Features of the use of light alloys in the marine climate of the arctic zone

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Abstract. The movement of mining and processing industries to the North poses the task of analyzing the performance of materials traditionally used in structures and products. The paper presents the results of comparative studies of magnesium alloy MA2-1 and aluminum alloy AMg6 in the marine climate of Northern latitudes. The studies were carried out after simulating the long-term operation and storage of alloys in northern latitudes, namely after long 1000-hour exposures at a temperature of -600 °C, aging in a salt fog chamber. We analysed the impact of external climatic factors, typical of northern latitudes, on the mechanical properties and a comparative assessment of the corrosion resistance of alloys in a marine climate.

1. Introduction
The primary task facing the Russian Federation is the development of the shelf zone of the Arctic seas and adjacent coastal areas, in the depths of which there are significant reserves of hydrocarbons, ore deposits of such scarce and expensive metals as gold, platinum, tungsten, copper, cobalt, nickel, tin. The movement of the mining and processing industries to the north sets the task to re-examine the possibility of using traditional structural materials, such as aluminum and magnesium alloys, in the marine climate of the Arctic Ocean.

2. Materials and methods
Light alloys are increasingly used in structures and products for various purposes. Their use becomes especially relevant in equipment with strict requirements for weight and overall characteristics. Such alloys have a relatively high specific strength and several times lower density than the density of traditional steels. They have been used in aviation and shipbuilding, equipment for the extraction and processing of hydrocarbon raw materials, radio engineering, etc. These materials include widely used light alloys aluminum and magnesium [1].

In this work, comparative tests were carried out on two alloys – MA2-1. They were deformable magnesium alloy containing 0,2-0,6% of manganese, 3,8-5,0% of aluminum, 0,6-1,5% of zinc, and deformable aluminum alloy AMg6 (5,8-6,8% of magnesium, 0,5-0,8% of manganese, not more than 1% of iron, silicon, titanium, copper and zinc). The MA2-1 alloy is mainly used in the form of sheet blanks, bars, plates and is widely used in instrument housings, in the housing elements of mobile equipment, electronic systems, for welded parts of complex configuration, fittings, gasoline and oil systems. Alloy AMg6 is used for the manufacture of welded parts of tanks and pipelines: shells, bot-
toms, flanges, pipe grids, etc. Semi-finished products of alloy AMg6 have been used in shipbuilding [2].

In the work we used rods of both alloys with a diameter of 100 mm according to GOST 21488-97. This was the AMg6 alloy and GOST 18351-73 and the MA2-1 alloy. Features of the equipment used in the marine climate of the Northern latitudes is prolonged (storage and operation) of equipment outdoors in extremely low temperatures, icing of the working surfaces (frost); when defrosting and high humidity conditions, the formation, in the working of ultrasonic crystals water drops (dew). In the warm part of the year, the equipment is exposed to aggressive corrosive effects of sea air [3, 4]. The influence of these factors should be investigated when determining the possibility of using alloys AMg6 and MA2-1 as hulls and other components of systems, long-term operation in the coastal zones of the Northern seas. The influence of the above factors on the mechanical properties of alloys has been studied. The effects of prolonged exposure in the open air were simulated by cooling the tensile and impact-bending test specimens in a climate chamber at minus 60°C. The cooling time varied from 200 to 1000 hours.

The influence of external climatic factors such as frost and dew was also simulated in the climate chamber. The same samples were placed in a climatic chamber and kept at a temperature of minus 60 °C for 100 hours with periodic purging of the chamber with wet water vapor to form a stable ice crust on the working surfaces of the samples. The samples processed in this way were placed in the grips of the test machines. The transfer time was not more than 60 seconds, which allowed preserving the ice crust during the tests. Dew-the temperature in the chamber was 20 °C, humidity 95%, exposure time 100 hours. The influence of sea air was simulated in two ways: the first – by exposure of samples to mechanical tests in a salt mist chamber at a temperature of 35 °C for 100 hours. The second tested the resistance of alloys to corrosion in accordance with the requirements of ESZKS GOST 9.913-90. For testing according to GOST 9.913-90, two types of samples were prepared - disks with a diameter of 100 mm and a thickness of 2.5 mm and samples for mechanical tests. Samples attached to nylon threads were completely immersed in a reactive corrosion medium heated to a temperature of 23 °C and representing a 3% solution of sodium chloride with the addition of 1% hydrogen peroxide. Such reagent composition and test conditions were selected in accordance with the requirements for the category of equipment performance for this climatic region, the conditions of its operation, storage and transportation in terms of the impact of climatic factors of the environment.

During the tests, the 0,1% hydrogen peroxide solution was added to the test medium once every five days; the solution itself was replaced every 10 days of the test. When replacing solution we photographed the actual state of the surface of the disc-shaped samples.

3. Results and discussion
The results of mechanical tests of alloys are given in table 1. As follows from the table, alloy AMg6 was practically not affected by external climatic factors, its properties after prolonged exposure. Simulating the impact of external climatic conditions of operation of equipment in coastal zones of Northern territories remains virtually unchanged. The properties of the alloy MA2-1 also do not undergo changes under the influence of temperature and ice action. At the same time, studies of alloy samples after exposure to salt mist showed a sharp decrease in time resistance, ductility and toughness. Visual inspection of the surface of the samples after exposure in the salt mist chamber showed that their surface is covered with a layer of white deposits. After removing a layer of deposits on the surface of impact samples and samples intended for uniaxial static tensile tests, corrosion defects such as flat ulcers with a diameter of up to 2-4 mm and a depth of more than 1 mm were found on the surfaces of the working parts of the samples.

To clarify the corrosion resistance of the alloys, additional corrosion tests of the samples were carried out. The tests were carried out by completely immersing the samples in a solution containing 3% sodium chloride and 0,1% hydrogen peroxide.
Table 1. Mechanical properties of alloys AMg6 and MA2-1 after prolonged exposure to external climatic factors*

| Climatic impact          | T   | Alloy AMg6 |                | Alloy MA2-1 |                |
|--------------------------|-----|------------|----------------|-------------|----------------|
|                          | °C  | $\sigma_0$ | $\sigma_{0.2}$ | $\delta_5$  | $KCV$          |
|                          | MPa | %          | MPa            | %           | J/cm$^2$       |
| Delivery condition       | 20  | 370        | 173            | 24          | 31.6           | 255            | 155            | 11            | 22.7          |
|                          | -60 | 410        | 180            | 21          | 27.4           | 310            | 215            | 8             | 16.4          |
| Freezing at minus 60 °C | 20  | 375        | 176            | 24          | 32.0           | 260            | 160            | 12            | 22.1          |
| - 200 h                  | -60 | 408        | 179            | 20          | 27.2           | 310            | 210            | 8             | 16.2          |
| Freezing at minus 60 °C | 20  | 371        | 175            | 23          | 31.3           | 257            | 157            | 11            | 21.0          |
| - 500 h                  | -60 | 412        | 181            | 21          | 27.0           | 305            | 211            | 8             | 15.8          |
| Freezing at minus 60 °C | 20  | 370        | 177            | 24          | 31.3           | 260            | 160            | 10            | 20.8          |
| - 1000 h                 | -60 | 415        | 182            | 21          | 27.5           | 305            | 155            | 9             | 15.4          |
| Exposure in salt mist   | 20  | 369        | 171            | 23          | 31.0           | 210            | 150            | 4             | 11.9          |
| 35 °C - 100 hours        | -60 | 404        | 179            | 20          | 27.3           | 235            | 205            | 1             | 8.7           |
| Frost                    | 20  | 372        | 170            | 23          | 31.2           | 252            | 155            | 10            | 22.0          |
| -60                      | 410 | 183        | 21             | 27.5         | 310            | 200            | 8             | 16.2          |
| Dew                      | 20  | 370        | 174            | 24          | 31.6           | 256            | 160            | 11            | 22.3          |
| -60                      | 407 | 181        | 21             | 27.0         | 311            | 205            | 9             | 16.5          |

* Note. The sizes of working parts of all samples were measured before imitation of external climatic influences.

The evaluation of the test results was carried out by changing the appearance of the samples; the presence, depth and amount of corrosion damage, as well as by changing the mechanical properties of the samples after aggressive environmental exposure. The test results are given in table 2 and in figure 1.

Figure 1. Samples after corrosion tests within 1000 hours: a) alloy AMg6, b) alloy MA2-1

The results of mechanical tests of the AMg6 alloy after a 100-hour exposure in a medium of 3% sodium chloride and 0.1% hydrogen peroxide are given in table 3. The samples for mechanical tests of the alloy MA2-1, sustained for 1000 hours in a solution of 3% sodium chloride and 0.1% hydrogen peroxide, were completely damaged by corrosion and it was not possible to carry out tests.
Table 2. Description of corrosion damage of AMg6 and MA2-1 alloy samples

| Time, hour before testing | Description of sample surface condition, the samples are machined, Ra 2.0 mkm |
|---------------------------|----------------------------------------------------------------------------------|
| **Alloy AMg6**            |                                                                                  |
| 240 hours                 | The surface of the sample is covered with a thin translucent layer of deposits.   |
| 720 hours                 | The surface of the sample is completely covered with a layer of white deposits, on the surface of the sample marked individual ulcers with a diameter of 0.2 mm. |
| 1000 hours                | The surface of the sample is completely covered with a layer of white deposits. Chains of small corrosion ulcers are visible on the surface of the sample. The diameter of the ulcers is not more than 0.3 mm. Single ulcers with a diameter of 1.0 mm and a depth of 0.5 mm are noted. |
| 2500 hours                | The surface of the sample is completely covered with a layer of white deposits. On the surface there are visible corrosion ulcers at a depth of more than 0.5 mm, diameter of up to 2.5 mm. |
| **Alloy MA2-1**           |                                                                                  |
| 24 hours                  | The surface of the sample has lost its metallic luster, is completely covered with thin oxide films, individual corrosion ulcers are visible, mainly concentrated in the peripheral part of the sample. |
| 48 hours                  | The surface of the sample is completely covered with a layer of deposits of gray and gray-green colors. Numerous corrosion ulcers were found. After removal of surface deposits, flat ulcers of a corrosive nature were found on the surface of the sample. Depth is up to 0.25 m, length is up to 1.5 mm. Density of defects is 2-3 ulcers per 1 cm². |
| 500 hours                 | The surface of the sample is completely covered with a layer of loose corrosion deposits of gray and white-gray colors. Deposits are easily exfoliated from the over-surface of the sample. Large corrosion defects up to 1 mm deep were found in the peripheral part of the sample. |
| 1000 hours                | The surface of the sample is completely covered with a layer of loose corrosion deposits of gray and white-gray colors. Deposits are easily exfoliated from the over-surface of the sample. The composition is deposition-oxides and chlorides of magnesium and aluminum chloride. Numerous large corrosion ulcers, including through ulcers, were found in the peripheral part of the sample. |

Table 3. Mechanical properties of alloy AMg6 exposed for 1000 hours in corrosive environment

| T test, °C | σB , MPa | σ0.2, MPa | δ5 , % | KCV, J/cm² |
|------------|----------|-----------|--------|------------|
| 20         | 365      | 171       | 11     | 31.2       |
| -60        | 412      | 181       | 8      | 27.0       |

Based on the corrosion resistance tests of the AMg6 and MA2-1 alloys, it was established that both alloys retain the stability of mechanical properties during long-term low-temperature operation. This is confirmed by the results of mechanical testing of samples after such external climatic influences as prolonged exposure to low climatic temperatures, icing, loss condensed moisture (dew) and can be used to manufacture casings and other components and parts of equipment operated on the Far North and the Arctic. Particular attention should be paid to the conditions in which the equipment will be operated, in the functions of the material for the manufacture of low-temperature equipment. Magne-
Sodium alloy MA2-1 is subject to corrosion under the action of chlorine-ion medium, the impact of which leads to the emergence and development of corrosion defects such as ulcers, developed by the mechanism of general corrosion. Even within 2 days of testing, the depth of corrosion ulcers was 0.25 mm, the diameter was up to 1.5 mm, the density of defects was 2-3 ulcers per 1 cm². With further exposure of samples in a corrosive environment, the density of corrosion defects increases and after 1000 hours of exposure grows into an almost continuous field; corrosion damage was detected. Thus, it is shown that the use of MA2-1 alloy can lead to accelerated destruction of products, operated and stored in the sea climate. Analysis of the surfaces of the samples of the AMg6 alloy after corrosion showed that the alloy has a significantly greater resistance to aggressive chlorine-ion environment. However, in the course of studies of the surface of the samples after a 1000- and 2500-hour exposure in an aggressive environment, damage was detected, developed by the mechanism of ulcerative corrosion and corrosion deposits of chlorides and oxides.

4. Conclusion
It is shown that alloys AMg6 and MA2-1 can be recommended for the manufacture of equipment operated outdoors in northern latitudes. However, when selecting the material for the manufacture of equipment, it is necessary to take into account the additional climatic conditions of operation and the area of the equipment. If in the areas, remote from the seas, these alloys can be used without restriction, then in the marine climate the use of magnesium alloy is possible only with the use of protective coatings [5].

Also on the basis of the conducted research, it was established that the relatively short-term use of the equipment made from the AMg6 alloy in the conditions of sea climate of northern latitudes (about one hour) does not need additional measures on anticorrosive protection. Long-term corrosion effects of the environment leads to the appearance of corrosion defects on the surface of the alloy AMg6 in the form of corrosion ulcers, looseness, chains of small corrosion defects. The layer of corrosion deposits consists of two groups of deposits. The first is a dense passivating layer of aluminum oxide with good adhesion to the surface of the sample. The second is separate conglomerates of loose deposits of magnesium oxide and chloride and aluminum chloride, easily removed from the surface of the sample. Therefore, despite the fact that the results of mechanical tests did not reveal the influence of the corrosive environment on the mechanical properties of the alloy. In order to prevent corrosion damage and loss of performance of equipment intended for long-term operation in a marine climate, it is recommended to protect the surface of the equipment using protective anticorrosive coatings.

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