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The kinetics of corrosion of the FeAl intermetallic phase-based alloys

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ABSTRACT

Purpose: Purpose alloys on intermetallic phase matrix of iron and aluminium are considered the future materials for high-temperature applications as they are highly resistant to oxidation. Oxidized intermetallic alloy FeAl forms a protective alumina layer. The paper presents results of tests concerning kinetics of corrosion processes of alloy on intermetallic phase matrix FeAl of the composition Fe40Al5CrTiB after casting and plastic treatment with the use of co-extrusion method. The aim of this paper was to determine the resistance to high-temperature corrosion in atmosphere of air for alloy Fe40Al5Cr0.2TiB.

Design/methodology/approach: Corrosion tests were conducted in temperatures 900, 950 and 1000°C in time 8 hours, kinetics of corrosion appointed on the thermogravimetry method. The condition of the surface of samples after tests was characterized with the use of electron scanning microscope and also the chemical composition of corrosion products was determined.

Findings: Conducted tests have shown a high corrosion resistant alloy Fe40Al5CrTiB in comparison. The resulting graphs show the kinetics of corrosion processes on the parabolic character of the process of creating high-temperature corrosion products.

Practical implications: The Al alloy have a high corrosion resistant with resistant conventional materials predestined to do work in high temperature in corrosion environment.

Originality/value: The aim of this paper was to determine the resistance to high-temperature corrosion in atmosphere of air for alloy Fe40Al5Cr0.2TiB.

Keywords: Intermetallic; FeAl; Kinetics of corrosion; Oxidation

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MATERIALS

1. Introduction

Nowadays, plastic materials working at elevated temperature and with high corrosion resistance are a subject of great interest of industry. One of the materials which fulfill these requirements is alloy based on intermetallic phases from the FeAl system. Due to high specific strength, high melting point, low density, good corrosion resistance, especially oxidation, as well as relatively high electrical resistivity and low thermal conductivity, these alloys may be used for components operating at high temperatures. This combination of properties allows applying FeAl intermetallic phases based alloys as substitutes for carbon steel, as well as currently used heatproof and heat-resistant alloys [1,2]. FeAl alloys can also be an initial material for multicomponent alloys and composites formation [3]. These materials attain the desired properties because of the crystalline structure showing a long-range order. Enlargement of the long range order is obtained by increase of the Al content [4]. Many years of studies on FeAl intermetallic phase-base alloys showed that proper selection of aluminum, chromium macro-additive and alloy micro-additives improves the properties of the alloy [5].

Corrosion-proofness of alloys based on FeAl intermetallic phase depends largely on the structure. In the case of alloy after crystallization the microstructure has a number of faults such as: shrinkage porosity, dendrites, heterogeneity of chemical composition and coarseness. Forming of alloys based on FeAl intermetallic phase removes casting defects to a large degree, which results in fragmentation of the microstructure and removal of shrinkage porosity and voids. This also effects in improvement of the physicochemical and mechanical properties [6-8]. Studies of the corrosion resistance of alloys carried out in the research [9] lead to the conclusion that the corrosion resistance of Fe40Al5CrZr alloy at elevated temperatures after forming is higher if compared to the resistance of the alloy after crystallization.

Alloy based on FeAl intermetallic matrix phase has a higher resistance to oxidizing and reducing environments than alloy based on Fe_3Al intermetallic matrix phase [10]. This alloy is resistant to oxidation to about 1200°C and has good corrosion resistance in aqueous environments. Furthermore, FeAl phase shows significant resistance to the effects of salt environment at a temperature of 650°C and with the compounds of sodium chloride and carbon at temperatures up to 900°C. Improvement of mechanical properties of these alloys results from their usage in the creation of modifying elements. Zirconium, boron, titanium and fine-dust Y_2O_3 are the best additives that improve the strength of alloys based on intermetallic phases at elevated temperatures as well as ductility and corrosion resistance to both isostatic and cyclic oxidation. The positive impact of these elements on the kinetics of the oxidation of alloys on intermetallic matrix phase takes place in both oxygen and aggressive gas mixtures containing oxygen and sulfur environment [11,2].

This work presents the results of research conducted on Fe40Al5CrTiB alloy. When determining the kinetics of the oxidation of the alloy, the primary task is to derive the kinetic law, according to which the process of oxidation occurs and determination of the speed of process reaction constants [13,14].

It has been proved that FeAl matrix alloy meets the requirements for heat-resistant materials used in corrosive environments and the extent of degradation after the tests is so small as to be said that the alloys could potentially be used as the material for the manufacture of turbocharger components [15]

The aim of the research undertaken in this study is to determine the corrosion resistance of FeAl intermetallic matrix phase-base alloys in an oxidizing environment at high temperature.

2. Materials for research and methodology

The composition of tested FeAl intermetallic matrix phase alloy is shown in Table 1. The process of alloy melting was performed in a vacuum. Pure ingredients were used for smelting: technically pure ARMCO iron and ARO aluminum with purity by weight of 99.99%. Homogenizing annealing was performed at 1050°C for 72 h in order to unify the chemical composition. The resulting material was processed by extrusion forming, above all in order to refine the microstructure. Then the samples in the shape of a cylinder with a diameter of 10 mm were cut from ingots, which were grinded using sandpaper with gradation up to 1000 and then polished with diamond paste of 1 μm particle size. Before oxidation, the samples were degreased in ethyl alcohol. Isothermal oxidation was carried out at a temperature of 900°C, 950°C and 1000°C for 8h. Measurements were made using Setar GDTD16 thermobalance. Gas flow rate was 1l/h. The kinetics of oxidation was determined by measuring the weight change of samples for a particular temperature. Observations of the surface condition after corrosion tests were performed using Hitachi S4200 scanning electron microscope with EDS X-ray microanalysis system.

Table 1.
Chemical composition of Fe40Al5CrTiB alloy

	Fe	Al	Cr	Ti	B
Fe40Al5CrZrB [% wt.]	9.24	4.72	5.84	0.18	0.016

3. Results and discussion

Tests on oxidation of FeAl intermetallic matrix phase alloy in the respective temperatures for 8 h showed change in their mass. Oxidation curves shown in Fig. 1 and 2 demonstrate that aluminum was selectively oxidized forming passive layers of Al_2O_3. The rate of diffusion in this layer is determined by the oxidation process, the kinetics is compatible with the parabolic oxidation rate law:

$$(\Delta m/s)^2 = k_p'' \, t + C \qquad (1)$$

where: *Δm*-weight gain per area unit *s* at time *t*, k_p''-parabolic oxidation rate constant, $g^2 \cdot cm^{-4} \cdot s^{-1}$, C-constant associated with parabolic right deviation in the initial phase of the reaction.

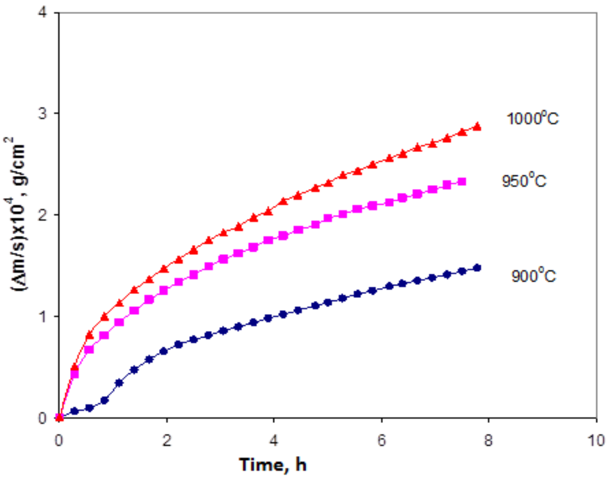

Fig. 1 Course of the oxidation of alloy based on the matrix of FeAl intermetallic phases (linear coordinate system)

It was assumed that the corrosive phenomena are parabolic, even if in some areas, the reliance does not meet the parabolic equation. These variations are the result of presence of different allotropic Al_2O_3 forms as corrosion products at different temperatures, as well as oxidation time. After rearranging equation (1) parabolic oxidation rate constant for the alloy after the test at a temperature of 900°C, 950°C and 1000°C was calculated (Fig. 2). Values of the k_p'' constants are shown in Table 2.

Observations of the surface of samples made using scanning electron microscope showed the presence of the areas containing most likely aluminum oxide (Fig. 3-8). In the initial stage of corrosion oxidation of iron in the surface layer and presence of heat-resistant Al_2O_3 layer, which tightly adheres to the substrate and insulates the rest of the material from the oxygen, occurs. After oxidation at 900°C surface was covered with oxides in the form of fine needles. The size of the corrosion products increased with the temperature of corrosion sample. Fig. 8 shows the surface of scale formed on the tested alloy at 1000°C. Mutual presence of oxides in the form of fine needles and oxides in the form of pellets is noticeable.

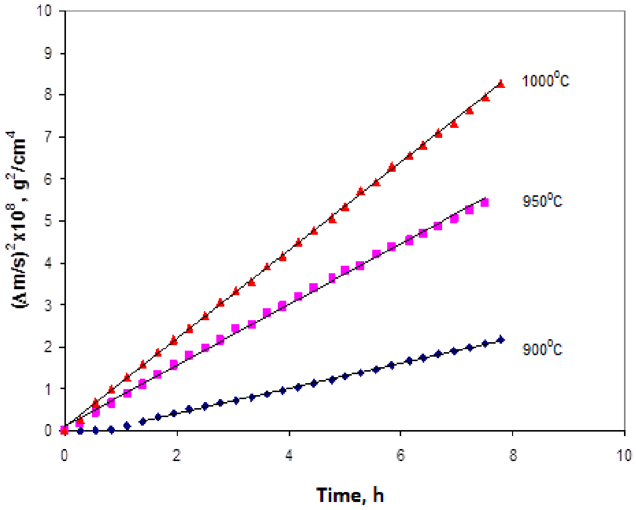

Fig. 2. Course of the oxidation of alloy based on the matrix of FeAl intermetallic phases (parabolic coordinate system)

Table 2.
The values of c k_p'' constants for the FeAl intermetallic compound

T [°C]	k_p'' [$g^2 \cdot cm^{-4} \cdot s^{-1}$]
900	$8.3 \cdot 10^{-13}$
950	$1.9 \cdot 10^{-12}$
1000	$2.9 \cdot 10^{-12}$

The studies of the chemical composition of the samples of alloy based on the matrix of FeAl intermetallic phases performed using EDS X-ray microanalysis showed appearance of areas corresponding to the chemical composition of indigenous material, oxygen and aluminum (Fig. 9-11). The chemical composition of Fe40Al5CrTiB alloy after corrosion tests at 900°-1000°C are shown in Table 3-5. The analysis of the oxide layer resulting from corrosion processes indicates that it consists mainly of aluminum oxide.

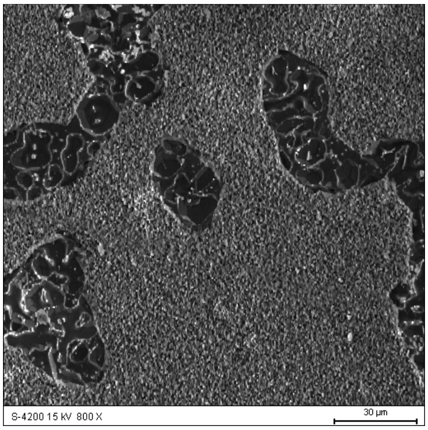

Fig. 3. Condition of the alloy surface after corrosion tests at 900°C

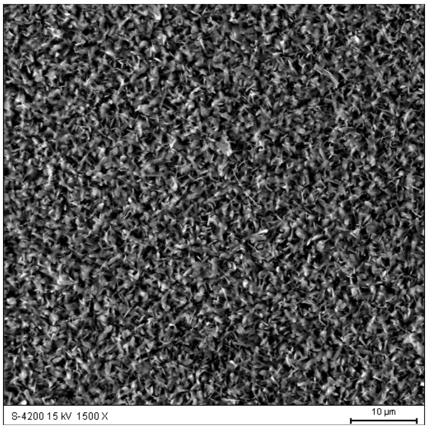

Fig. 4. Condition of the alloy surface after corrosion tests at 900°C. Visible corrosion products in the form of Al_2O_3 passive layer

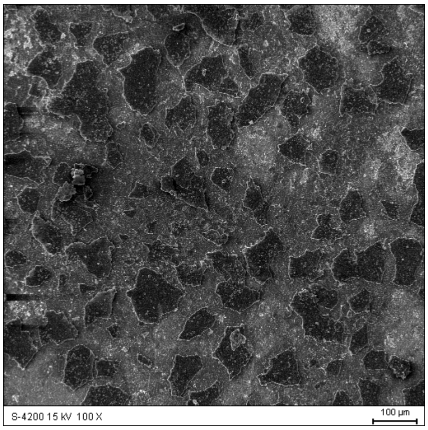

Fig. 5. Condition of the alloy surface after corrosion tests at 950°C

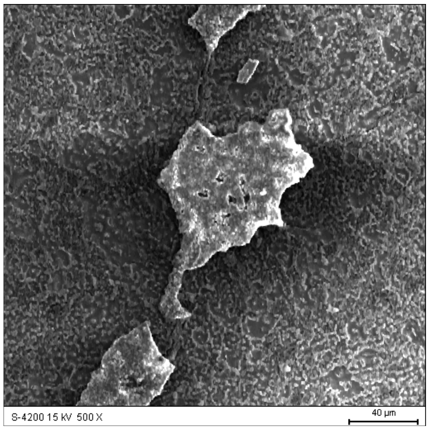

Fig. 6. Condition of the alloy surface after corrosion tests at 950°C. Visible Al_2O_3 passive layer on the sample surface

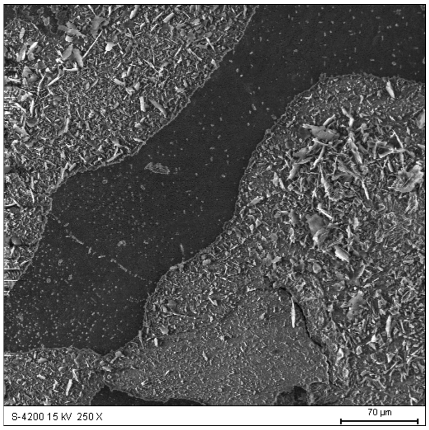

Fig. 7. Condition of the alloy surface after corrosion tests at 1000°C

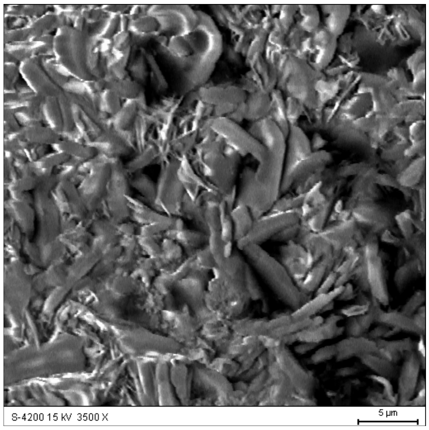

Fig. 8. Morphology of passive Al_2O_3 layer on the surface of the alloy after corrosion testing at 1000°C

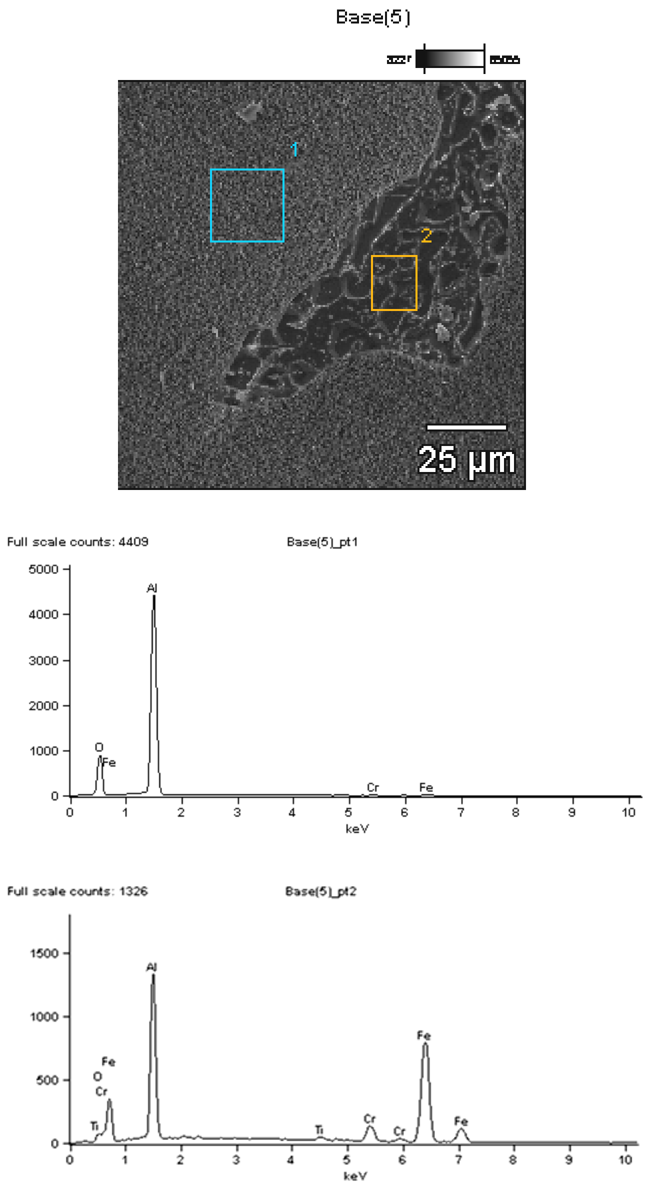

Fig. 9. Microanalysis of the chemical composition of Fe40Al5CrTiB alloy after corrosion tests at 900°C.

Table 3.
The chemical composition of Fe40Al5CrTiB alloy after corrosion tests at 900°C.

Atom %	O	Al	Ti	Cr	Fe
Base(5)_pt1	54.0	44.7	-	0.3	1.0
Base(5)_pt2	6.7	27.8	0.8	4.9	59.8

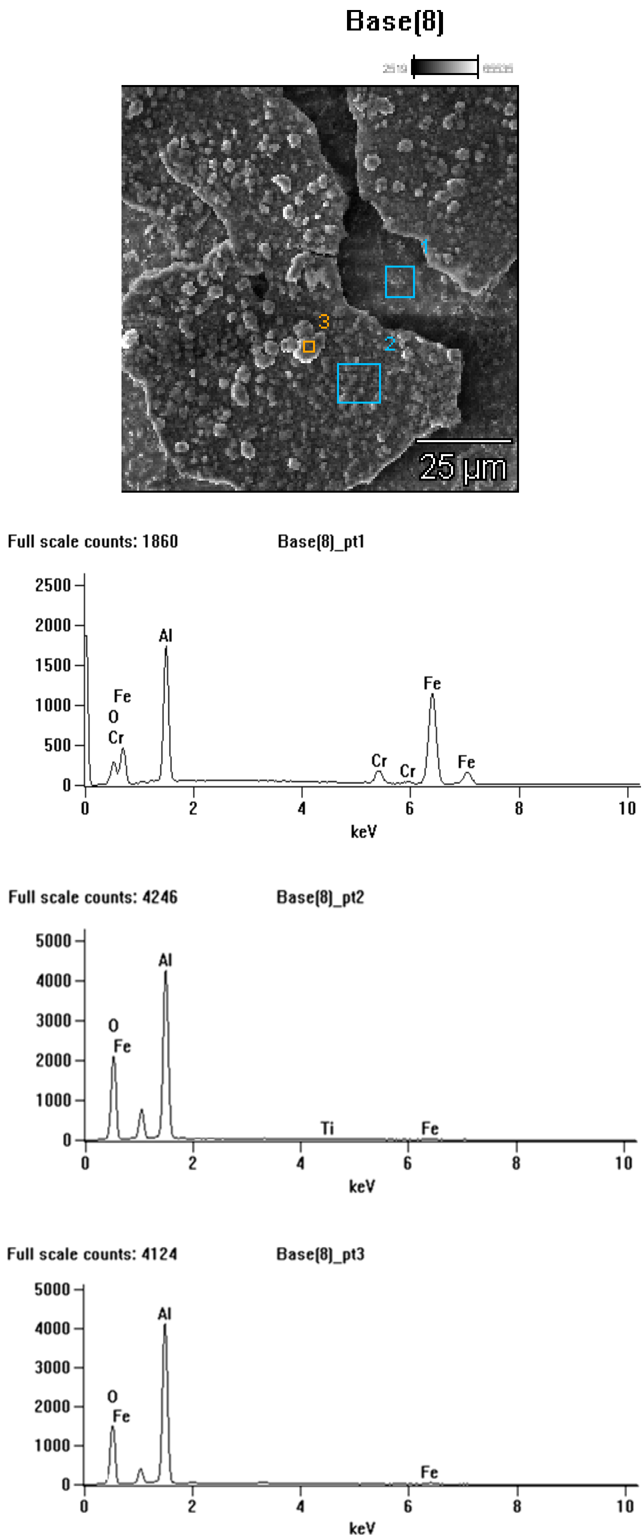

Fig. 10. Microanalysis of the chemical composition of Fe40Al5CrTiB alloy after corrosion tests at 950°C

Table 4.
The chemical composition of Fe40Al5CrTiB alloy after corrosion tests at 950ºC.

Atom %	O	Al	Ti	Cr	Fe
Base(8)_pt1	12.0	32.3	-	3.8	51.9
Base(8)_pt2	68.2	30.6	0.4	-	0.7
Base(8)_pt3	63.9	34.9	-	-	1.2

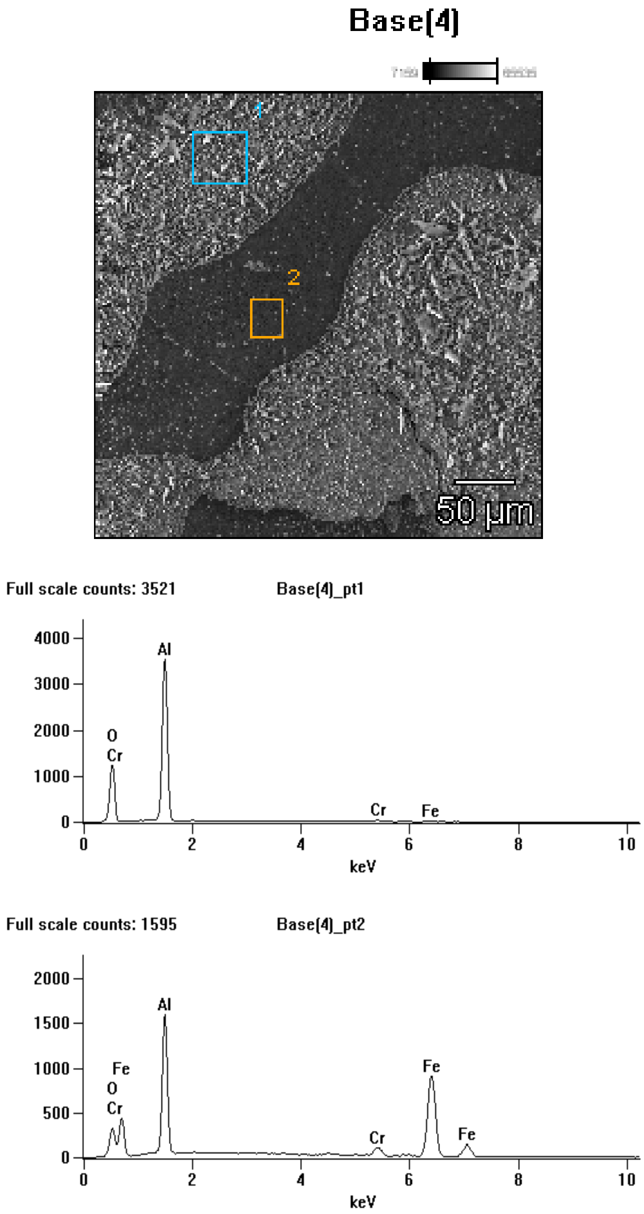

Fig. 11. Microanalysis of the chemical composition of Fe40Al5CrTiB alloy after corrosion tests at 1000°C

Table 5.
The chemical composition of Fe40Al5CrTiB alloy after corrosion tests at 1000ºC.

Atom %	O	Al	Cr	Fe
Base(4)_pt1	62.0	37.0	0.6	0.4
Base(4)_pt2	16.0	33.6	3.1	47.3

4. Conclusions

Conducted studies and analysis of their results lead to conclusion that alloys based on the matrix of FeAl intermetallic phase have good resistance to high-temperature corrosion in an oxidizing environment.

The examination of the curves shows that the process of oxidation is compatible with the parabolic law. This is confirmed by analysis of the dependences in parabolic coordinate system.

Corrosion resistance of the Fe40Al5CrTiB alloy is provided by passive Al_2O_3 layer formed on its surface. The presence of the passive Al_2O_3 layer in an oxidizing environment assures FeAl alloys very good heat resistance. The morphology of corrosion products depends on the temperature at which the material is subjected to the influence of oxygen. Detailed explanation of the phenomena of high temperature corrosion of alloys based on the matrix of FeAl intermetallic phase requires further research.

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Additional information

Selected issues related to this paper are planned to be presented at the 22nd Winter International Scientific Conference on Achievements in Mechanical and Materials Engineering Winter-AMME’2015 in the framework of the Bidisciplinary Occasional Scientific Session BOSS'2015 celebrating the 10th anniversary of the foundation of the Association of Computational Materials Science and Surface Engineering and the World Academy of Materials and Manufacturing Engineering and of the foundation of the Worldwide Journal of Achievements in Materials and Manufacturing Engineering.

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