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Protection enhancing of threaded connections of light-alloy drill pipes against contact corrosion

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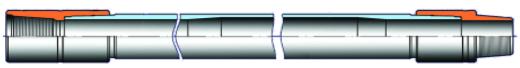
Abstract. When using light-alloy drill pipes (LAIDP) with steel tool joints, the development of contact corrosion is observed under certain operating conditions. The value of corrosion mainly depends on the difference in electrochemical potential (ECP) of the contacting metals. One of the effective methods for increasing the corrosion resistance of aluminum alloys is the micro-arc oxidation (MAO) method. This is an electrochemical process in combination with micro-arc-discharges phenomena at the anode-electrolyte border, which allows forming ceramic coatings of aluminum oxides on the surface, including its high-toughness and wear-resistant phase - α-Al_2O_3 (corundum). MAO-technology is a highly efficient and environmentally friendly process. At the forming of such a coating on the threaded part and in the tool joint zone of the pipe, a barrier for contact corrosion between the steel tool joint and the surface of the aluminum pipe is created. In this work, contact corrosion on samples in a pair of 1953T1 aluminum alloy - 40KhN2MA steel in a 5% NaCl solution at 80 °C was investigated. The data obtained showed the effectiveness of using protective MAO-coating to reduce contact corrosion and increase the reliability of the tool joint threaded connection of LAIDP.

1 Introduction

The increase of the share of horizontal wells, wells with a complex profile, and multilateral wells is a pronounced trend in the development of drilling for oil and gas in the last decade [1]. When drilling such wells, preconditions are arisen for the use of LAIDP-type drill pipes (light-alloy improved dependability drill pipes). Their design is a pressed pipe made of aluminum alloy (for instance, 1953T1) with upset ends, on which a trapezoidal thread with a stabilizing shoulder is cut for attaching the box and the pin of a drilling tool joint made of steel 40KhN2MA (Fig. 1).

LAIDP with internal upsets



Parameters (D16T / 1953T1 alloys)	LAIDP 90x9	LAIDP 103x9	LAIDP 147x11	LAIDP 147x13	LAIDP 147x15	LAIDP 168x13
Load, kN • allowable (0.8 <s_T) • ultimate	595 / 879 744 / 1099	691 / 1020 864 / 1276	1221 / 1805 1527 / 2256	1423 / 2102 1779 / 2627	1618 / 2389 2022 / 2986	1648 / 2431 2057 / 3039
Torque, kNm • allowable (0.8 < s_T) • ultimate	10.1 / 14.9 12.6 / 18.6	13.7 / 20.2 17.1 / 25.3	35.4 / 52.3 44.3 / 65.4	40.2 / 59.4 50.2 / 74.2	44.5 / 60.2 55.6 / 75.2	54.4 / 80.3 68.0 / 100.4
Maximum internal pressure, MPa	56,9 / 84,0	49.7 / 73.4	42.6 / 62.9	50.3 / 74.3	58.0 / 85.7	44.0 / 65.0

Fig. 1. Drilling pipe of LAIDP type.

The use of LAIDP allows us to reduce the loads during rotation and movement of the drill string and ensure the achievement of farther extended reach drilling targets, in comparison with steel strings, if all other conditions being equal [2]. The difference in electrochemical potentials of the contacting materials in LAIDP with a steel tool joint in a corrosive environment is often a source of contact corrosion, which is reflected with a greater extent in the aluminum pipe section adjacent to the box [3-5]. Such a corrosion damages occurred, for example, when drilling at the Tarim oil field in the People's Republic of China [6].

To reduce or eliminate contact corrosion in the aluminum-steel connection, it is necessary to create conditions that provide either displacement of the electrode potential or the absence of direct metal contact by applying, for example, an insulating coating. The latter approach was investigated in work [7], in which an anodic oxide film was used as such a coating, and showed the effectiveness of its application.

In the processing of aluminum alloys to increase their corrosion resistance, wear resistance, and other surface properties, recently, along with traditional anodizing, the micro-arc oxidation (MAO) method is widely used.

The MAO method [8-11] is an electrochemical process of ceramic coating formation under the action of micro-arc discharges on the alloy surface, consisting mainly from oxides of the processed aluminum alloy including its high-strength phase alpha-Al_2O_3 and compounds of an electrolyte.

MAO technology is a highly efficient and environmentally friendly process. The forming of such a coating in the joint-pipe zone and on the threaded part of the pipe creates a barrier for contact corrosion between the steel joint and the surface of the aluminum pipe. In

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this case, the density of corrosion currents decreases due to an increase of electrical resistance of the contact and the creation of an electrical insulation barrier in the part of the pipe adjacent to the joint, which is a potential zone of corrosion damage.

The use of MAO-coating in the manufacture of LAIDP pipes was recommended in 2013 when the experimental processing of the thread with a stabilizing shoulder on the pipe was performed [3]. Then the first studies were carried out on samples simulating the connection zone [4]. The results were promising, but research has not been continued.

This paper presents the first stage of a new research program on the possibility of increasing the corrosion resistance of pipes made of 1953T1 aluminum alloy against contact corrosion by forming the MAO-coating in the contact zone of the pipe.

2 Materials and investigation methods

The samples for contact corrosion tests simulating a threaded connection "steel tool joint - aluminum pipe" were made from aluminum alloy 1953T1 with dimensions: 100 mm long, 10 mm in diameter and a threaded part (M8-6g) with a length of 17 mm, the couplings were made of steel 40KhN2MA with dimensions: length - 25 mm, diameter - 15 mm, thread - M8-6H.

Before testing, the samples were thoroughly checked, cleaned from contamination, degreased, checked for screwing and unscrewing, measured, and weighed. Some of the steel couplings (5 pieces), for a closer approximation to reality, were treated in a phosphate solution, as it takes place during operation. For this, a solution of the following composition was used: phosphoric acid - 85 g/l; zinc oxide - 17 g/l; sodium nitrate - 2 g/l; distilled water - 1 liter. The phosphating process was carried out at a temperature of 120 °C for 30 minutes.

The MAO-coating was formed on the samples of 1953T1 aluminum alloy in a weakly alkaline electrolyte with the composition: 2 g/l KOH + 9 g/l $Na_2SiO_39H_2O$ + 4 g/l 6($NaPO_3$) for 15 and 30 minutes. The thickness of the formed coating was 15-20 and 35-40 microns, respectively.

In addition, since the MAO-coating has a sufficiently high porosity, especially in the surface layer, to reduce this one, some of the aluminum alloy samples (with numbers 12 and 22), after MAO-processing were treated by fluoroplastic suspension (F- 4D) and then were dried for 30 minutes in a drying oven at a temperature of 150 °C. Table 1 presents the initial data on the samples before testing.

Table 1. Data on tested samples.

Code of samples	Length mm	Thread mm	Diam. mm	Thickn.of MAO.μm	Weight g
Aluminum alloy 1953T1					
0	99.50	17.40	9.896	---	19.279
1	99.60	17.40	9.927	---	19.455
11	99.30	17.30	9.934	18.00	19.347
12 F	99.30	17.10	9.944	26.00	19.318
13	99.20	17.10	9.974	19.50	19.501
21	99.30	17.10	9.921	38.50	19.363
22 F	99.30	17.00	9.939	58.50	19.296
23	99.50	17.20	9.907	36.00	19.248
Steel 40KhN2MA					
0	24.90	24.90	14.80	-----	25.218
1 ph	24.80	24.80	14.90	-----	25.089
11	25.00	25.00	14.90	-----	25.878
12 ph	25.00	25.00	14.70	-----	24.255
13 ph	25.00	25.00	14.70	-----	25.138
21	24.80	24.80	14.80	-----	25.161
22 ph	24.80	24.80	14.80	-----	25.342
23 ph	25.10	25.10	14.80	-----	24.898

To control the corrosion resistance, two connections of the samples (“pipe” - coupling) were made without MAO-coating. All samples were designated in accordance with the accepted code and then assembled into connections. Samples 0 and 1 were without MAO-coating, while the steel coupling of sample 1 was subjected to phosphating (marking by ph in Table 1), samples 11-13 were with MAO coating 15-20 μm thick, samples 21-23 - with MAO-coating 35-40 μm thick, samples of steel couplings with numbers 12, 13, 22, and 23 were subjected to phosphating. Free ends of the couplings were plugged with fluoroplastic plugs.

For testing, a 5% sodium chloride solution was used at a temperature of 80 °C, for which, samples dipped into the solution were placed into a drying oven (see Fig. 2).

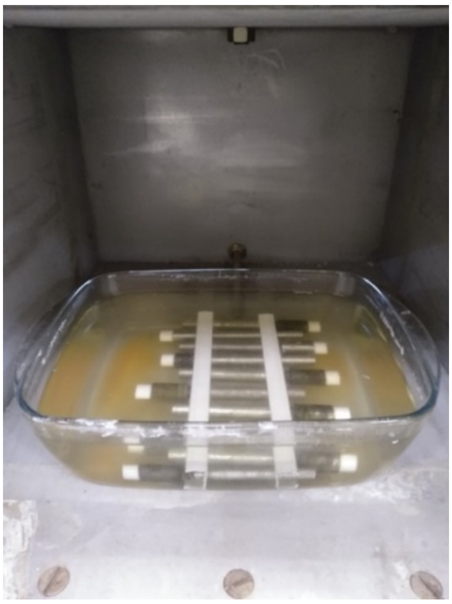


Fig. 2. Samples in a 5% NaCl solution in a drying oven during contact corrosion tests.

The total exposure time was 1390 hours, of which 260 hours at a temperature of 80 °C, the remaining 1130 hours at a temperature of 20 °C.

After exposition in a corrosive environment, the samples were cleaned of corrosion products, measured, weighed, and the results were recorded in the journal.

To observe changes in the surface layer, a Carl Zeiss SIGMA scanning electron microscope with an energy-dispersive attachment was used.

Changes in the qualitative and quantitative composition of the test materials were evaluated using a portable XRF analyzer DELTA Professional with the new X-Count technology.

3 Results of research and discussing

The view of the samples after exposition in a corrosive environment is shown in Fig. 3.

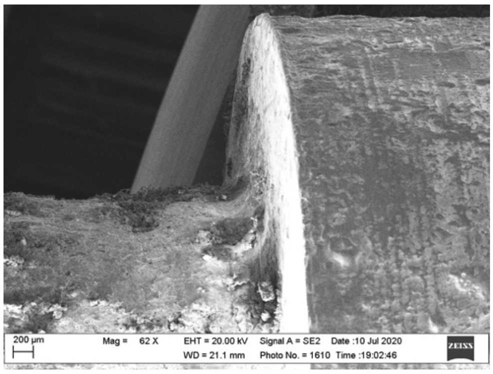
Fig. 3. Samples after tests in corrosion environment.

The results of subsequent measurements and weighing of samples after testing are presented in Table 2.

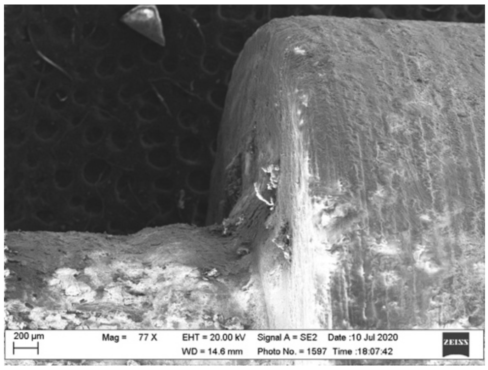
Table 2. Data of samples after tests.

Code of samples	Weight, g	Loss/Gain g	Thickn.of MAO.µm	Note
Aluminum alloy 1953T1				
0	19.266	0.013	---	
1	19.447	0.008	---	
11	19.338	0.009	18.00	
12 F	19.312	0.006	26.00	F4-D
13	19.498	0.003	19.50	
21	19.368	-0.005	38.50	
22 F	19.295	0.001	58.50	F4-D
23	19.252	-0.004	36.00	
Steel 40KhN2MA				
0	25.212	0.006	-----	
1 ph	25.079	0.010	-----	Phosphat.
11	25.875	0.003	-----	
12 ph	24.254	0.001	-----	Phosphat.
13 ph	25.135	0.003	-----	Phosphat.
21	25.115	0.046	-----	
22 ph	25.290	0.052	-----	Phosphat.
23 ph	24.846	0.052	-----	Phosphat.

Analysis of surface changes in the contact zone of the samples showed that typical corrosion products in the form of flakes with cracks in the uncoated aluminum alloy samples are predominated (Fig. 4 *a, b*). At the same time, no such formations are observed on the samples with MAO-coating (see Fig. 4 *c, d*).



a



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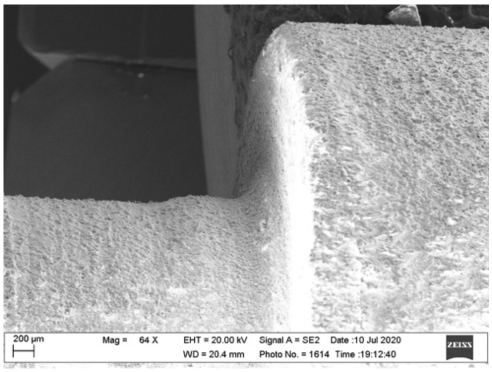
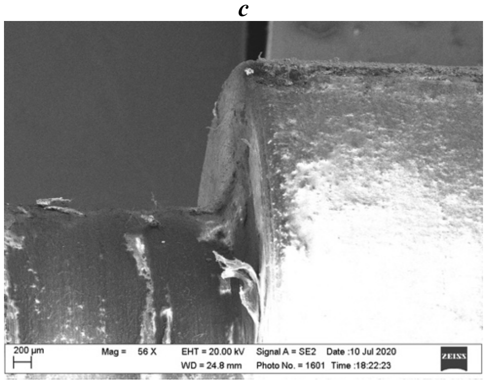


c

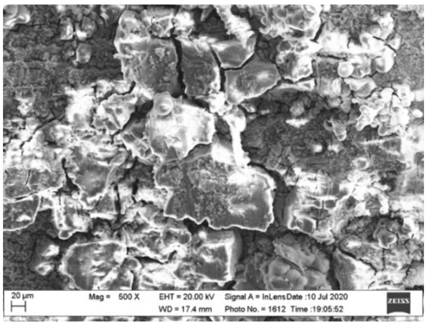


d

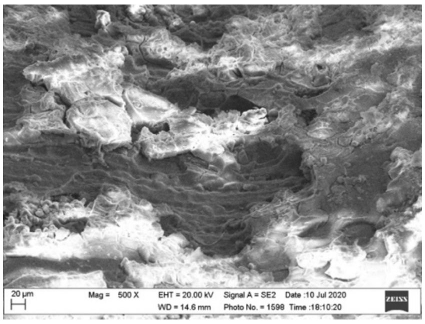
Fig.4. View of the contact zone of aluminum samples (face end and beginning of the threaded part): *a* - sample 0, *b* - sample 1, *c* - sample 12, and *d* - sample 21. Magnification - 65x.

Steel couplings practically did not undergo any corrosion damages, except for the appearance of changes of colour and light deposits of corrosion products, which were then cleaned off. At the same time, it should be noticed, to a lesser extent, such changes were typical for the samples subjected to a preliminary phosphating.

A more subtle examination of the surface with a scanning microscope (at a magnification of 500x) showed that, indeed, corrosion products on uncoated aluminum alloy samples are quite bright presented (Fig. 5 *a* and *b*).



a



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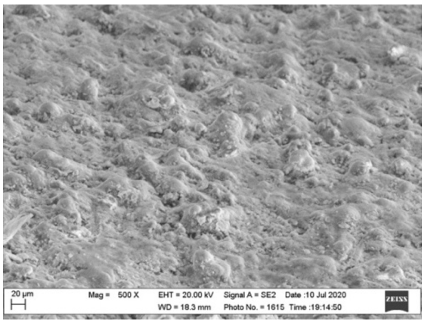

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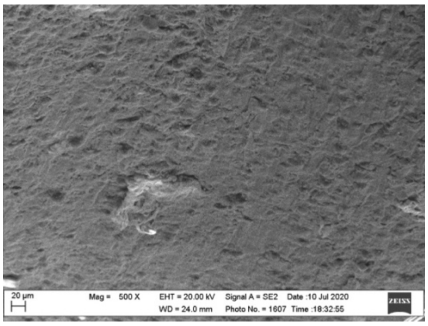


d

Fig. 5. View of the contact zone of samples from alloy 1953T1: *a* - sample 0, *b* - sample 1, *c* - sample 12, and *d* - sample 21. Magnification - 500x. (Samples *a* and *b* - without MAO coating, *c* - MAO-coating of 18 μm thick + fluoroplastic film, *d* - MAO-coating of 38.5 μm thick).

The study of the elemental composition of the aluminum alloy samples at the place of contact with the steel coupling on the DELTA Professional device showed that on samples without MAO treatment (samples 0 and 1), the elemental composition differs markedly (see Table 3) from the initial one [12], which according to OST1-92014-90 has the following approximate chemical composition,%: Al - balance, Mg 2.4-3.0; Zn 5.6-6.2; Mn 0.1-0.3; Cu 0.40-0.80; Zr <0.10; Cr 0.15-0.25; Fe <0.25; Si <0.2.

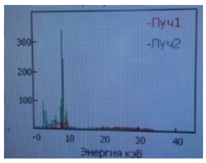
Table 3. Elemental composition of samples, %

Elements	Samples of alloy 1953T1			
	0	1	12	21
Al	75.57	77.02	37.81	40.81
Si	-	1.29	47.84	35.47
Zn	20.96	17.82	7.28	19.17
Mg	-	-	5.24	-
Cu	2.57	2.19	0.78	2.09
Fe	0.41	0.68	0.37	0.80
Mo	-	-	0.44	0.66
Mn	0.42	0.51	0.20	0.45
Cr	-	0.34	-	0.36
Zr	0.07	0.083	0.036	0.13
Pb	-	-	-	0.05

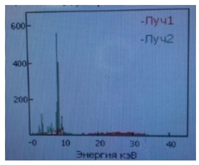
Moreover, the content of magnesium in both samples is not detected (while in the original alloy its content is from 2.4 to 3.0%). On the other hand, the copper content increased significantly (more than 2%), in contrast to the initial one - 0.4 - 0.8%.

In the samples treated by the MAO method (samples 12 and 21), there is a noticeably increased silicon content, which is explained by the presence of silicon-containing compounds (SiO_2 oxides, $3Al_2O_32SiO_2$ mullite) in the MAO coating.

The nature of the samples chemical composition change can also be seen in the graphical diagrams of the chemical composition investigation (Fig. 6).



a



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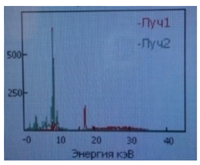

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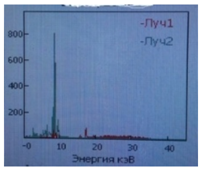
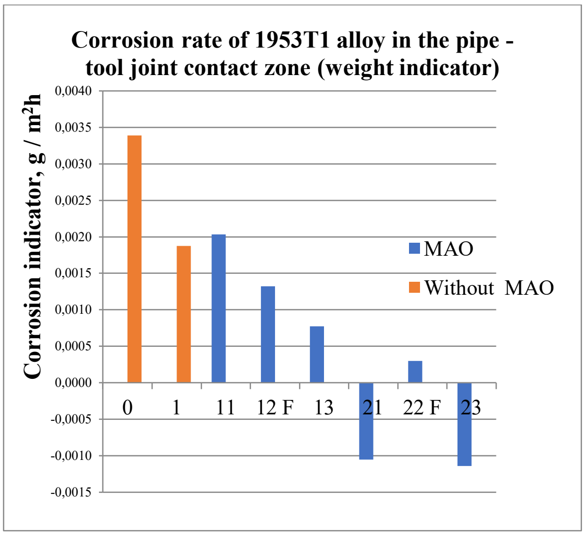


d

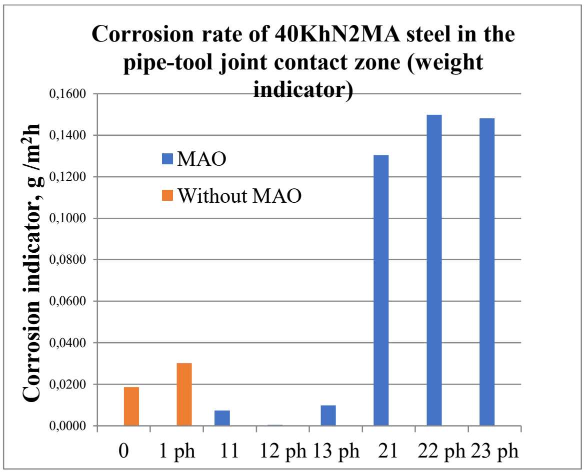
Fig. 6. Graphical interpretation of investigated samples chemical composition of alloy 1953T1: *a* - sample 0; *b* - sample 1; *c* - sample 12; *d* - sample 21.

These deviations in the chemical composition of the tested samples can be associated with the formation of compounds in a corrosive environment of sodium chloride during the exposition - corrosion products (see Fig. 5 *a, b*), which include these elements.

The calculated values of the corrosion rate by weight (g/m^2h) showed that the presence of a corrosion-resistant MAO-coating in the contact zone reduces the corrosion rate of the aluminum alloy (Fig. 7).



a



b

Fig. 7. Calculated values of the corrosion rate of samples from aluminum alloy 1953T1 (*a*) and steel 40KhN2MA (*b*).

The corrosion rate of steel couplings in the joints with a thicker MAO-coating thickness is significantly more. Thus, with a smaller thickness of the MAO-coating, the resistance against contact corrosion is higher.

4 Conclusion

Analyzing the presented data, it can be concluded that the use of MAO-coating as a protective barrier in the contact zone of a threaded joint of an aluminum pipe and a steel coupling allows reducing the corrosion rate of an aluminum pipe and can be recommended for the use in operation. At the same time, in order to reduce contact corrosion of the steel coupling, the thickness of MAO-coating on the aluminum alloy should be formed as lower as the best.

References

1. M.Ya. Gelfgat. *Razvitie technologiy bureniya skvazhin – klyuchevoe napravlenie razvitiya neftegazovoy otrasli*, Vestnik assotsiatsii burovykh podryadchikov, **1**,19-27, (2020)
2. M.Ya. Gelfgat, *et al*. *Drillstring with aluminum alloy pipes design and practices*, paper **SPE** 79873 presented at the 2003 SPE/IADC Conference, Amsterdam, The Netherlands, 19-21, (2003)
3. M.Ya. Gelfgat, V.V. Chizhikov et all. Arctic and Extreme Environments Conference & Exhibition, *Application of Aluminum Alloy Tube Semis: Problems and Solutions in the Development of Exploration, Production and Transportation Business of Hydrocarbons in the Arctic*, **SPE** 166919, Moscow, Russia, October 15-17, (2013)
4. S.S. Kolesov, R. Badrak, V.V. Chizhikov et al. *Galvanic effects in drilling equipment challenges and solutions of corrosion resistance*. 32 Eurocorr 2014 «European Corrosion Congress», Pisa, Italy, 8-12 September (2014)
5. S.S. Kolesov, S.Yu. Kondratev, V.V. Chizhikov, O.V. Shvetsov. *Issledovanie struktury I svoystv burilnykh trub iz splava D16T posle expluatatsii v usloviyakh neftedobychi*. Zagotovitelnoe proizvodstvo v mashinistrornii, №4, 39-43, (2011)
6. *Analysis of damage to LBTPN-147x13 made of alloy D16T, discovered during drilling of the well Xa-15 at the Tarim field in China*. Scientific and technical report of the Research and Development Center "Weatherford-Polytechnic", St. Petersburg, 19 p. (2010)
7. O.V. Shvetsov. *Improving the operational reliability of drill pipes made of aluminum alloys D16 and 1953*. Author. diss. Ph.D., St. Petersburg, 22 p, (2014).
8. A.A. Logunov Ed., *Microarc oxidation. Science and humanity - almanac*. Moscow, Znanie, p. 341 (1981)
9. A.V. Nikolaev, G.A. Markov, B.I. Peshchevitsky. *A new phenomenon in electrolysis*, Izv. SO AN USSR, Ser. chem. sciences. **Issue 5**, pp. 32-33, (1977)
10. V.N. Malyshev. *Effective electrochemical transformation method of valve metals surface layer into high-tensile ceramic coating*. in Book: *Chemical Reactions on Surfaces*. **Chapter 7**. Edit. J.I. Duncan and A.B. Klein., Nova Science Publishers. pp. 211-262, (2008)
11. I.V. Suminov, P.N. Belkin, A.V. Apelfeld, V.B. Lyudin, B.L. Crete *et al. Plasma-electrolytic modification of the surface of metals and alloys. "Technosphere"*, **Tom 2**. Moscow, 512 p, (2011)
12. OST1 92014-90 *Deformable aluminum alloys*. Stamps, (1990)