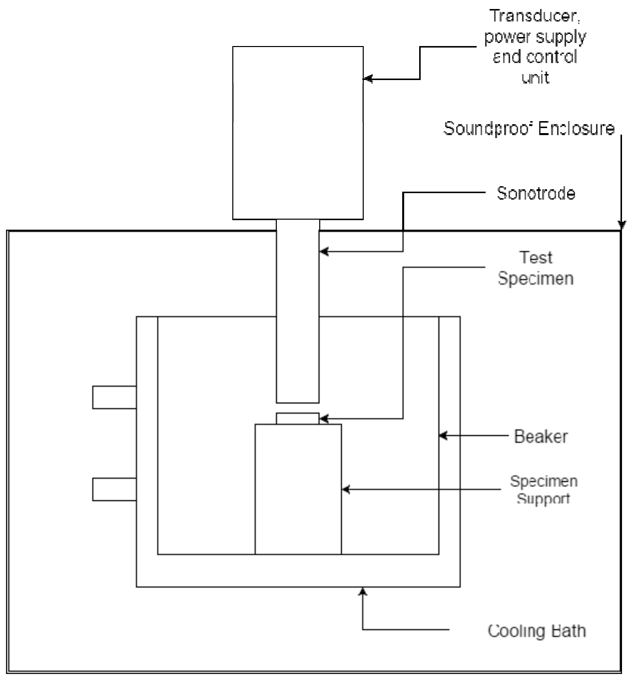

Fig. 7. Test configuration schematic

Table 2. *The composition of drilling mud used to do research*

Component	Distilled water	Bentonite OCMA	Antisol FL 30000
Amount	700 [ml]	7 [g]	1,4 [g]

RESULTS AND DISCUSSION

The relationship between materials coatings and steel P110 cumulative mass loss versus time established in Fig. 8 distilled water and Fig. 9 drilling mud. For purpose of comparison, results were listed in Table 3 and 4.

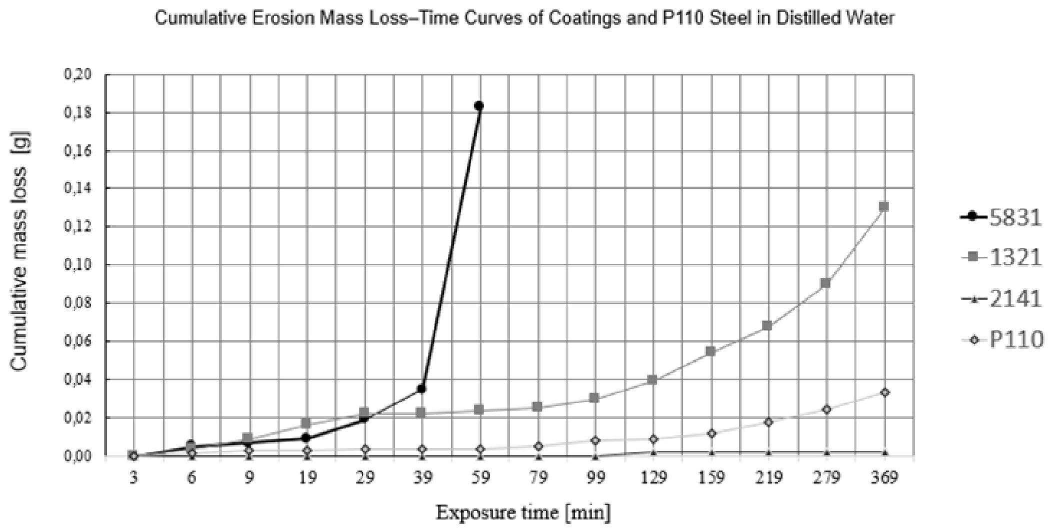

Fig. 8. Results of cavitation tests (erosion curves) in environments of distilled water

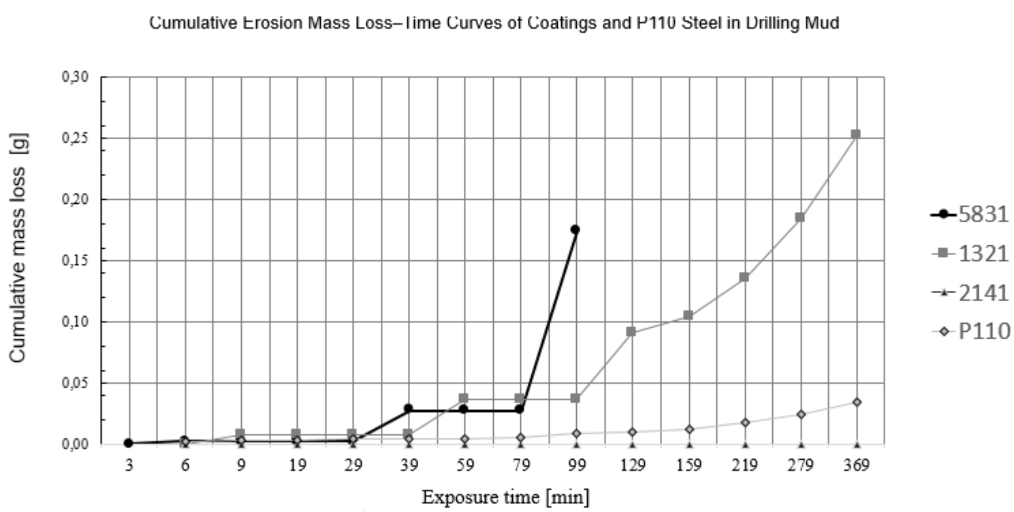

Fig. 9. Results of cavitation tests (erosion curves) in environments of drilling mud

Table 1. *Results of mass loss coatings after cavitation erosion in distilled water*

Coating	Mass of probe without coating [g]	Mass of probe with coating [g]	Mass of coating [g]	Mass loss of coating after 369 min of cavitation [g]	Mass of rest coating on probe after 369 min of cavitation [g]	% amount of cumulative lost coating weight
5831	9,002	9,189	0,187	0,1830	0,0040	**97,86%**
1321	8,920	9,132	0,212	0,1297	0,0823	**61,18%**
2141	8,965	9,204	0,239	0,0020	0,2370	**0,84%**

Table 2. *Results of mass loss coatings after cavitation erosion in drilling mud*

Coating	Mass of probe without coating [g]	Mass of probe with coating [g]	Mass of coating [g]	Mass loss of coating after 369 min of cavitation [g]	Mass of rest coating on probe after 369 min of cavitation [g]	% amount of cumulative lost coating weight
5831	9,033	9,254	0,221	0,183	0,038	**82,81%**
1321	8,124	9,628	1,503	0,130	1,374	**8,63%**
2141	8,912	9,204	0,292	0,002	0,290	**0,68%**

The microscopic observation from Scanning Electron Microscopy (SEM) shown results of effect of cavitation erosion on coatings 1321 (Fig. 11), and 2141 (Fig. 12). For the sample coated 5831 SEM images not been made, because the coatings was detached in 80% from steel probe in all two studied cases: water (30 min) and drilling mud (90 min) (Fig. 8-9, Table 3-4). The so high adhesion failure may be caused by the thermal mismatch between the coating and substrate or by local thermal softening of coating. Adhesion plays an important role in the incubation period and ensures the protection of the substrate material against mass lose. Coating 1321 reviled a significant degradation during the test, but not detached out from the surface of probe (Fig. 4). In the pictures (Fig. 11) see visible surfaces after cavitation treated, the material has been deformed and expose the internal structure of protective two-component epoxy structure with ceramic strengthening grains. The 1321 material is eroding by initiating cracks at interface of matrix/ceramic particles that following propagation in an epoxy matrix. The cracks combine and cause chip off epoxy matrix. This results in exposure of ceramic particles and pluck them out from matrix support. Authors conclude that cavitation phenomena of high pressure micro-jet impacts that act on surface when bubbles collapse. Under influence of this phenomenon coating 1321 may undergo local thermal softening, which has essential impact on the coatings deformation. The soft epoxy resin first to erode away, leaving behind the exposed ceramic particles Fig.11.

Material 2141 coating of two-component polyurethane is characterized by high plasticity behaviour reminiscent of elastomer. SEM results shown in Fig. 12 the essence of the impact of cavitation erosion on the material. Fig. 12 A) shown a cavities of spherical shapes, which have causes of micro-jet impact generated during implosion of cavitation bubbles. Fig. 12 B) shows one of such voids and cavitation impacts in the traces formed on the sample surface. Also visible cracks formed in the area near cavitation craters, cavitation load initiate fracture that develop on surface of the eroded material and leading to loose of thin flakes of material (delamination). However, the weight loss was unnoticeable, the accuracy of scales not captured changes in the mass of the coated sample. The outstanding observed results can be attribute of the strong adhesive connection of coating.

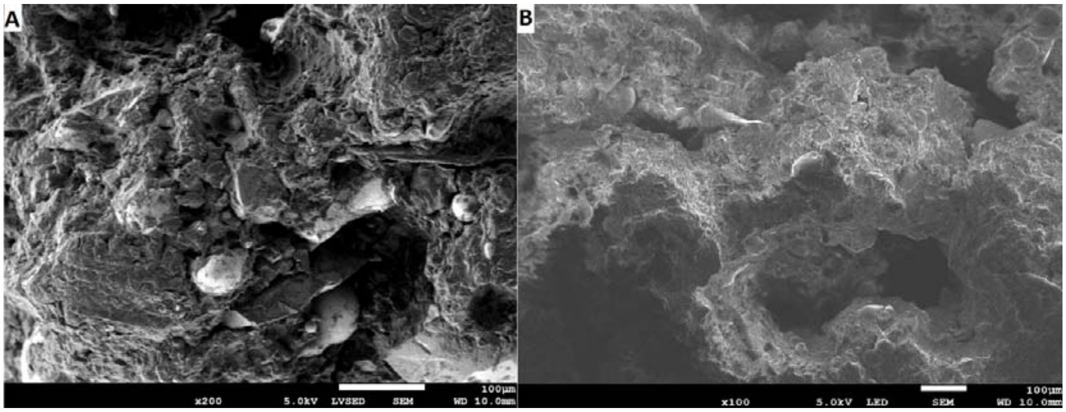

Fig. 11. SEM photos of coating 1321 sample after end of cavitation tests in distilled water

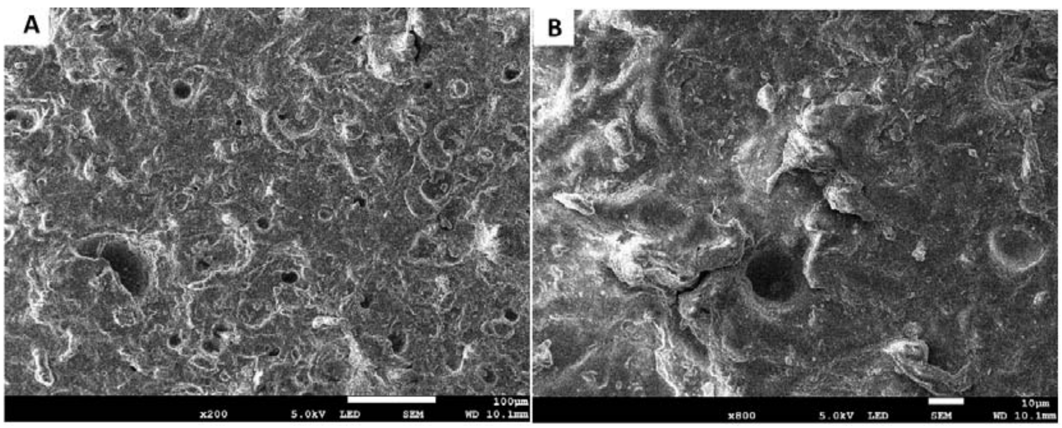

Fig. 12. SEM photos of coating 2141 samples after end of cavitation in distilled water

Fig. 13 shows micrographs of tested surface steel P110 sample. Two mechanisms of mass removal where observed. Formation of deep micro-cavities due to micro-jet action and cracking of the material from slip line or grain boundaries.

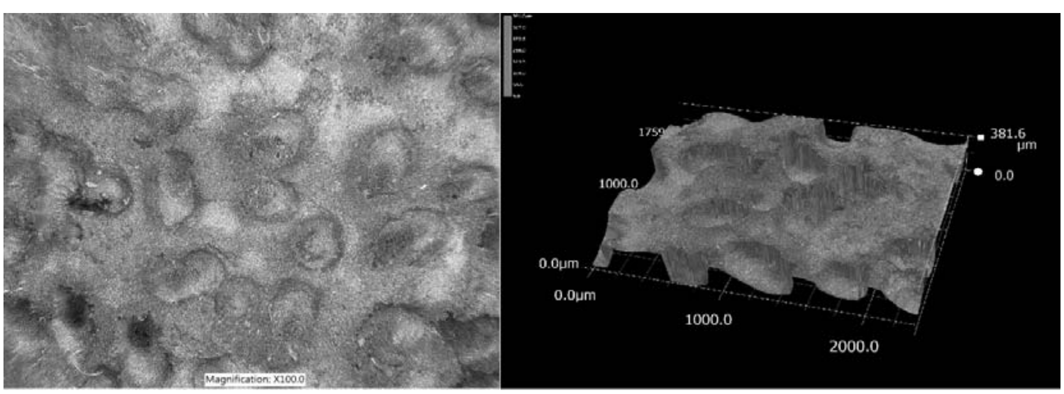

Fig. 13. Optical microscope photos of eroded surface of P110 sample tests in distilled water

SUMMARY AND CONCLUSIONS

The above tests results indicate cavitation erosion residence of three different coatings. The all tests was performed on the stand with counterprobe. The cumulative mass losses of the coatings deposited on P110 stainless steel during cavitation test in two environments of water and drilling mud are shown in Fig. 8-9. The conducted studies shows that tests in environmental of drilling mud decreases cavitation erosion rate [18]. The deposition of coating 5831 (St-barrier) has decreased the mass loss middling 90% (Table 3,4) in comparison of coating mass before tests on probes in two different environments. The 2-part polyurethane 2141 coating has the best cavitation erosion protection properties due to its longest incubation period and smallest mass lost among all tested coatings Fig.8-9. The cumulative mass loss of other coatings were higher than reference steel P110 Fig.8-9. The deposition of 5831 coating increase in 1/3 of test time and end 80% detachment of coated layer from probe. This results preventing examination of this sample. The 1321 coating also have good cavitation resistance, which was confirmed by the low cumulative mass loss, but still higher than stainless steel P110. Coating 2141 has received the smallest cumulative mass losses during performed tests. As the further work, number of research of coatings properties used in industry can be investigated and compared with conducted tests.

Cavitation erosion wear behaviour of Belzona 1321, 2141 and 5391 coatings were studied and compared. The main conclusions can be made from the results.

1) Results indicate that the material 5831 has the highest degree of cumulative mass degradation in the shortest period of cavitation time in distilled water environment and drilling mud,
2) The material 2141 was the most resistant to the process of cavitation erosion. Whole cumulative mass degradation was 4,0 mg in 369 min. of cavitation in two tests,
3) The material 1321 also withstood the whole cavitation time, but with greater mass loss,
4) The material 5831 has not withstand the whole test and after 60 min. for distilled water and 130 min. for drilling mud sever from probes surface.

ACKNOWLEDGMENTS

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