Arch. Metall. Mater. **62** (2017), 4, 2281-2286

DOI: 10.1515/amm-2017-0336

D. PASEK*#, J. CEBULSKI*

INFLUENCE OF PLASTIC DEFORMATION DURING EXTRUSION PROCESS ON HEAT RESISTANCE ALLOYS Fe40Al

The article presents the results of studies on the effects wrought on the corrosion resistance of the alloy matrix phase intermetallic FeAl. Researches were carried out on the Fe40Al5Cr0.2TiB alloy and involved the oxidation of the samples after the crystallization after plastic deformation made by extrusion. The tests were performed in an oven in air at 1100°C for 100, 300 and 500 h. Determined to change the mass of the samples after corrosion research setting kinetics of corrosion processes, as well as an analysis of the microstructure of the alloy after the crystallization and after forming. The structure was examined using light microscopy and scanning electron microscopy and X-ray microanalysis with EDS chemical composition of the corrosion products. The test results revealed that plastic deformation during extrusion of intermetallic alloy led to structural changes, the effect of which was to improve the heat resistance at a temperature of 1100°C.

Keywords: corrosion resistance, plastic deformation, alloys intermetallic phase matrix FeAl, Al_2O_3, extrusion

1. Introduction

Currently, construction materials is one of the most widely analyzed and constantly growing group of the engineering materials. The implementation of new materials into industrial practice allows to build more durable and reliable machine parts and equipment, among other things, adapted to operate at high temperature and other special conditions [1]. One of the widely developing materials is based alloys intermetallic phases. Among these alloys, the iron – aluminum alloys are particularly of interesting [2]. The alloys based on intermetallic phase matrix FeAl are often investigated due to its particular utility properties. They have many advantages, among which we can distinguish low density, relatively low price of raw materials, and good resistance to oxidation. However, these alloys have also disadvantages. The largest of these is the lack of ductility at ambient temperature. Attempts have been made to eliminate these disadvantages, because of the promising possibility of using these materials [3]. The research conducted to improve the properties of plastic alloys of the Fe-Al were oriented towards the implementation of the alloy base macro- and microadditions and selection of optimal parameters of heat treatment and also for the preparation of material for the further mold of plastic deformation [4-6]. In order to improve the ductility and fracture toughness these alloys are subjected to plastic deformation processes to give a fine-grained size structure. Plastic deformation causes partial removal of casting defects such emptiness, shrinkage, dendrites [7,8]. The application of too high temperature in the processing of plastic does not allow a fine-grained microstructure and desired mechanical properties. Therefore, it should be performed with the use of mechanical working processes, characterized by a low speed deformation – rolling or extrusion at elevated temperature [9,10]. The alloys based on intermetallic phase matrix FeAl are characterized by very good resistance to high-temperature corrosion, and also good corrosion resistance in both oxidizing atmosphere to a carburization and sulfur-containing compounds [11]. Construction materials, which are covered with outer layers of intermetallic phases of FeAl, have a much higher utility properties [12]. This work was carried out as a comparative study of heat resistance intermetallic alloy Fe40Al5Cr0.2TiB in the state after crystallization and after plastic deformation.

2. Materials and Experimental procedure

Material used in the research consisted of Fe40Al5Cr0.2TiB alloy samples after crystallization and after extrusion process. The chemical composition of the alloy is shown in Table 1. Plastically formed material was obtained by extrusion method by own authorship that is patent protected [13]. This method is non-compliance in other technological solutions. Plastic deformation by extrusion method was carried out at 1100°C. Diameter charge was 18 mm, and after forming obtained material with a diameter of 12 mm. Plunger speed during the extrusion was 5 mm • s–1. There is no information in the literature to obtain

* SILESIAN UNIVERSITY OF TECHNOLOGY, DEPARTMENT OF MATERIALS ENGINEERING AND METALLURGY, 8 KRASIŃSKIEGO STR., 40-019 KATOWICE, POLAND

Corresponding author: dorota.pasek@polsl.pl

a material having such a large degree of plastic processing.Alloy microstructure based on intermetallic phase FeAl before corrosion tests was analyzed by light microscope OLYMPUS GX51. The tests were made for both samples after crystallization and after extrusion process. The kinetics of corrosion was determined for the temperature of 1100°C for up to 500 h. Corrosion tests were carried out in air environment. The kinetics of corrosion was determined by discontinuous. For each sample the weight before and after the corrosion test was checked on laboratory weight accuracy 10^{-4}g. Determination of the corrosion surface was carried out on a scanning electron microscope equipped with a Hitachi S4200 ray detector EDS (Energy Dispersive Spectroscopy).

TABLE 1

Chemical composition of the Fe40Al5Cr0.2TiB alloy

Fe40Al5Cr0.2TiB	**Content of elements [% mass.]**				
element	Fe	Al	Cr	Ti	B
% mas.	68,21	23,66	5,77	0,15	0,015

3. Results

The course of the kinetics of corrosion processes intermetallic alloy Fe40Al4Cr0.2TiB leads to the conclusion that this material has a very good corrosion resistance when compared to other metallic materials for high temperature operation. Plastic processing improves heat resistance to a greater degree than other metallic materials, due to the fact that the intermetallic alloy Fe40Al5Cr0.2TiB after casting has a lot of casting defects, which include: shrinkage, dendrites, the heterogeneity of the chemical composition and the graininess of the material (Fig. 1). These characteristics cause substantial limitation of the practical application of the intermetallic alloys FeAl in the state after crystallization. Plastic deformation alloy matrix intermetallic FeAl largely removes casting defects (Fig. 2). The microstructure of the alloy after forming the grains has a more regular shape than the control samples after crystallization. A desired feature, however, is the grain size which is much smaller than in the case of alloys after crystallization. Changes in the microstructure of the alloy matrix FeAl, along with a change in temperature and the amount of deformation are mapping changes in its mechanical properties. In order to compare the mechanical properties of the tested alloy in tension performed a static test. The tests were performed on the Zwick machine type: BT1 – FR100THW.AZK at room temperature. As a result of the static tensile test for a sample after the crystallization is not obtained yield strength due to embrittlement of the material. In the case of a sample value obtained after extrusion of the yield strength of about 475 MPa and a higher tensile strength compared to the sample after the crystallization. The test results are shown in Table 2. The tests breakthroughs alloy based on intermetallic phase Fe40Al5Cr0.2TiB crystallization, and after plastic deformation (extrusion) made on scanning electron microscope (SEM). Breakthrough sample after crystallization is characterized by cracks in the interdendritic space and has a character of intergranular fracture. Breakthroughs samples after plastic deformation cracks characterized transcrystalline flaky fracture with small areas of the turn ductile (Fig. 3a,b). Grain refinement and the removal of shrinkage and voids caused a significant increase in strength properties as well as strength in relation to the state after homogenization, and improving corrosion resistance.

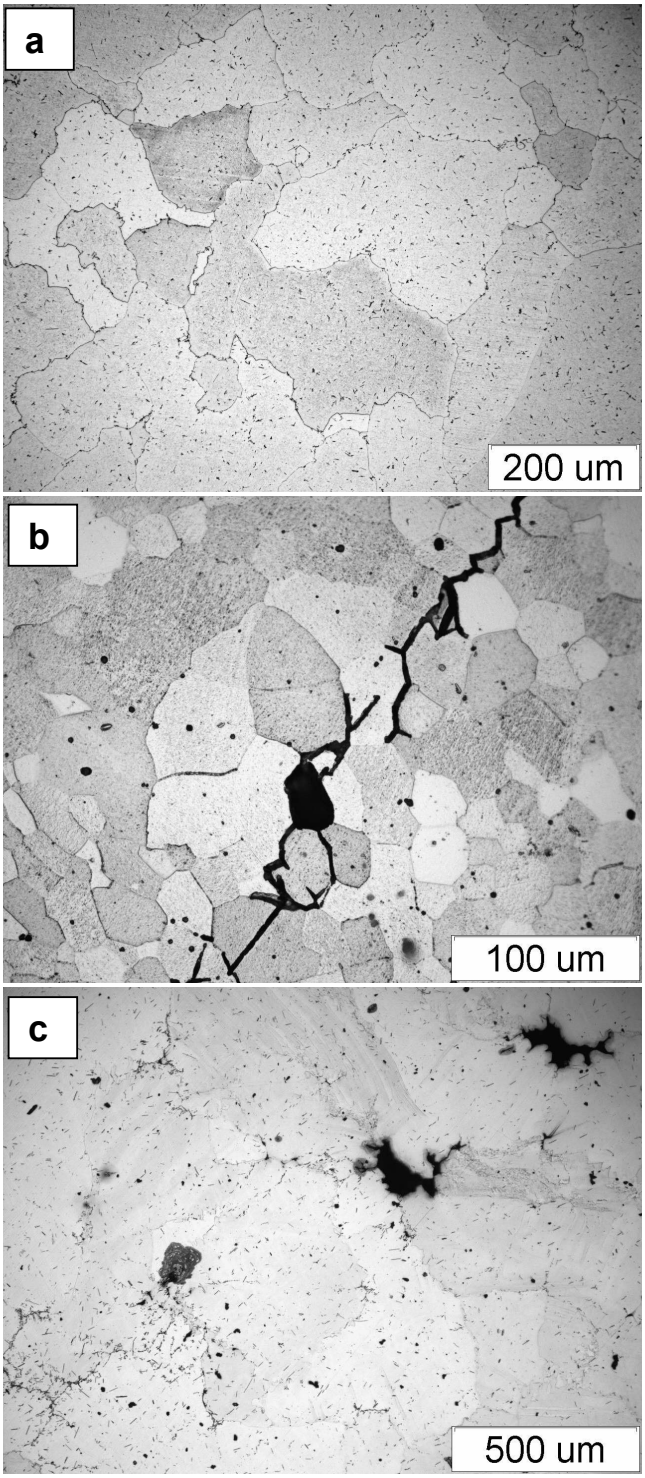


Fig. 1. Microstructure of the Fe40Al5Cr0.2TiB alloy after crystallization: a) graininess of the material, b) cracks, c) shrinkage

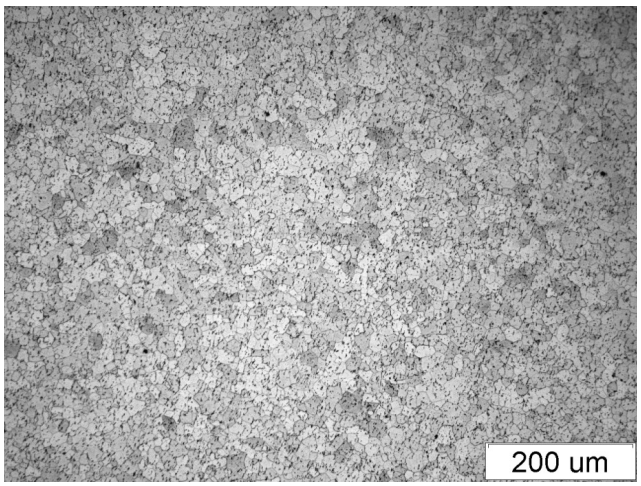


Fig. 2. Microstructure of the Fe40Al5Cr0.2TiB alloy after plastic deformation

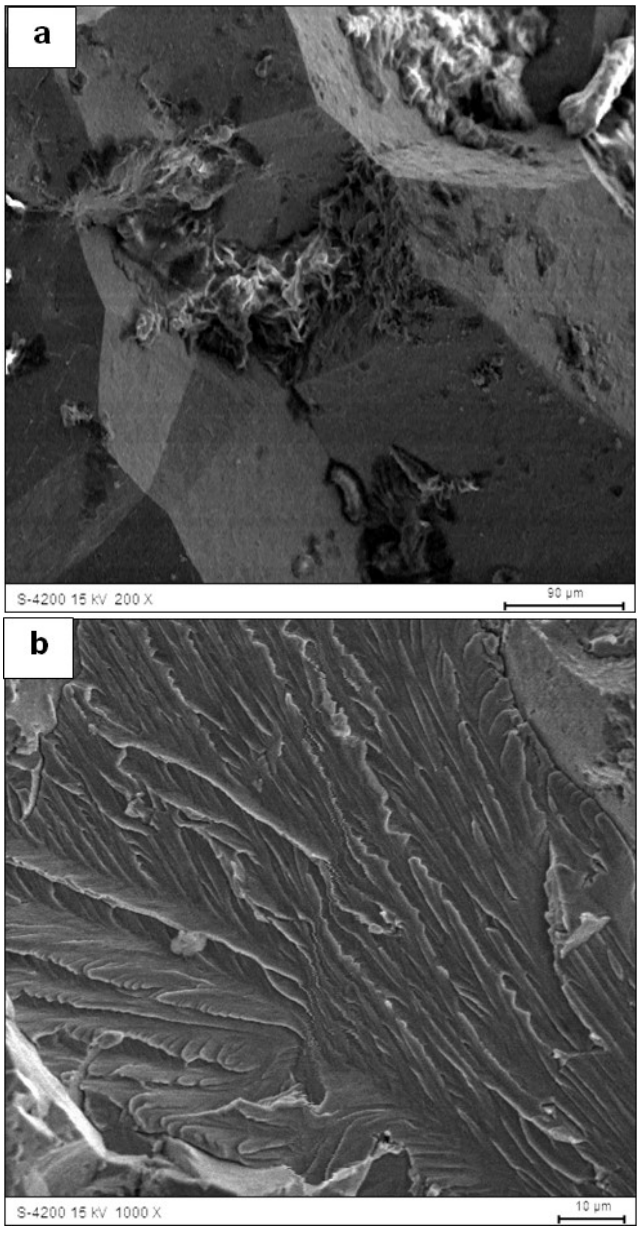


Fig. 3. Surface fracture alloy Fe40Al5Cr0.2TiB: a) after crystallization, b) after extrusion

TABLE 2

The results of the static tensile test

Sample	R_m, MPa	$R_{0,2}$, MPa
after crystallization	458	undefined
after extrusion	510	470

Observations of the samples surface made by a scanning electron microscope revealed that the surface areas were aluminum-containing oxides. The presence of Al_2O_3 passive layers gave FeAl alloys very good heat resistance in an oxidizing environment [14]. The occurrence of heat-resistant layer of Al_2O_3, which tightly isolates the rest of the material of oxygen provides the materials high heat resistance (Figs. 4,5). The EDS X-ray microanalysis of chemical composition of FeAl samples shows that in the oxidation process corrosion products are formed mainly containing Al compounds, resulting in a loss of aluminum from the surface of the material (Figs. 6,7). The effect grain refiner the microstructure as a result of plastic deformation of intermetallic alloy Fe40Al5Cr0.2TiB is particularly important.

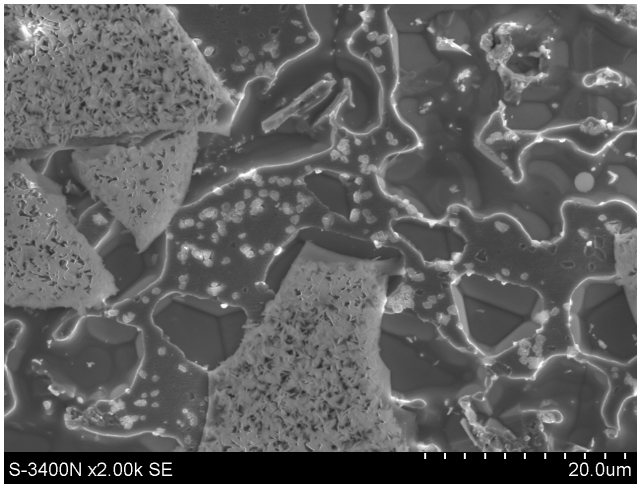


Fig. 4. The surface condition of the alloy Fe40Al5Cr0.2TiB the corrosion tests for 500 hours at 1100°C in the state after crystallization

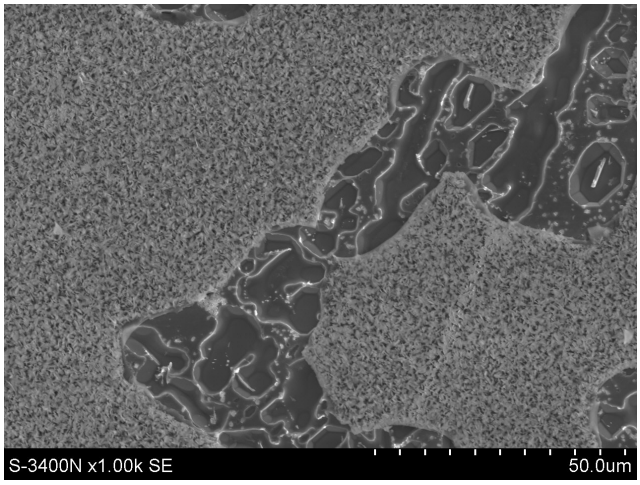
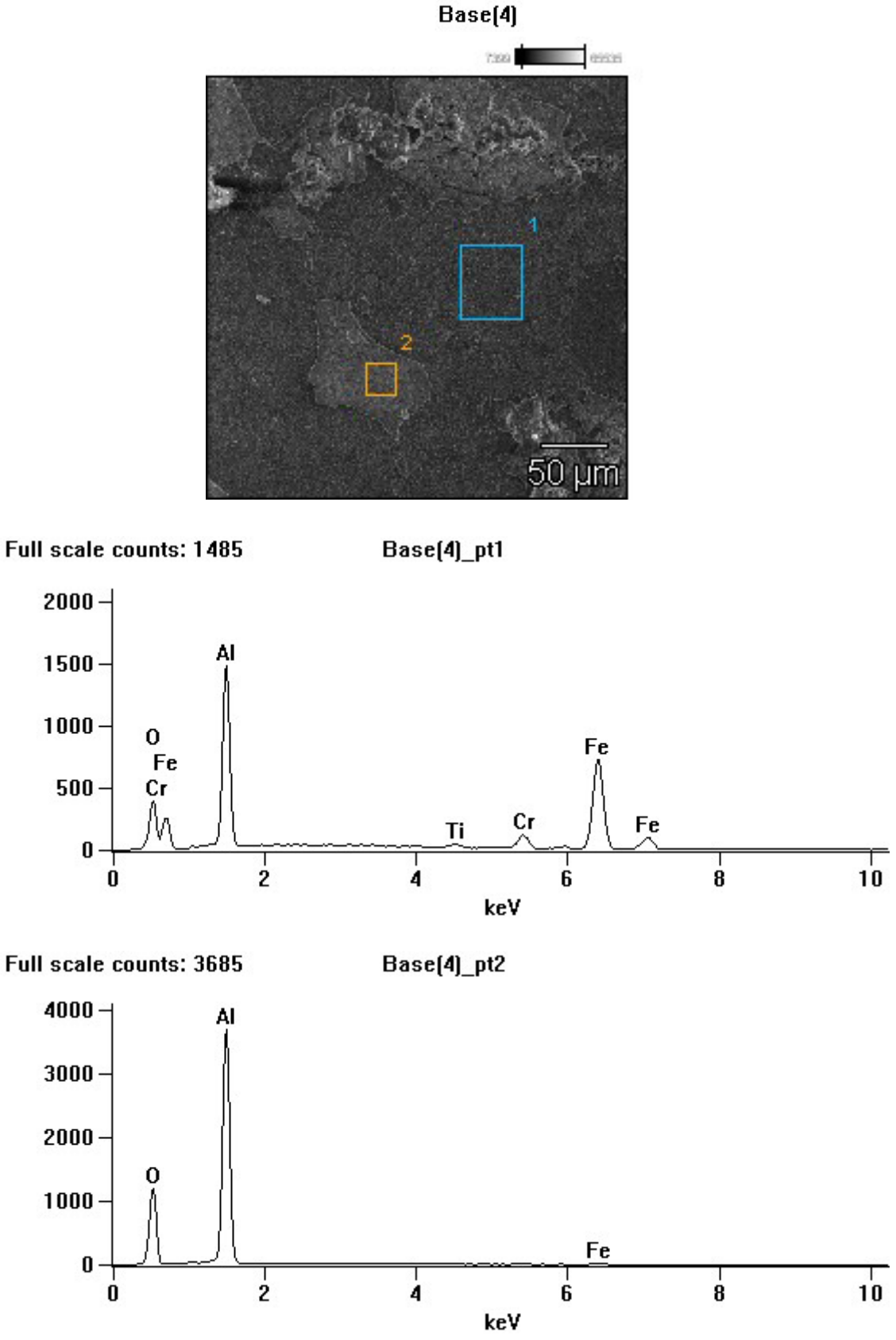
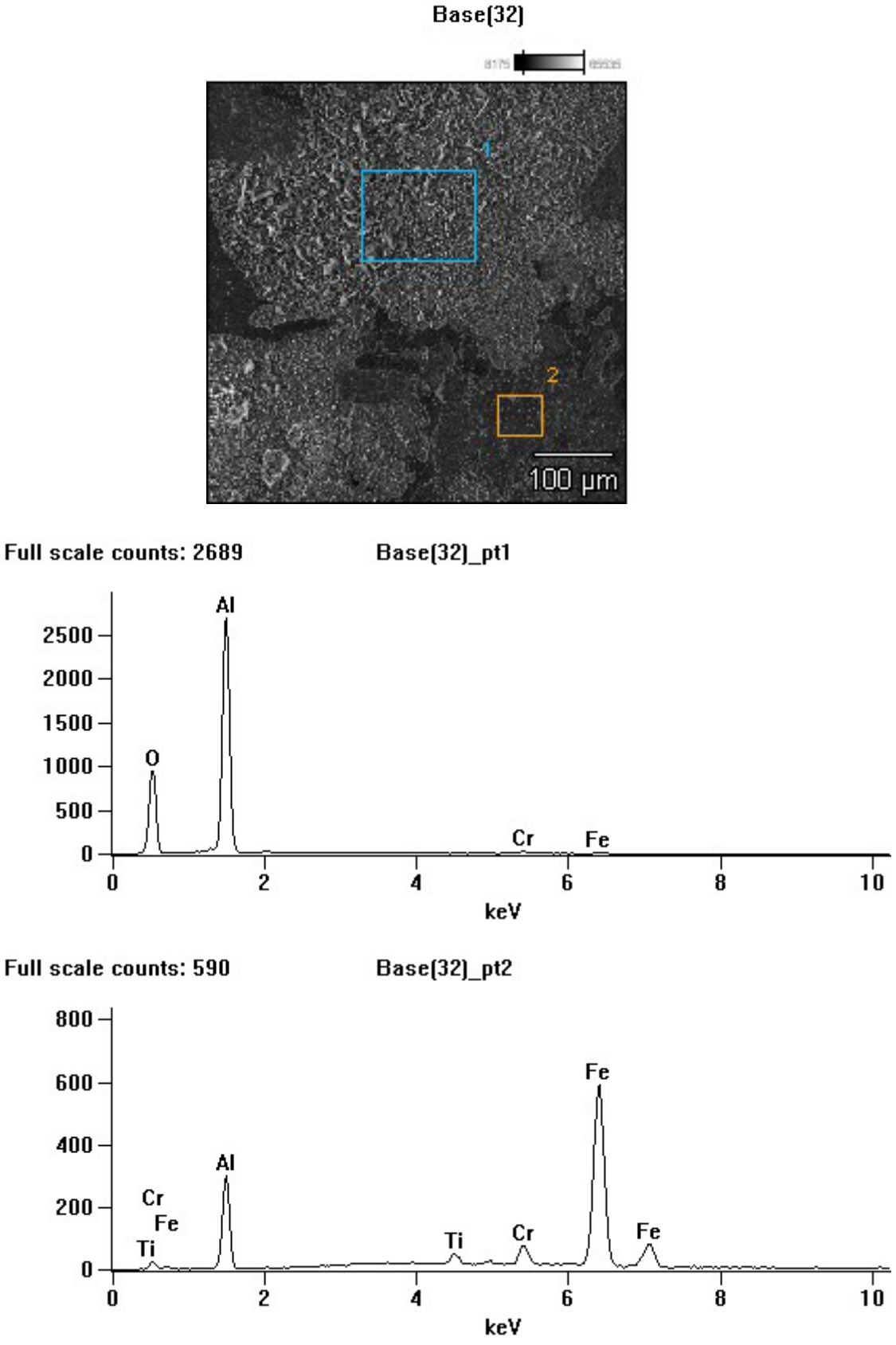


Fig. 5. The surface condition of the alloy Fe40Al5Cr0.2TiB the corrosion tests for 500 hours at 1100°C in the state after plastic deformation



Weight %	***O***	***Al***	***Ti***	***Cr***	***Fe***
Base(4)_pt1	9.6	24.5	0.6	4.8	60.6
Base(4)_pt2	48.1	50.0	-	-	1.9

Fig. 6. Microanalysis of chemical composition of Fe40Al5Cr0.2TiB alloy after crystallization and corrosion test



Weight %	***O***	***Al***	***Ti***	***Cr***	***Fe***
Base(32)_pt1	44.7	51.7		1.6	2.0
Base(32)_pt2		9.9	1.7	4.4	84.0

Fig. 7. Microanalysis of chemical composition of Fe40Al5Cr0.2TiB alloy after plastic deformation and corrosion test

The microstructure of the alloy FeAl reworked visually is much finer than the alloy after casting. Sectional area of the flat is ten times smaller than the grains after crystallization. The kinetics of corrosion processes (based on mass change of samples) was determined by measuring the weight after oxidation at certain intervals according to (Eq. 1), [15]:

$$\left(\frac{\Delta m}{S_T}\right)^2 = k_p + C \qquad (1)$$

where: Δm – sample weight change, S_T – the sample surface at the process, k_p – parabolic oxidation rate constant, C – constant of integration, we take C = 0

Adopted integration constant = 0 due to the simplified calculation model. In fact, this value is C ≠ 0 due to various phenomena occur, such as dissolution of the gas in the metal, nucleation. The improvement in the corrosion resistance for the samples after extrusion in comparison to the samples after crystallization was obtained. The course of the oxidation kinetics are shown in (Fig. 8). In both cases the samples after crystallization and samples after extrusion has been a small increase in mass in the subsequent intervals. The process is a parabolic. The weight gain is associated with the formation of the melt surface corrosion products in the form of a passive oxide Al_2O_3, which form a tightly adherent layer impede the spinal oxygen transport. Long times of the samples to withstand the oxidizing environment, are associated with a phenomenon where build up on the surface of the oxide layer and the peeling of and creation. This process is related to diffusion of aluminum and loss, which can lead to changes in the chemical composition of the base metal and the loss of its properties.

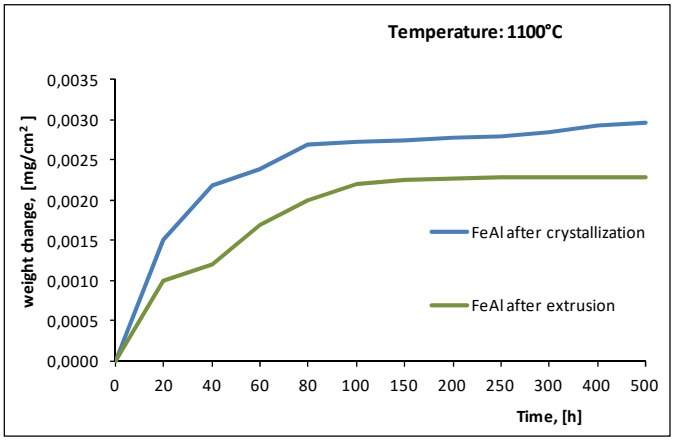


Fig. 8. Kinetics of corrosion of alloy Fe40Al5Cr0.2TiB after crystallization and after extrusion

4. Conclusions

Research and analysis of the results lead to the conclusion that the test materials show different high temperature corrosion resistance. Alloy based on intermetallic phase FeAl after crystallization has a coarse microstructure. Plastic deformation during extrusion process causes fragmentation of the microstructure and improving corrosion resistance. 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 and intermetallic alloy Fe40Al5Cr0.2TiB after forming has a higher heat resistance than the cast state. This is due to the fact that the crystallization of the alloy has a plurality of casting defects such as voids, shrinkage porosity, dendrites, and the heterogeneous microstructure coarse. The good corrosion resistance of the alloy Fe40Al5Cr0.2TiB provide a passive layer of Al_2O_3 is formed on its surface.

REFERENCES

[1] S. Jóźwiak, Aluminki żelaza. Sekwencja przemian fazowych w procesie nieizotermicznego spiekania proszków żelaza i aluminium, 2014 BEL Studio, Warszawa.
[2] S. Dymek, Hutnik – Wiadomości Hutnicze **6**, 220-222 (1998).
[3] Z. Bojar, W. Przetakiewicz, Materiały metalowe z udziałem faz międzymetalicznych, 2006 BEL Studio, Warszawa.
[4] J. Xia, C.X. Li, H. Dong, Wear **258**, 1804-1812 (2005).
[5] B. Szczucka-Lasota, B. Formanek, J. Mater. Process. Tech. **164**, 935-939 (2005).
[6] T. Śleboda, J. Krawczyk, M. Madej, M. Paćko, Arch. of Metall. Mater. **54** (4), 1231-1237 (2009).
[7] J. Barcik, N. Nieśpiałowski, M. Prewendowski, Hutnik – Wiadomości hutnicze, **11**, 548-555 (2004).
[8] M. Palm, G. Sauthoff, Intermetallics **12**, 1345-1359 (2004).
[9] W. Szkliniarz, E. Hadasik, T. Mikuszewski, Inż. Mat. **6**, 844-848 (2004).
[10] D.G. Morris, I. Gutierrez-Urrutia, M.A. Munoz-Moriis, J. Mater. Sci. **43**, 7438-7444 (2008).
[11] K. Kulak, M. Kupka, Inż. Mat. **4**, 514-518 (2011).
[12] M. Kupka, Struktura i właściwości stopów na osnowie fazy FeAl otrzymywanych w procesach metalurgicznych, 2005 Wydawnictwo Uniwersytetu Śląskiego, Katowice.
[13] J. Cebulski, K. Tytko, Przeróbka plastyczna metodą wyciskania zwłaszcza stopów na osnowie fazy międzymetalicznej FeAl, Patent nr 208310, decyzja Urzędu Patentowego Rzeczypospolitej Polskiej z dnia 26.11.2010.
[14] H.J. Grabke, Intermetallics **7**, 1153-1158 (1999).
[15] S. Mrowec, Kinetyka i mechanizm utleniania metali, 1982 Wyd. Śląsk, Katowice.