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Increasing of the resistance against contact corrosion of LAIDP with steel tool joints

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Abstract. This paper discusses the possibility of protection enhancing against contact corrosion of light-alloy drill pipes (LAIDP) by forming a ceramic coating on threaded parts of the aluminum drill pipe using the micro-arc oxidation (MAO) method. When such a coating is formed in the zone of connection of the pipe with steel tool joint and on the threaded part of the pipe, a barrier for contact corrosion between the steel tool joint and the surface of the aluminum pipe is created. Studies of this paper were directed to determine the electrochemical potentials (ECP) on samples in a pair of aluminum alloy 1953T1 and steel 40KhN2MA in a 5 % NaCl solution at 20 °C and their influence on the contact corrosion. The results obtained showed that protective MAO-coating reduce the contact corrosion of the pipe and increase the reliability of connection between the LAIDP pipe body and the steel tool joint.
Keywords: contact corrosion; light-alloy drill pipes; micro-arc oxidation method

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Introduction

Nowadays, a significant increase in the share of horizontal wells, wells with complex profiles and multilateral wells is watched when drilling for oil and gas [1,2]. This creates the prerequisites for using LAIDP (light alloy improved dependability drill pipes) which design presents a pressed pipe made of 1953T1 aluminum alloy with upset ends and cut the trapezoidal thread in accordance with ISO 15546-2011 [3] for attaching the tool joint made from the steel 40KhN2MA.

The use of LAIDP allows reducing the torque and drag loads during rotation and movement of the drill string in a borehole during directional wells drilling. Using of LAIDP in the drill string provides the opportunity to make a longer borehole from the same drill rig [4–6]. The connection of an aluminum pipe with a steel tool joint in a corrosive environment, due to the difference in electrochemical potentials of the contacting materials, is often a reason for the contact corrosion which can occur in the section of the aluminum pipe adjacent to the steel tool joint [7–10]. Similar corrosion damages were encountered, for instance, during drilling at the Tarim field located in China [11].

To reduce the contact corrosion in the aluminum-steel connection, it is necessary to create conditions that provide the elimination of direct metal contact between steel tool joints and aluminum pipe. This can be made by applying an insulating coating. The recent research in this field was proposed in [12] when the aluminum oxide obtained by anodization was used as such a coating that showed its effectiveness.

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The MAO method [13–15] arose from traditional anodizing, but the processing is carried out at the higher values of potentials and currents that provide the surface of an aluminum alloy treatment not only electrochemical in electrolyte but by the action of micro-arc discharges having temperature up to 6000-8000 °C [16]. Such conditions are highly providential for forming a hard α-aluminum oxide (corundum) with high mechanical properties (microhardness up to 20 GPa). Due to the uncial properties of aluminum oxide, these coatings are very resistant to wear, corrosion, heat, and insulation.

The main feature of this technology is an environmentally friendly process and highly efficient. When such coating is formed in the zone of aluminum pipe connection with steel tool joint including the threaded part of the pipe, a barrier that prevents the contact corrosion between the steel and aluminum surfaces is created. This barrier is reducing the density of corrosive currents and increasing the electrical resistance of the contact on the part of the pipe adjacent to the steel tool joint. The study performed with samples simulating a threaded connection "steel tool joint - aluminum pipe" [17] showed good resistance against contact corrosion in a corrosive environment in these pairs.

This paper is a further investigation in this direction and presents some results of a research program of increasing the corrosion resistance of drilling pipes made of 1953T1 aluminum alloy against contact corrosion by forming MAO-coating in the contact area of the pipe and tool joint.

Materials and Methods

For investigation of electrochemical potentials and corrosion currents on the samples, the same grades of the materials used in the drilling were taken: aluminum alloy – 1953T1, and steel – 40KhN2MA. This steel is usually used to manufacture tool joints in accordance with International Standard ISO 11961-2020 [18,19] for aluminum pipes connection in the drill string and is chromium-nickel-molybdenum structural alloy steel. 40KhN2MA is smelted in open electric furnaces and by the method of electroslag remelting and characterized by high mechanical properties. The form and dimensions of samples were as follows: square plate from aluminum alloy – 30 × 30 × 5 mm, square plate from steel – 13.4 × 13.4 × 5 mm with 6.5 mm diameter holes in the center.

The MAO-coating was formed on the samples of 1953T1 in the same conditions as during the previous studies [17] – in a weakly alkaline electrolyte for 15 and 30 min and the thickness of the formed coating was 15-20 and 35-40 μm respectively.

It should be noticed that the coating on samples was formed not on the whole sample surface but only on the part of the surface adjacent to the contact zone. In this connection, the section with MAO-coating on the sample was formed only on one side of the sample and the surface of coating was not more than one-fourth of the whole surface of the sample. To prevent the coating formation on other surfaces of the sample it was isolated by silicone.

The accepted coding of samples was the same as used in ref. [17]. Samples 0 and 1 were without MAO-coating, samples 11-13 were with MAO coating 15-20 μm thick, samples 21-23 were with MAO-coating 35-40 μm thick, samples of steel with numbers 1, 12, 13, 22, and 23 were subjected to phosphating at the same conditions as in [17]. Two samples from aluminum alloy with numbers 12 and 22 were treated in addition by fluoroplastic suspension (F-4D).

Before the start of the experiment, measurements of electrochemical potentials and corrosion currents were carried out in an electrochemical cell for each pair of samples in a 5 % NaCl solution at the temperature 20 °C using a two-electrode scheme [20]. For this aim, the potentiostat PARSTAT 4000 and the software VersaStudio were used. After these preliminary measurements, the original samples were assembled into pairs (Fig. 1) and kept for 336 hours in a 5 % NaCl solution at 80 °C in a drying oven (Fig. 2). After exposition in a corrosive environment, the samples were cleaned of corrosion products and visually evaluated.

Then there were carried out the repeated measurement of electrochemical potentials and corrosion currents and the data recorded into the journal.

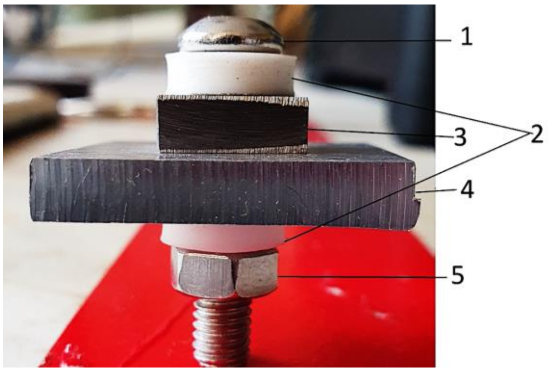


Fig. 1. Assembly of contact pair samples: 1 - bolting; 2 - flouroplastic spacers; 3 - steel sample; 4 - aluminum alloy sample; 5 - nut

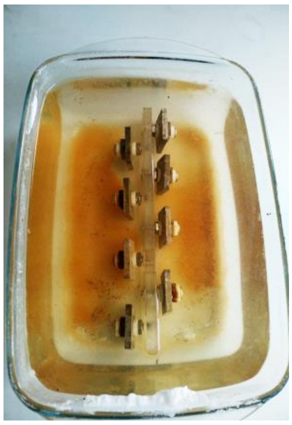


Fig. 2. Collected assemblies of pair samples in 5 % NaCl solution at 80 °C

Results and Discussion

The view of samples assembled pairs after exposition in a corrosive environment is represented in Fig. 3.

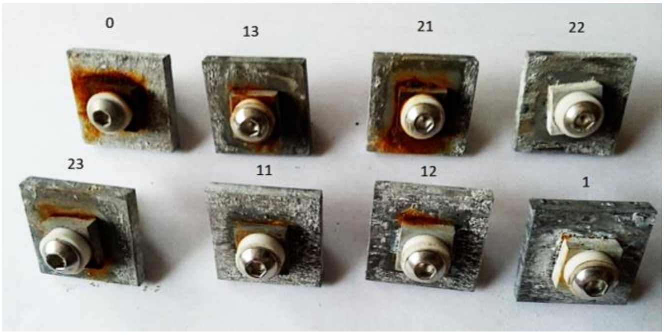


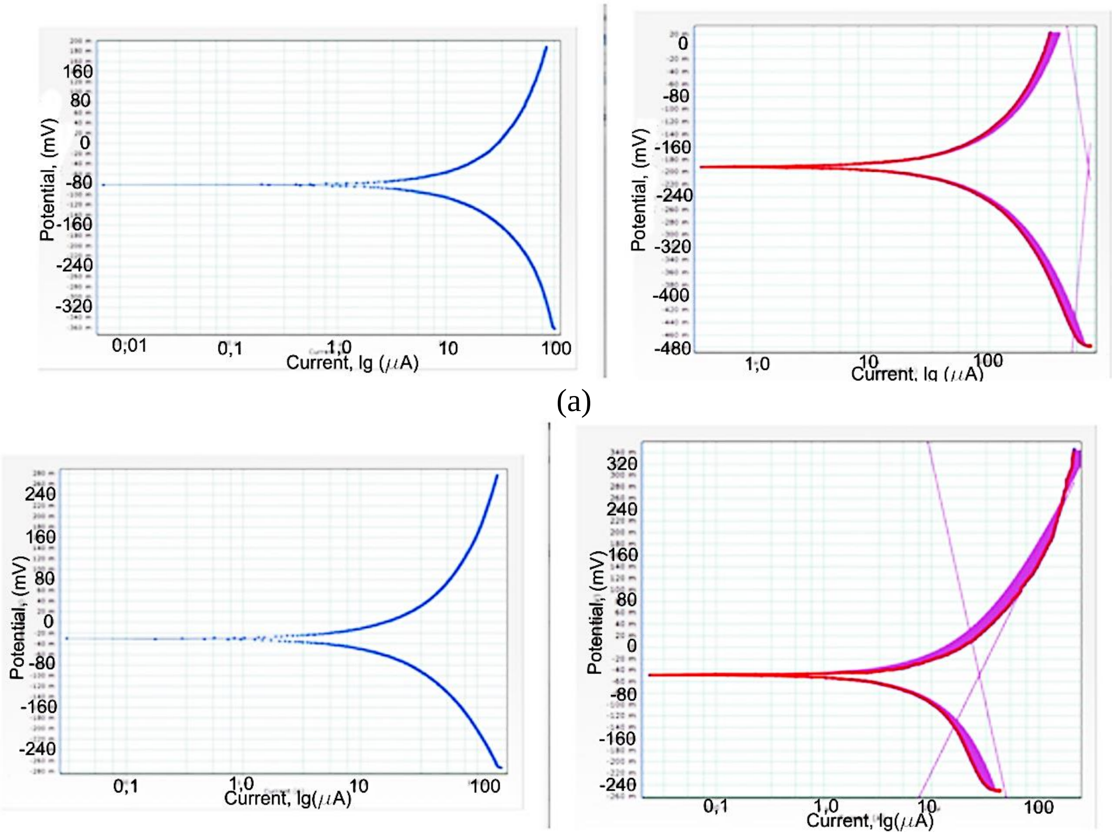
Fig. 3. Samples after exposition in 5 % NaCl solution at 80 °C during 336 hours

Figure 4 shows the electrochemical potentials versus corrosion currents for samples without MAO-coating (a) - samples 0, and with the coating (b) - samples 23 in two states – before the corrosion test (on the left) and after it (on the right).

All experimental data obtained are represented in Table 1. The results show that the effect of prolonged hydrothermal action on the samples is reduced to the following.

After a corrosive test on the surface of the samples of pair 0, an abundant amount of corrosion product was noticed. After cleaning them, on the surface of the aluminum alloy sample in the contact zone with the steel sample, irregularities in the form of micro-ulcers were observed. Samples of pair 1 did not show outer any signs of corrosion, but after disassembly and cleaning, similar surface damage was revealed as in pair 0 in the form of micro-ulcers, but more pronounced.

For pairs 11 and 12, corrosion of the steel sample in the form of local spots was noted. In pair 13, the same as in pairs 12 and 11, the steel sample corroded, but more actively. The first inspection of pair 21 revealed a large volume of corrosion product deposited on the aluminum sample. But after cleaning them, no any damages of MAO-coating were found. It was concluded that only the steel sample has corroded.



(a)

(b)

Fig. 4. Tafel polarization curves for samples of some pairs: (a) sample 0; (b) sample 23 (on the left – before corrosion test, on the right – after exposition in corrosion environment)

Table 1. Results of measurements and visual estimation

Samples	Thickness of MAO-coating, μm	Potential before test, mV	Corrosion current before test, μA	Potential after test, mV	Corrosion current after test, μA	Corrosion damages	Notes
0	Without MAO	-80.679	242.291	-191.641	687.463	presence	-
1	Without MAO	-134.413	13.029	-13.944	465.456	presence	Phosphated steel
11	15	-96.678	154.236	6.795	365.000	low	Phosphated steel
12F	23	-138.384	876.718	-82.034	25.890	presence	F-4D added
13	17	-316.313	2.715	-51.229	22.297	presence	Phosphated steel
21	28	103.515	94.757	34.403	17.945	presence	Phosphated steel
22F	36	40.006	79.960	413.415	0.672	no	F-4D added
23	30	-30.326	149.348	-48.254	27.985	low	Phosphated steel

Samples of pair 22 did not show any changes on the surfaces in the contact zone, and there were no signs of corrosion. Corrosion products are present around the contact perimeter of pair 23. But signs of MAO-coating violation of the integrity were not noticed.

Repeated measurements of the polarization curves from the samples were also carried out in a 5 % aqueous solution of NaCl at T = 20 °C. During corrosion studies, corrosion potentials, corrosion currents, and Tafel coefficients were determined. All potentials of aluminum samples are represented relative to their corresponding steel samples.

Based on the data in Table 1, for a more visual assessment of the results, diagrams were drawn up (see Figs. 5, and 6).

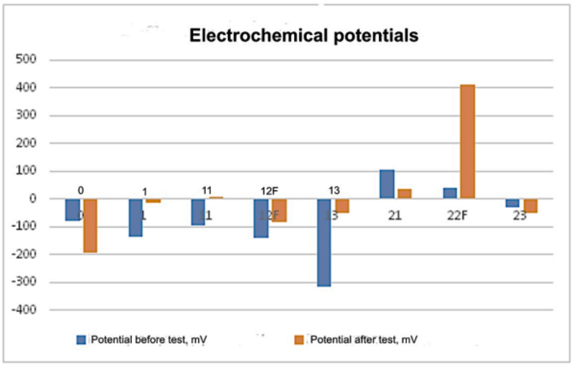


Fig. 5. Electrochemical potentials of investigated samples

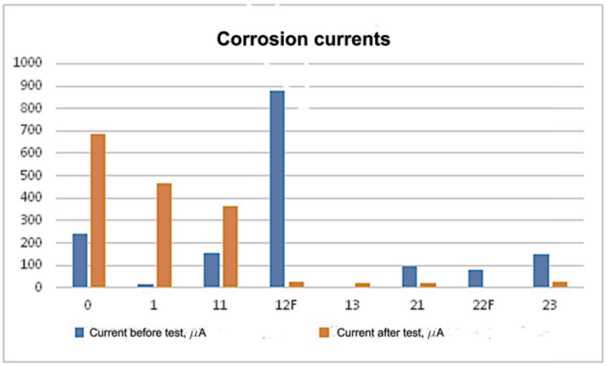


Fig. 6. Calculated corrosion currents

Comparing the results obtained, we can say the following:

1. for samples of pair 0, after the test, the corrosion current value was maximum among all presented pairs, and for pair 22, on the contrary, it was minimum. Having linked these values with a visual assessment of samples, it is permissible to assert that the lower the value of the corrosion current, the lower will be the contact corrosion;
2. the phosphating of steel samples directly affects the process of contact corrosion, namely, it helps to reduce the corrosion current. This is most likely due to the fact that the phosphating steel layer represents also an insulator at the points of contact;
3. samples of pairs 11 and 13 had MAO-coatings 15 and 17 μm thick, respectively. After exposition in 5% NaCl solution, the coatings were damaged. This means that the thickness of MAO-coating lower than 20 μm cannot keep the integrity and should be increased over this value;
4. additional treatment of samples from aluminum alloy with MAO-coating by fluoroplastic suspension play in whole its positive role but is ambiguous;
5. forming the MAO-coating on the contact zone reduces significantly the corrosion current, increasing thereby the corrosion resistance of aluminum alloys.

Conclusions

Thus, the held investigations have shown that in most cases the corroded material was steel. Using the MAO-coating as an insulator to improve the resistance from contact corrosion of aluminum drill pipes is quite appropriate. The recommended thickness of the coating should be about 30-40 μm because at lower thickness is it possible to develop some damages of coating and breakdown of its completeness.

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