HEAT RESISTANCE OF INTERMETALLIC PHASE MATRIX Fe-Al ALLOYS IN STEAM ENVIRONMENT

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Abstract

The paper presents the results of studies aimed at determination of corrosion resistance intermetallic phase matrix of FeAl alloy in a steam environment at 850 °C. The comparison of heat resistance of Fe40Al5Cr0,2TiB intermetallic alloy with heat-resistant steel with austenitic structure X25CrMnNiN25-9-7 was also presented at the article. After surface corrosion studies, the chemical composition of corrosion products was determined. The obtained results showed very good resistance of Fe40Al5CrTiB alloys to high temperature corrosion in steam environment compared to corrosion resistance of X25CrMnNiN25-9-7 steel. The results of research conducted in this field are the basis for further research.

Keywords: Corrosion resistance, high-temperature corrosion, alloys intermetallic phase matrix FeAl

1. INTRODUCTION

The development of material engineering of heat-resistant materials is closely related to many areas of industry, and above all with the power engineering, aviation, engineering and automotive industries. However, the main consumer of steel and heat-resistant steel is thermal energy, and therefore its development depends to a large extent on the availability of materials and technologies available on the market, which allow to fulfil increasing requirements of quality. The requirements for steels designee for work at elevated temperatures far exceed the standard specifications used in structural calculations [1-4].

Basic heat-resistant materials, which have been used for many years, are metal alloys, including steel for working at elevated temperatures and also nickel and cobalt alloys. Based on the results of the carried out research, concerning the selection of materials and the relevant technological processes, it has been proved that on the matrix of iron, nickel and titanium with aluminium can be formed a new group of constructive alloys with a special mechanical properties and a stable structure at high temperature [2,3,5-7].

Alloys on the matrix of intermetallic phases are characterized by an orderly internal structure and properties which are the result of the existence of three types of bonds: metallic, ionic and covalent. The energy of binding two different atoms is greater than the bonds between the same elements in the alloy. This provides a structured solution. Thanks to these features, intermetallic alloys have special physical, chemical and mechanical properties [1,2]. FeAl intermetallic phases, containing from 36% to 51% aluminum atoms, have stable properties in a wide range of temperature. These phases also feature a low density of 5.5 g/cm^3 and a high corrosion resistance compared to conventional construction materials, as well as resistance to aggressive environments, seawater, carburizing, sulfur action. Phases Fe-Al have also very good tribological properties at elevated temperatures. The discussed intermetallic phases are therefore a prospective structural material for use in such industries as automotive and energy [5-7,9,10].

2. MATERIALS AND EXPERIMENTAL PROCEDURE

The tests were performed on Fe40Al5Cr0,2TiB intermetallic alloys after plastic processing, the chemical composition of which is shown in **Table 1**. Due to the fact that the material after the casting was characterized by brittleness and coarseness of the microstructure and heterogeneity of the chemical composition, heat treatment and plastic alloy processing were used. Homogenizing annealing was performed at 1050 ° C for 72 h for to unify the chemical composition of the alloy. The next step was plastic molding by co-extrusion in the manner of patent No. 208310 [8]. The use of this method, in comparison to conventional extrusion, allows to obtain a plastically deformable material without cracks, thus improving the plastic properties of the alloy and the microstructure homogeneity and grain size.

The reference material was a heat-resistant steel X25CrMnNiN25-9-7 with an austenitic structure, which has a working temperature of up to 1150 °C and therefore it is close to the permissible operating temperature of the Fe40Al5Cr0.2TiB intermetallic alloy. The chemical composition of steel is shown in **Table 2**. This material is mainly used for internal combustion engine valves. The test specimens were cut from 0.8 mm thick rolled sheet.

The obtained materials were made of corrosion test samples in two variants:

- samples with variable geometry cross section (wedge) of Fe40Al5Cr0,2TiB intermetallic alloy with dimensions: a = 10mm; B = 15mm; H = 0.4 mm (**Figure 1**);
- rectangular shaped samples of Fe40Al5Cr0,2TiB intermetallic alloy and austenitic steel X25CrMnNiN25-9-7 with dimensions: a = 10mm; B = 12 mm; H = 0.4 mm (**Figure 2**).

The prepared samples were subjected to oxidation in a water vapor atmosphere at 850 °C for 100 h. The experiment was carried out in a furnace designed to test for heat resistance in a steam environment. Surface analysis after corrosion was performed on an HITACHI S-4200 electron microscope equipped with an EDS (Energy Dispersive Spectroscopy) X-ray detector that determines the chemical composition of corrosion products.

Table 1 Chemical composition of Fe40Al5Cr0,2TiB alloy

Component	Fe	Al	Cr	Ti	B
Content [mass %]	69.47	24.53	5.80	0.19	0.01
Content [atom %]	54.80	40.10	4.86	0.18	0.06

Table 2 Chemical composition of X25CrMnNiN25-9-7 steel

Component	C	Cr	Mn	Ni	N	Si	S	P
Content [mass %]	0.2-0.3	24-26	8-10	6-8	0.2-0.4	<1	<0.015	<0.045

3. RESULTS

Visual studies were conducted on samples after corrosive tests in a steam environment at 850 °C for 100h. The samples are shown in **Figure 3**. It has been established that samples made of Fe40Al5Cr0,2TiB intermetallic alloy have a homogeneous colour of surface while a sample made of X25CrMnNiN25-9-7 steel has surface with of different colour. This variation consists of the presence of a brighter area in the form of a "border" at the outer edge of the sample (**Figure 3**, sample 3).

The tests of surface condition have shown that the material after the heat-resistant test for both the cuboid and the wedge-shaped sample is covered with a heterogeneous (non-continuous) oxide layer. The high content of aluminium in the test material makes easier to form of a thin, passive layer of Al_2O_3 oxides, which form a hermetic, high melting layer to prevent further corrosion of the material [8]. The conducted X-ray EDS microanalysis of the chemical composition showed on the sample 1 surface (the wedge-shaped) presence of scale as Al_2O_3 oxides. However this surface varies, depending on the thickness of the tested sample.

Numerous sections of the oxide layer are visible at points 1 to 4, which increase as a result of continuous diffusion of aluminium to the surface of the sample. The loss of aluminium contained in the intermetallic alloy increases with the reduction of the sample thickness. Reducing the aluminium concentration in the alloy (as a result of its oxidation) results in an internal diffusion phenomenon, which may result in cavities under the scale [9]. The surface of No. 2 sample is homogeneously covered with a passive layer. For No. sample (made of austenitic steel X25CrMnNiN25-9-7), material was subjected to a corrosion test in a steam environment at 850 °C and this material does not show heat resistance properties comparable to the heat-resistant Fe40Al5Cr0.2TiB intermetallic alloy. Fe40Al5Cr0,2TiB.

On the surface of No. 3 sample (made of austenitic steel X25CrMnNiN25-9) a corrosive layer was found and numerous cracks, resulting in degradation of the material was observed. Determination of approximate aluminium content in the Fe40Al5Cr0.2TiB alloy was made by using the EDS method. The oxygen content was only approximate due to the used analytical method. The structure and growth mechanism of the protective scale Al_2O_3 on heat-resistant alloys depends of the type of metal in the matrix. Alloys on the FeAl intermetallic phase throughout the entire temperature range remain single phase. For this reason, the Al_2O_3 layer develops over the whole of their surface at the time of contact of the hot metallic phase with oxygen, regardless of the temperature [9]. Under of the scale surface, during the oxidation of the intermetallic Fe40Al5Cr0.2TiB alloy, concentration gradients and cavities are formed. It can be seen on the bare (empty) FeAl surface in the Al_2O_3 oxide crushing areas (**Figure 7**). The formation of indentations is the result of the consumption of aluminium and its loss in FeAl. Gradient concentration of aluminium and its diffusion outside causes the reverse gradient of iron concentration and the occurrence of internal iron flow. Gradient concentrations are most pronounced after a short time of oxidation [9].

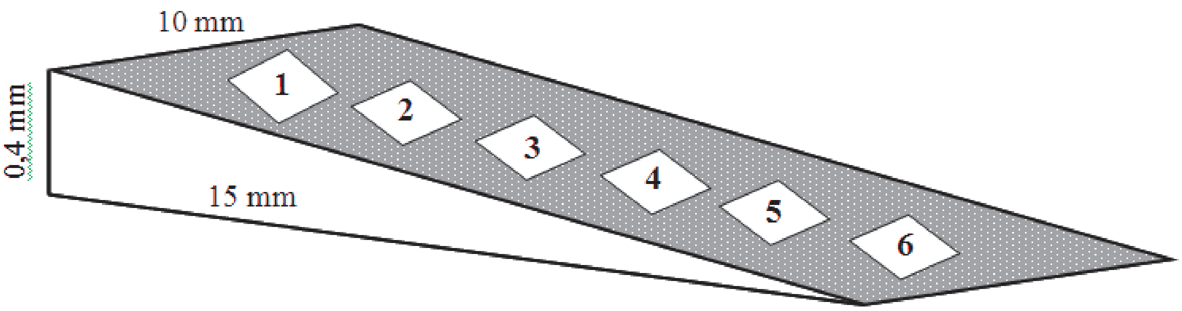


Figure 1 Diagram of a wedge-shaped test sample No. 1 Fe40Al5Cr0,2TiB alloy

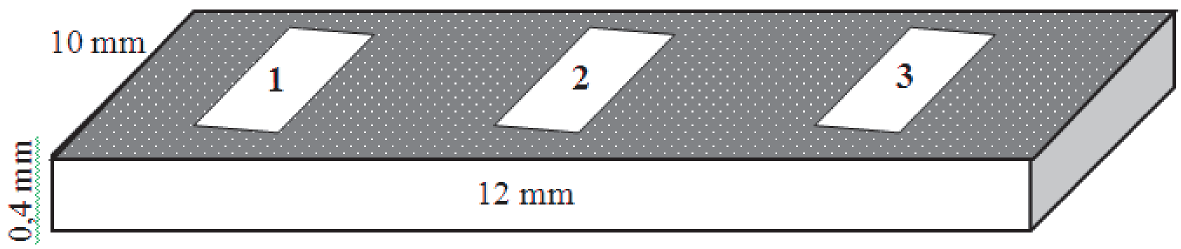


Figure 2 Diagram of test samples No. 2 and 3 from Fe40Al5Cr0,2TiB intermetallic alloy and X25CrMnNiN25-9-7 austenitic steel

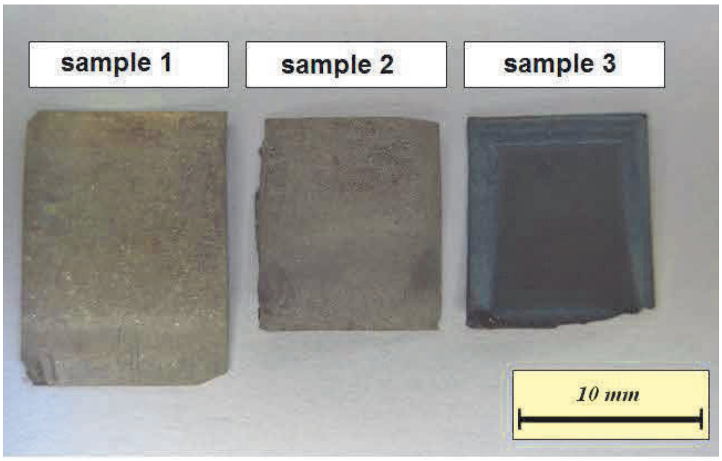


Figure 3 View of samples subjected to corrosion: 1-cross-section of wedge-shaped alloy of the FeAl intermetallic phase, 2-cross section in the shape of a rectangle of alloy on the FeAl alloy phase, 3- cross section of X25CrMnNiN25-9-7 steel

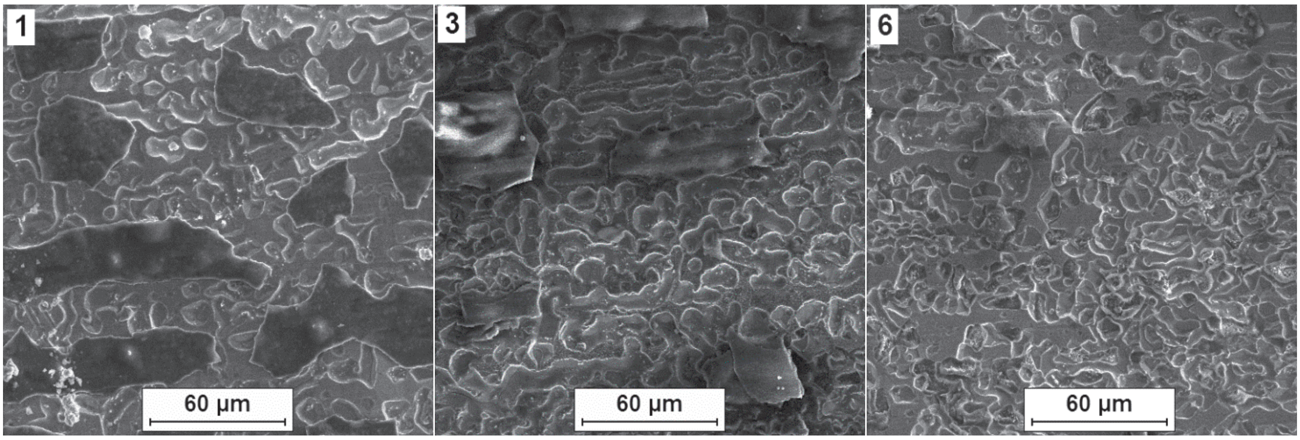


Figure 4 Surface state of the sample surface at wedge of the Fe40Al5Cr0,2TiB intermetallic alloy after corrosion test in steps 1, 3 and 6

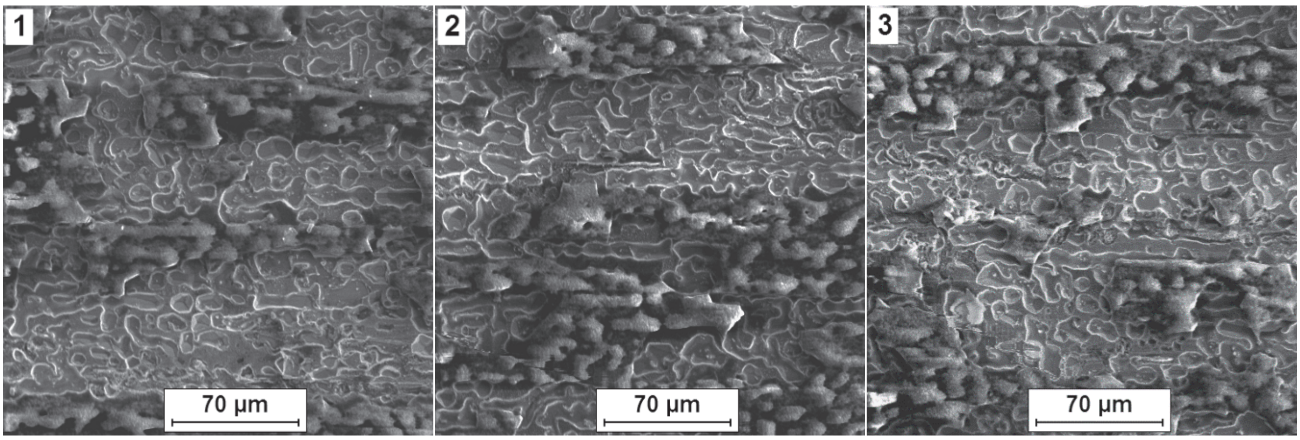


Figure 5 Surface condition of rectangular sample from Fe40Al5Cr0,2TiB intermetallic alloy after corrosion test in 1, 2 and 3

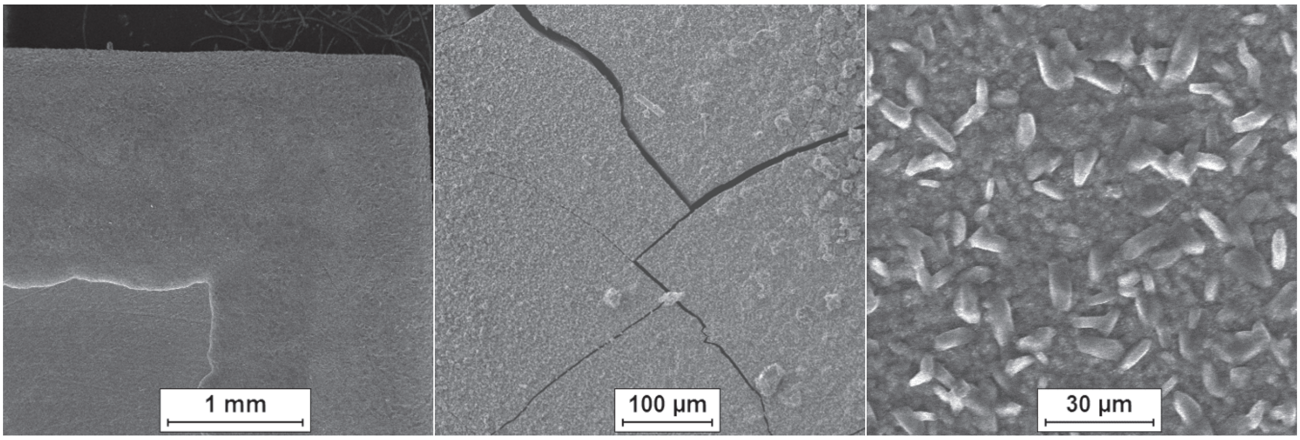
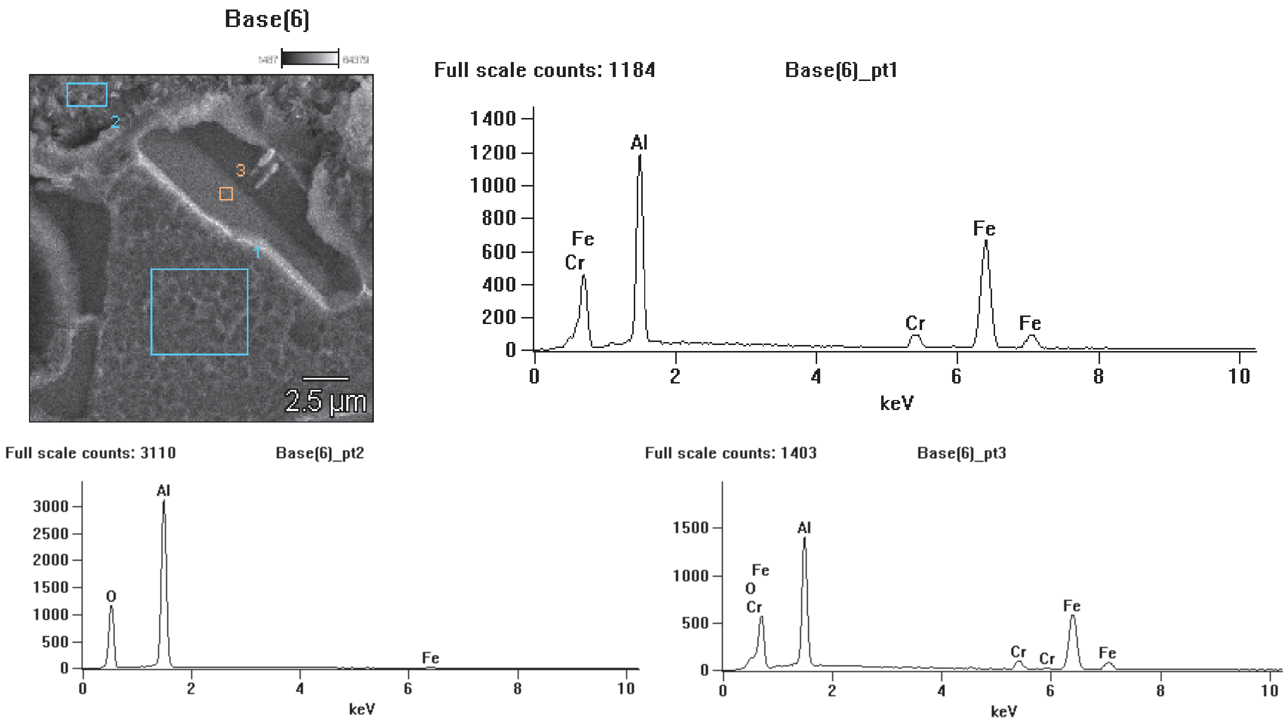
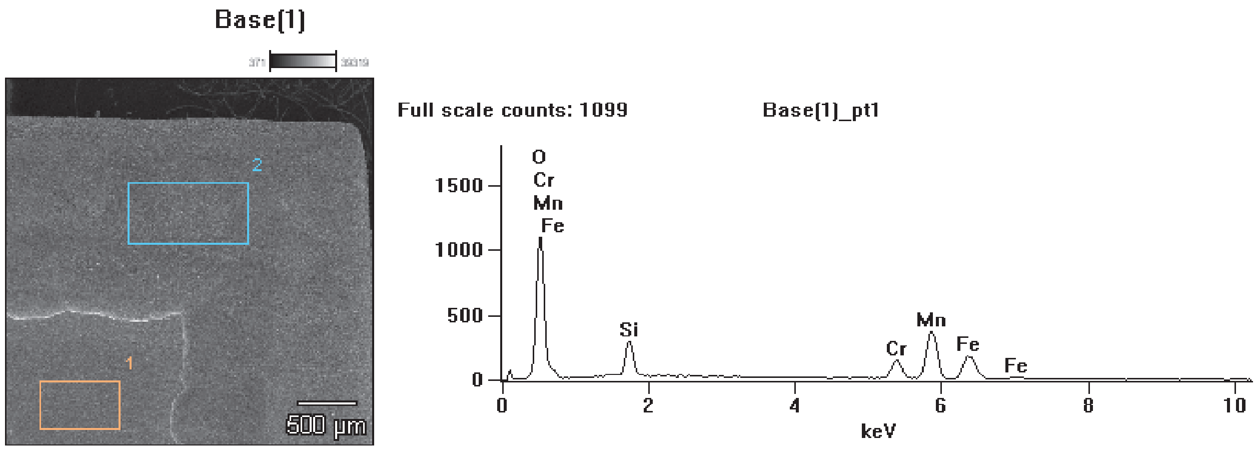


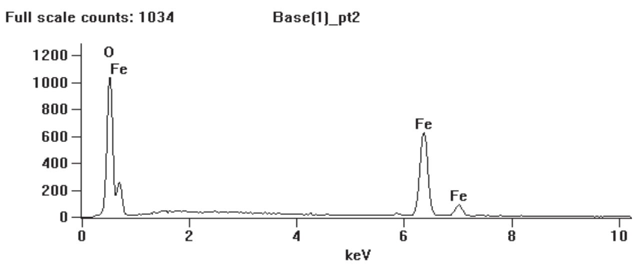
Figure 6 Surface condition of the rectangular sample fromX25CrMnNiN25-9-7 steel after corrosion tests



% mas.	O	Al	Cr	Fe
1	16.70S	18.78	4.46	60.07
2	46.27S	52.02		1.71
3	19.12S	21.50	4.00	55.38
%at.	*O*	*Al*	*Cr*	*Fe*
1	35.98	23.99	2.95	37.07
2	59.62	39.75		0.63
3	39.05	26.03	2.51	32.40

Figure 7 X-ray microanalysis of chemical composition of sample no. 1 from Fe40Al5Cr0,2TiB intermetallic alloy with variable geometry of section after corrosion tests at 6 point





% mas.	*O*	*Si*	*Cr*	*Mn*	*Fe*
1	22.78S	5.78	10.61	38.79	22.04
2	28.88				71.12
% at.	*O*	*Si*	*Cr*	*Mn*	*Fe*
1	48.52	7.01	6.95	24.06	13.45
2	58.63				41.37

Figure 8 X-ray microanalysis of chemical composition of specimen 1 of X25CrMnNiN25-9-7 steel

4. CONLUSION

Analysis of Fe40Al5Cr0,2TiB intermetallic alloy and X25CrMnNiN25-9-7 steels in a steam environment (850 ° C), based on the presented studies, has shown that the alloy resistance of FeAlAl3Cr02TiB intermetallic alloy is higher than that of the tested steel. Evidence of this is the analysis of the surface condition and the corrosion products produced on the tested materials. Analysis of literature data, in particular the corrosion kinetics of alloys from the Fe-Al system, proves that alloys of this system exhibit very good corrosion resistance at high temperatures, far exceeding the heat resistance of structural steels. However, obtaining the full characterization of Fe40Al5Cr0,2TiB intermetallic alloy resistance in a steam environment requires further research into the speed of corrosion processes, the morphology of corrosion products and the mechanism of passive layers formation.

Therefore, the results of the obtained studies show that the investigated material on the FeAl alloy has a higher corrosion resistance than the corrosion resistance of austenitic steel of X25CrMnNiN25-9-7 structure, this justifies the need for further investigation in this regard. One of the basic determinants of the very good heat resistance of FeAl alloys is the formation of a passive Al_2O_3 layer in the air at high temperature. The heat-resistance studies conducted in the steam environment showed the similarity of passive layers of corrosion products as in air. Also analysis of the surface state in terms of the morphology of the formed Al_2O_3 oxides showed similarity to the oxide layers formed in other corrosive environments, however, the determination of the corrosion rate of corrosion products in the FeAl alloy in the steam environment requires analysis of the diffusion processes in both corrosion products and in the native material. Considering the potential use of FeAl alloys, it is important to note that the working temperature of the materials exposed to the corrosive environment with water vapour usually does not exceed 800-850 ° C. For this reason, high temperatures of Al_2O_3 oxides in corrosion products should not be expected.

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