www.czasopisma.pan.pl PAN www.journals.pan.pl

Arch. Metall. Mater. **63** (2018), 3, 1423-1427

DOI: 10.24425/123821

J. CEBULSKI*[#], D. PASEK*

# THE USE OF PLASTIC WORKING ALLOYS FeAl TO PERFORM CONTROLS ELEMENTS OF TURBOCHARGER IN DIESEL ENGINE

Operating conditions turbocharger (high temperature and corrosive environment) mean that the device is classified into one of the most elements of the emergency drive unit of the car. The failure rate can be reduced through the use of modern heat-resistant materials, which include based alloys FeAl intermetallic phase. Intermetallic alloys belong to the group of materials known as prospective due to their advantageous properties, in particular their high specific strength, high melting point and good resistance to corrosion and oxidation at high temperatures. In the article presented results of the research axis roll control system variable geometry blades made of intermetallic alloy Fe40Al5Cr0,2TiB as a substitute so far made of austenitic steel. A verification service conditions, comparing the degradation of the material previously used by manufacturers of turbochargers for elements of the control system degradation axes made of intermetallic alloy Fe40Al5Cr0,2TiB. The study consisted of determining microstructure and corrosion products after use. Observations of the structure and the surface of the corrosion tests were performed using light microscopy, scanning electron microscopy and X-ray microanalysis EDS chemical composition.

*Keywords:* FeAl, turbocharger, intermetallic alloys, heat resistance, material structure

## 1. Introduction

At present turbochargers are commonly used in motorcar combustion engines as they improve engine operating parameters, in particular torque characteristics, efficiency and they reduce impurities in exhaust gas [1]. They are composed of a turbine propelled on the exhaust gas side and a compressor, mounted on a joint shaft. The rotating unit constitutes the main element of its structure which is kept in the central body by use of slide bearings. Temperature increase occurs mainly at high engine loads, which has impact upon reducing the turbocharger's life [2,3]. The temperature of exhaust gas from a compression ignition engine is about 700°C, while for spark ignition engines it can be more than 1000°C [4]. Due to high exhaust gas temperature and frequent pressure changes as well as high rotational speed reaching 200 000 rpm the elements of the hot part get degraded more quickly [5,6]. Apart from high temperature, another element of the environment that causes wear and destruction of a turbocharger is exhaust gas which includes e.g. nitrogen oxides, carbon and sulphur oxides as well as aldehydes and hydrocarbons. Therefore, selecting appropriate materials for particular parts of a turbocharger, which are characterised by high heat resistance as well as abrasion and corrosion resistance is important [7]. Based on the results of carried out works concerning the selection of materials and appropriate technological processes it has been shown that alloys based on the matrix of iron, nickel and titanium compounds with aluminium can create a new group of structural compounds with special mechanical properties and stable structure at high temperature [8,9]. The materials that meet these requirements are e.g. alloys based on the matrix of the intermetallic phase of FeAl containing from 36% to 51% of aluminium atoms, which have stable properties within a broad range of temperatures [10]. They are also characterised by high corrosion resistance as compared with traditional structural materials, resistance to aggressive environment, sea water, carburizing, the effects of sulphur and very good tribological properties at higher temperatures [11,12]. A large number of defects of metallurgic origin is a factor that makes it significantly more difficult to use the casts as materials for making finished structural elements. Plastic working of the FeAl intermetallic alloy results in significant improvement of mechanical properties and high-temperature corrosion resistance. This work presents the results of tests on axles of rollers in the variable vane geometry control system, with the vanes made of intermetallic alloy Fe40Al5Cr0.2TiB, which were installed in a turbocharger and tested at the distance of 80 thousand km. Theoretical analyses were verified in operating conditions by comparing the wear and deterioration of the roller axles in the engine filling pressure control system, made of the Fe40Al5Cr0.2TiB intermetallic alloy, with the level of wear of the material used for roller axles by turbocharger manufacturers.

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

[#] Corresponding author: janusz.cebulski@polsl.pl

## 2. Materials and experimental procedure

The material for the tests was an alloy on the FeAl intermetallic phase matrix. What hinders commercial application of those alloys is their low plasticity after crystallisation and tendency to brittle cracking, particularly at low temperature. The above properties are a limitation to formation of elements out of those alloys with use of classic production technologies and thus they preclude the application of intermetallic alloys as structural materials. Further development of alloys based on the FeAl intermetallic phase matrix and their use in the industry depend on improvements to their plasticity and workability [13,14]. Plastic working by use of classic methods (rolling, forging, extrusion) leads to the occurrence of numerous cracks or it is altogether impossible. The elements used for the tests were made of Fe40Al5Cr0.2TiB alloy which was processed by direct extrusion in a way which allows to obtain material without cracks. The possibility of shaping FeAl intermetallic alloys in the plastic working process is particularly important in the aspect of potential practical applications of that material, as the FeAl intermetallic alloy after crystallisation has a much less uniform structure with bigger crystallites, with many defects of metallurgic origin as compared with a great majority of other materials obtained in the casting process. Fig. 1 presents a comparison between the microstructure of the FeAl intermetallic alloy after crystallisation and after plastic working. Plastic working of the FeAl intermetallic alloy is possible in the case of rolling when shields preventing contact between the rolled material and the rollers are used, because otherwise numerous cracks occur in the material (Figs 2,3). A similar situation occurs during classic extrusion of FeAl alloys. It is, however, possible to shape the FeAl intermetallic alloy in a way which does not generate cracks (Fig. 4) by extrusion without the need to use shields which are quite inconvenient to remove. However, the process requires

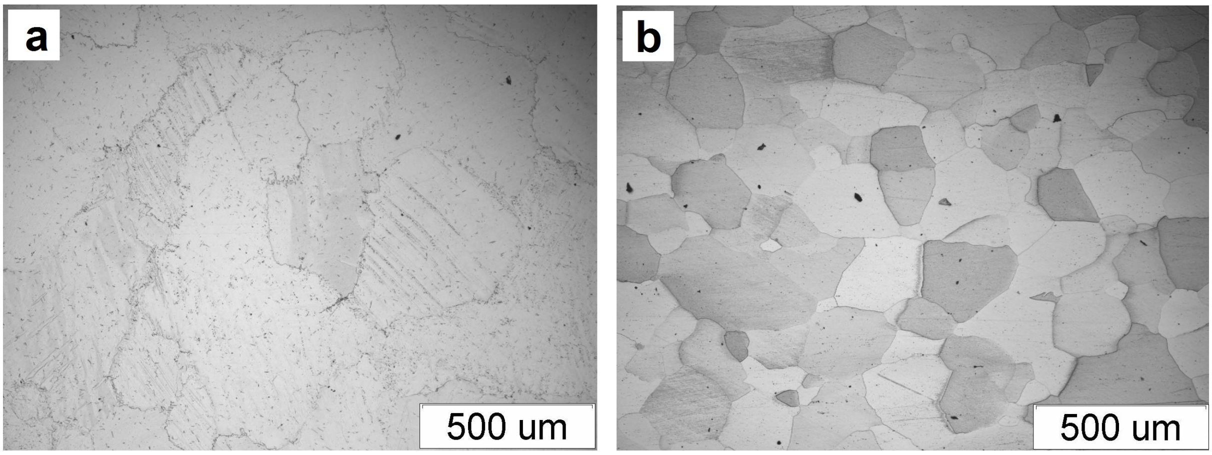


Fig. 1. FeAl intermetallic alloy microstructure after crystallization, and after forming


Fig. 2. FeAl method to shield the alloy during rolling


Fig. 3. Effect alloy FeAl during rolling without shields (1) and using shields (2)


Fig. 4. FeAl alloy effect during extrusion in a conventional manner (1) and using a special method (2)

the application of a technology based on appropriate recipient formation and the application of initial heating of the system in which the extrusion process is carried out [15].

Due to structural changes obtained in plastic working the final material has such plasticity which allows its practical application. After plastic working the material was used to produce rollers for the charging pressure control system in compression-ignition engines [16]. The axle was made in the process of spark machining (Fig. 5). It was tested in a BMW 730d with an M57

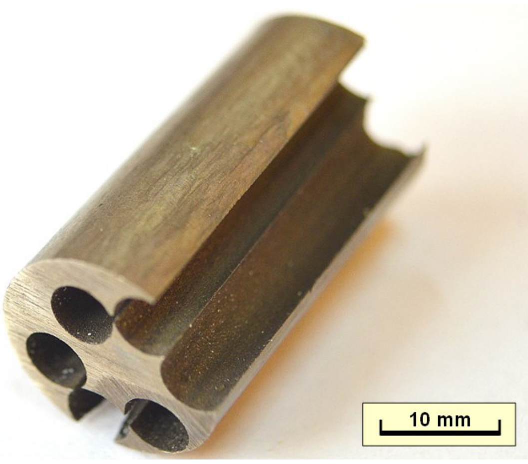


Fig. 5. Method implementation of an axis rolls turbocharger control

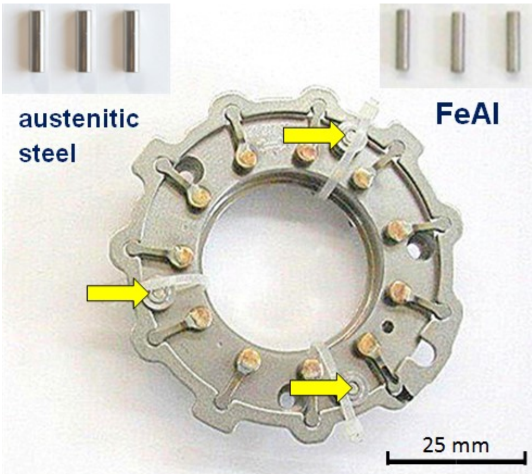


Fig. 6. System variable geometry turbocharger control the area of application axes made of alloy FeAl [16]

engine with a turbocharger, where the FeAl intermetallic alloy was used for the axles of rollers in the variable vane geometry system (Fig. 6). The field tests were carried out at the distance of 80 thousand km. After road tests the supercharger was dismantled and its components were tested in terms of their surface condition by use of a scanning electron microscope. In the tests the focus was on determining the condition of the surface of roller axles in the air pressure control system in the suction manifold of the engine.

## 3. Results of test

Due to the conditions of work of a turbocharger (high temperature, corrosion environment), it is one of the combustion engine components with the highest failure rate. This failure rate can be reduced by using state-of-the-art materials which include alloys based on the FeAl intermetallic phase matrix. The carried out tests of the turbocharger pressure control system roller axles showed that the material used as a substitute for the material that has been used so far, has very good properties which allow us to presume that in this case the probability of failure as a result of seizure of the variable vane geometry system is lower. After comparing the condition of the surface of elements made of FeAl alloys after tests at the distance of 80 thousand km we can say there are no signs of tribological wear.

The tests of roller axle surface after their operation at the distance of 80 thousand km were performed on a scanning electron microscope. On the surface of the rollers small amounts of corrosion products and carbon deposits (compounds derived from motor oil and fuel combustion) were found (Fig. 7). The condition of the surface after corrosion tests was established by use of a HITACHI S4200 scanning electron microscope with an

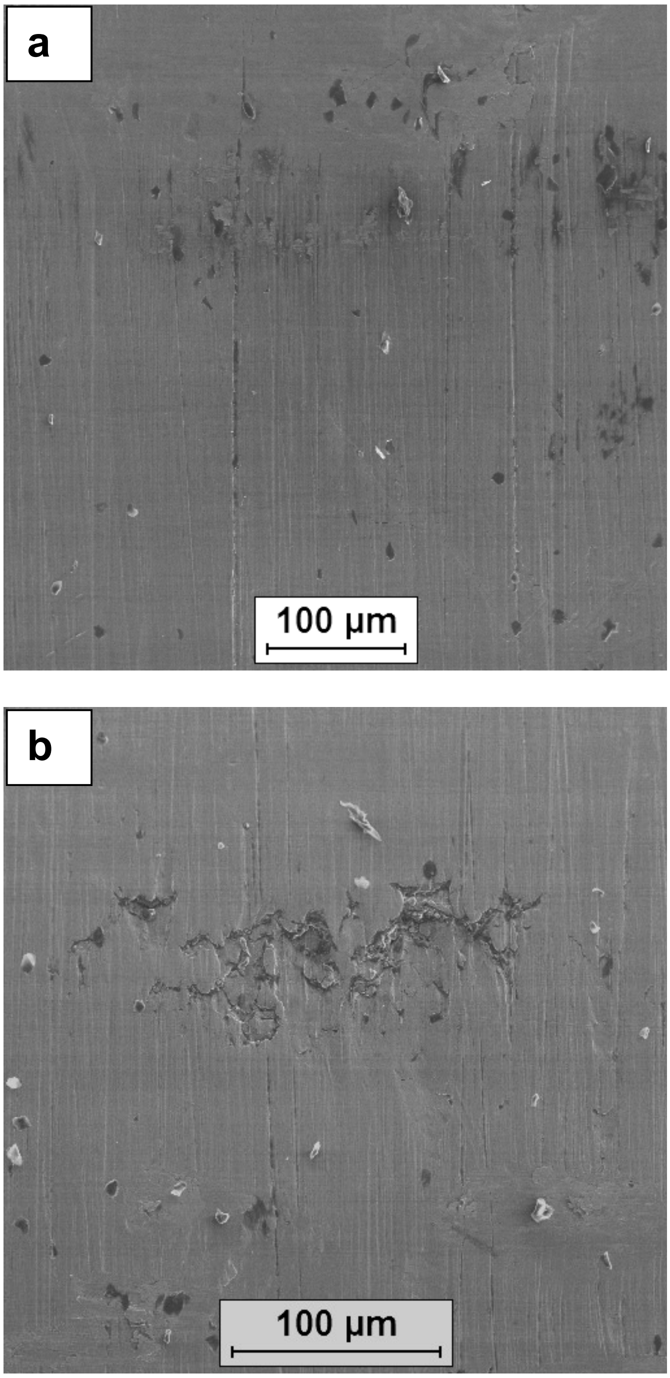


Fig. 7. Surface roll control system pressure turbocharger (SEM) a) visible traces of carbon deposits, b) the surface oxidized

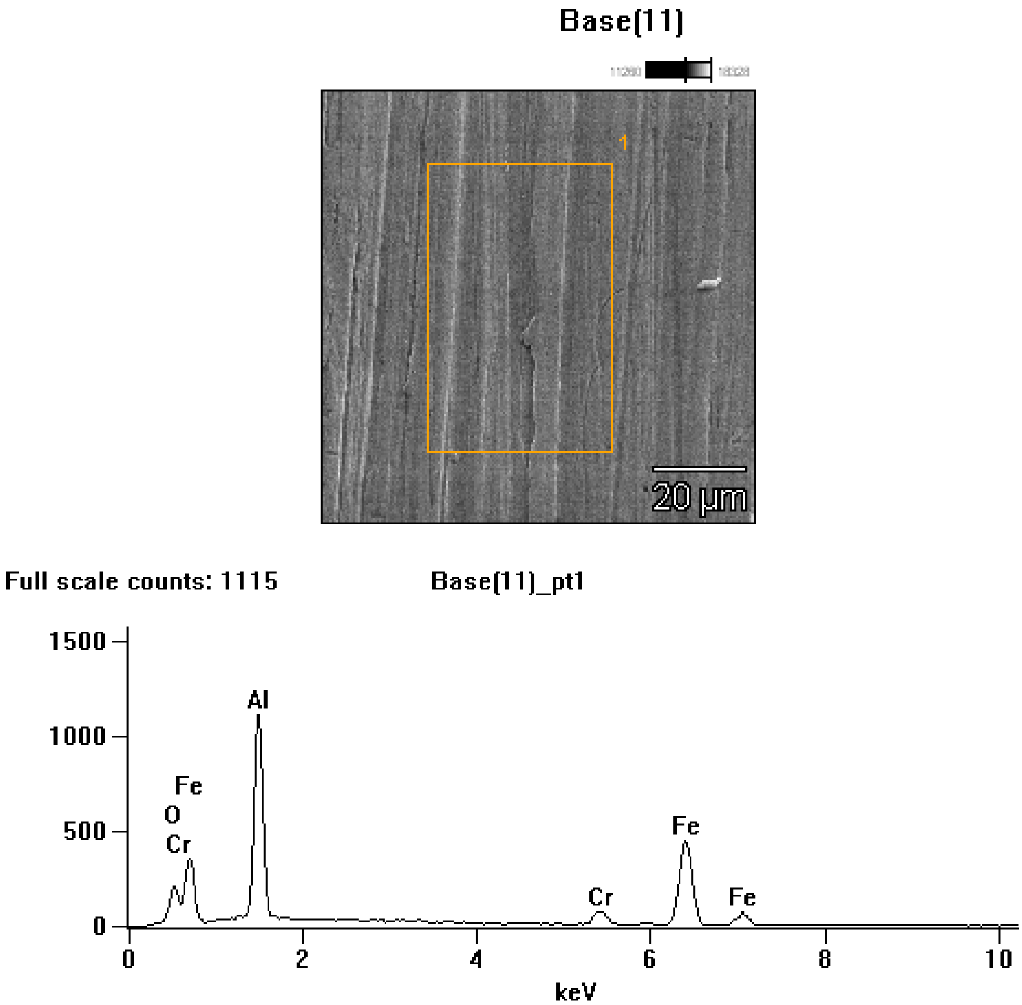


Fig. 8. X-ray microanalysis chemical composition axis of the roller

TABLE 1

Chemical composition after X – ray microanalysis axis of the rolle

| Weight % | Al | Cr | Fe |
|---|---|---|---|
| Base(11)_pt1 | 30.9 | 6.4 | 62.3 |

EDS (Energy Dispersive Spectroscopy) X-ray detector. It was determined that there were areas covered by a layer of $Al_2O_3$ oxides on the surface of the Fe40Al5CrTiB alloy (Fig. 8). The EDS analysis of the chemical composition showed that there were areas on the surface of the roller axles made of the FeAl intermetallic alloy which corresponded in terms of chemical composition with the native material as well as aluminium, oxygen and carbon (Fig. 9).

## 4. Conclusions

Plastic working of the FeAl intermetallic alloy allows us to obtain material of highly reduced number of casting defects, which can have practical application and can be used for the production of structural components of compression-ignition engine turbocharger. Obtaining the material in the plastic working process without the need to use shields is possible by extrusion when appropriate process conditions are maintained. Field tests of a car equipped with a modified turbocharger used at the distance of 80 thousand km showed that the FeAl intermetallic alloy is a material that can be used to make components of the hot part of a turbocharger as a substitute for materials that have been used so far. The operating parameters of the ECU (Engine Control Unit) had the correct value throughout the whole test and the data readouts of the motor supply system were within the correct ranges as defined by the car manufacturer. It has been shown that the FeAl intermetallic alloy meets the requirements of heat-resistant materials when working in corrosion environment, and the level of degradation after field tests is so small that it creates the possibility of potential application of FeAl in turbocharger component production. The obtained results are an inducement to do further research and scientific work on this matter.

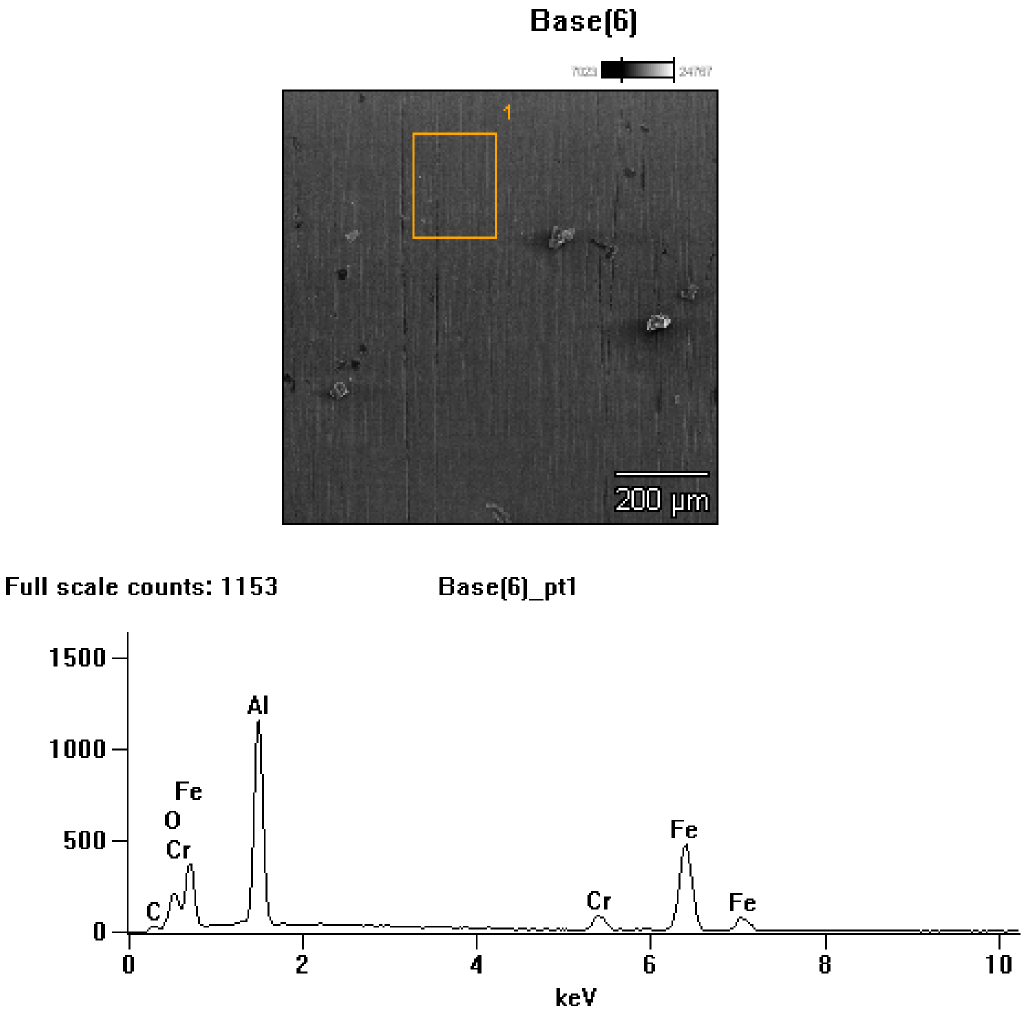


Fig. 9. X-ray microanalysis chemical composition axis of the roller

TABLE 2

Chemical composition after X – ray microanalysis axis of the rolle

| Weight % | Al | Cr | Fe |
|---|---|---|---|
| Base(6)_pt1 | 30.7 | 6.9 | 62.3 |

REFERENCES

[1] K. Jiao, H. Sun, X. Li, H. Wu, E. Krivitzky, T. Schram, L.M. Larosiliere, Appl. Energ. **86**, 2494-2506 (2009).
[2] B. Schweizer, M. Sievert, J. Sound Vib. **321**, 955-975 (2009).
[3] M. Deligant, P. Podevin, T. Lamquin, F. Vidal, A. Marchal, Proceedings of the ASME 2010 Internal Combustion Engine Division Fall Technical Conference, 1-8 (2010).
[4] J.W. Chen, Mech. Syst. Signal Pr. **29**, 77-89 (2012).
[5] T. Tetsui, Mat. Sci. Eng. **A 329-331**, 582-588 (2002).
[6] B.A. Pint, J.A. Haynes, B.L. Armstrong, Surf. Coat. Tech. **215**, 90-95 (2013).
[7] E. Rymaszewski, Nowoczesny warsztat **7-8**, (2011).
[8] N. Masahashi, G. Kimura, M. Oku, K. Komatsu, S. Watanabe, S. Hanada, Corros. Sci. **48**, 829-839 (2006).
[9] S.C. Deevi, V.K. Sikka, Intermetallics **4**, 357-375 (1996).
[10] J. Bystrzycki, R.A. Varin, Mat. Sci. Eng. **A 270**, 151-161 (1999).
[11] R. Jasionowski, W. Przetakiewicz, D. Zasada, Archives of Foundry Engineering **11**, 97-102 (2011).
[12] J. Grabian, K. Gawdzińska, B. Głowacki, Archiwum Technologii Maszyn i Automatyzacji **24**, (2004).
[13] J. Barcik, N. Nieśpiałowski, M. Prewendowski, Hutnik – Wiadomości hutnicze **11**, 548-555 (2004).
[14] D.G. Morris, I. Gutierrez-Urrutia, M.A. Munoz-Moriis, J. Mater. Sci. **43**, 7438-7444 (2008).
[15] J. Cebulski, K. Tytko, 2010, Przeróbka plastyczna metodą wyciskania zwłaszcza stopów na osnowie fazy międzymetalicznej FeAl, Patent nr 208310, decyzja Urzędu Patentowego Rzeczypospolitej Polskiej z dnia 26.11.2010 r.
[16] H.J. Grabke, Oxidation of NiAl and FeAl, Intermetallics **7**, 1153-1158 (1999).