Archives of Materials Science and Engineering

Volume 30
Issue 2
April 2008
Pages 81-84

International Scientific Journal
published monthly by the
World Academy of Materials
and Manufacturing Engineering

# Ordering process of Fe28Al and Fe28Al5Cr alloys

**L. Pająk [a,*], J. Kansy [a], A. Hanc [a], G. Dercz [a], M. Jabłońska [b]**

[a] Institute of Materials Science, University of Silesia,
ul. Bankowa 12, 40-007 Katowice, Poland
[b] Institute of Materials Science, Silesian University of Technology,
ul. Krasińskiego 8, 40-019 Katowice, Poland
* Corresponding author: E-mail address: lpajak@us.edu.pl

Received 30.01.2008; published in revised form 01.04.2008

**ABSTRACT**

**Purpose:** The comparison of ordering process in Fe28Al and Fe28Al5Cr alloys annealed for 8, 16 and 48 hours at 1000°C was performed. The composition of studied alloys is closed to one of $Fe_3Al$ phase.

**Design/methodology/approach:** The studied alloys were melted in induction furnace under vacuum. Next the alloys were gravitatively casted into cylindrical graphite moulds. The alloy samples were annealed at 1000°C for 8, 16 and 48 hours. The ordering process was analyzed by X-ray diffraction, Mössbauer spectroscopy and positron annihilation methods.

**Findings:** Different behaviour of Fe28Al and Fe28Al5Cr alloys during annealing for 8, 16 and 48 hours at 1000°C was found. The $Fe_3Al$ phase of $DO_3$ type structure was stated only in the sample of Fe28Al alloy annealed for 48 hours. The FeAl phase appeared to be the main phase in the other samples.

**Research limitations/implications:** The applied investigation methods appeared to be useful in the studies of long range ordering process. Application of Rietveld refinement method enabled the verification of qualitative phase analysis and the determination of lattice constant parameters. Relatively great grain sizes in studied samples made the exact determination of long range ordering parameters difficult.

**Practical implications:** The information on the phase transformation during the heat treatment of alloys, including long range ordering, are of prime importance for technological processing. The structures with long range ordering significantly affect the properties of alloys with intermetallic phases.

**Originality/value:** Good correlation between the results of X-ray diffraction, Mōssbauer spectroscopy and positron annihilation methods were obtained. Addition of chromium made the long range ordering process slower.

**Keywords: Metallic alloys; X-ray phase analysis; Iron aluminides; Long range ordering; Rietveld refinement; Mössbauer spectroscopy**

**MATERIALS**

## 1. Introduction

Alloys with intermetallic phases are intensively studied now. Iron aluminides are an interesting class of materials. They offer a good combination of mechanical properties, good weight/strength ratio, corrosion resistance and relatively low material cost. It makes the alloys based on iron aluminides potential candidates for the substitution of stainless steels in application at moderate to high temperature. Technical application of these alloys is restricted by poor ductility at low temperatures [1-4]. The possibilities of overcoming this restriction by introduction of additional alloy components are intensively studied [5-9].

The aim of the present paper is the analysis of chromium addition on the ordering process of Fe28Al alloy. The Rietveld

refinement method appeared to be very useful in the microstructure characterization of different materials with metallic and ceramic phases [10-19]. During Rietveld analysis a whole diffraction pattern is employed. Mössbauer spectroscopy was also applied to gain further insights into the structural evolution of the local environment around the iron atoms. Positron annihilation was used for the determination of vacancy concentration.

## 2. Materials and experiment

The studied alloys of nominal composition presented in Table 1 were prepared using the gravity casting technique. Melts were produced in induction furnace under a pressure of 1.0 MPa. Melted charge was homogenized and casted into graphite moulds. Such process was repeated three times with a mechanical cleaning between operations. As a result, the ingots in the form of rods were obtained with dimensions of Ø = 12 mm and l = 120 mm. The alloy samples were annealed for 8, 16 and 48 hours at 1000°C and cooled with furnace.

Table 1.
Chemical composition of studied alloys (at%)

| | Al | Mo | Cr | Zr | C | B | Fe |
|---|---|---|---|---|---|---|---|
| Fe28Al | 28.0 | 0.20 | - | 0.05 | 0.1 | 0.01 | 71.6 |
| Fe28Al5Cr | 28.0 | 0.20 | 5.0- | 0.05 | 0.1 | 0.01 | 66.6 |

X-ray diffraction patterns were collected using X-ray Philips diffractometer equipped with graphite monochromator on diffracted beam. The copper radiation was applied. During X-ray data collection the samples were rotated. Investigations of local Fe configurations formed in the studied materials were carried out by Mössbauer spectroscopy. The measurements of the $^{57}$Fe Mössbauer spectra were performed in transmission geometry by means of a constant spectrometer of the standard design. The 14.4 keV gamma rays were provided by a 50 mCi source of $^{57}$Co/Rh. The spectra of the samples were measured at room temperature. The measurements of positron lifetime were made at room temperature using the conventional fast-fast spectrometer with time resolution of 270 ps for Co-60. The positron source of ~740 kBq activity covered by 5 μm Ni foil was placed between two pieces of the investigated samples.

## 3. Results and discussion

X-ray diffraction patterns for Fe28Al and Fe28Al5Cr alloy samples are presented on Fig. 1 and Fig. 2, respectively.

The presence of $Fe_3Al$ phase ($DO_3$ type structure) is clearly seen for Fe28Al alloy sample annealed for 48h. The FeAl (B2 type structure) phase is the main one of the other samples. Because of relatively great grain size (~115 μm and ~150 μm for Fe28Al and Fe28Al5Cr alloys, respectively) of studied samples the relation between the intensities of corresponding diffraction lines of FeAl and $Fe_3Al$ phases are disturbed. This makes the estimation of the long range order parameter difficult. Lattice constant parameters determined by Rietveld refinement method show the tendency of their decreasing with the increase of annealing time. On Figures 3 and 4 the Rietveld plots with residual curves are presented for samples with main phase of FeAl (B2 type structure) and $Fe_3Al$ ($DO_3$ type structure), respectively.

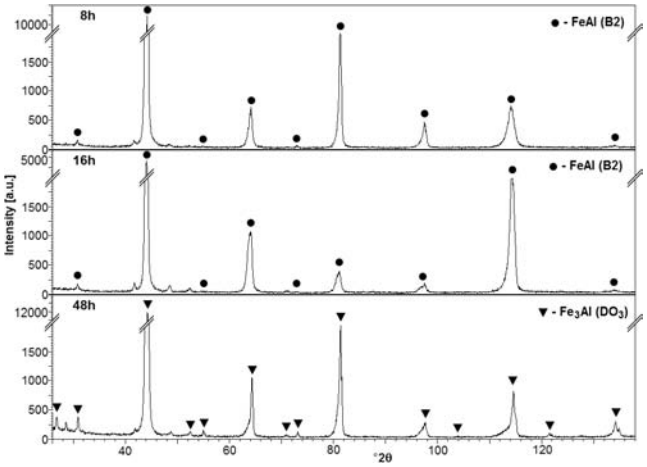


Fig. 1. X-ray diffraction patterns of Fe28Al alloy samples annealed at 1000°C for 8, 16 and 48 hours

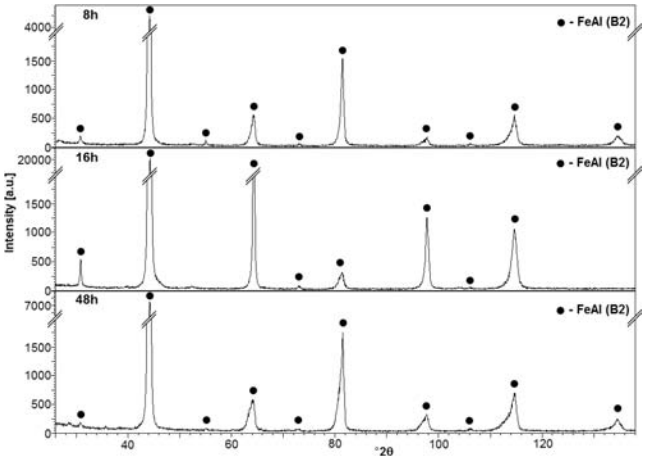


Fig. 2. X-ray diffraction patterns of Fe28Al5Cr alloy samples annealed at 1000°C for 8, 16 and 48 hours

The goodness of fit (GoF) parameter is often used to control the quality of fitting of calculated pattern to the experimental one, and is defined as a ratio of the weighted residual error, $R_{wp}$ to the expected error, $R_{exp}$. $GoF = R_{wp} / R_{exp}$

The best values of GoF parameter obtained for studied samples are of the order of 2.2 what seems to be satisfactory because of relatively great grain size of studied samples.

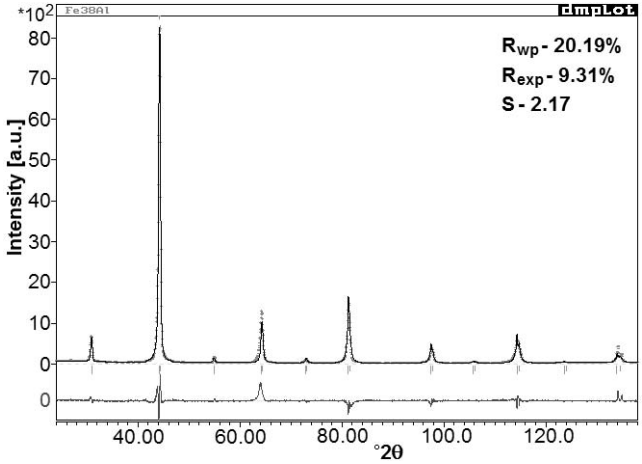


Fig. 3. Rietveld refinement plot for sample with FeAl (B2 type structure) main phase

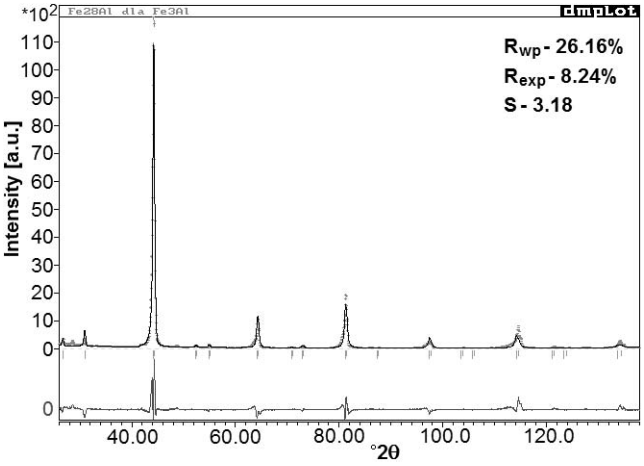


Fig. 4. Rietveld refinement plot for sample with $Fe_3Al$ ($DO_3$ type structure) main phase

Figure 5 presents Mössbauer spectra of the samples annealed for 48h at 1000°C for both studied alloys. These spectra are the superposition of Zeeman sextets indicating the existence of magnetic phases with different degree of atomic ordering. In spectrum of Fe28Al5Cr sample (Fig. 5b) dominate the component corresponding to nonmagnetic phase [20]. Maximum value of hyperfine magnetic field ($B_{hf}$) of $^{57}Fe$ for Fe28Al sample (~300 kGs) corresponds to the configuration of 8 iron atoms in the nearest surroundings of Mössbauer nuclide. This indicate that $Fe_3Al$ phase of $DO_3$ type structure is the main phase of Fe28Al alloy sample annealed for 48h at 1000°C in accordance with X-ray diffraction analysis (Fig. 1). Mössbauer spectrum of Fe28Al5Cr alloy sample (Fig. 5b) is quite different from one of Fe28Al sample (Fig. 5a). Maximum value of $B_{hf}$ is much lower than 300 kGs what exclude $Fe_3Al$ phase to be the main phase of Fe28Al5Cr alloy sample annealed for 48h at 1000°C. Central part of involved spectrum is described by component characteristic of nonmagnetic phase. This phase is FeAl one of B2 type structure according to X-ray diffraction analysis.

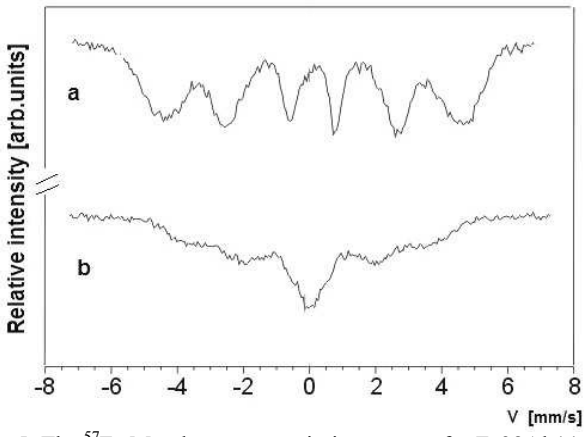


Fig. 5. The $^{57}Fe$ Mössbauer transmission spectra for Fe28Al (a) and Fe28Al5Cr (b) alloys annealed for 48 h at 1000°C

The studies of point defects performed by positron annihilation indicate the presence of monovacancies in iron sublattice. The concentration of monovacancies significantly depends on the chromium addition. The number of vacancies in Fe28Al alloy samples after cooling with furnace is almost twice higher than in Fe28Al5Cr alloy samples after the same heat treatment [20]. Such character of point defect structure can suggest that ordering process during slow cooling is mainly controlled by diffusion mechanism ongoing by vacancy concentration. Low vacancy concentration in samples with chromium probably makes the atomic ordering process slower what can explain the observed difference in final phase composition of Fe28Al and Fe28Al5Cr alloys after the same heat treatment.

## 4. Conclusions

- Comparison of long range ordering process in Fe28Al and Fe28Al5Cr alloys was performed. Good correlation between the results of X-ray diffraction, Mössbauer spectroscopy and positron annihilation methods were obtained.
- $Fe_3Al$ phase of $DO_3$ type structure was found only in Fe28Al alloy sample annealed at 1000°C for 48h. FeAl phase of B2 type structure appeared to be the main phase of the other studied samples.
- Positron annihilation studies indicate lower concentration of vacancies in Fe28Al5Cr alloy samples in comparison with the samples of Fe28Al alloy. It can be the reason of slower long range ordering process in Fe28Al5Cr alloy.

## Acknowledgements

The work was supported by the State Committee of Scientific Research, Grant no. PB-581/T/2006.

## References


[1] S. Kobayashi, S. Zaefferer, A. Schneider, D. Raabe, G. Frommeyer, Optimisation of precipitation for controlling recrystallization of wrought $Fe_3Al$ based alloys, Intermetallics 13 (2005) 1296-1303.

[2] Y.D. Huang, L. Froyen, Recovery, recrystalization and grain growth in $Fe_3Al$ based alloys, Intermetalics 10 (2002) 443-448.

[3] M. Jabłońska, K. Rodak, G. Niewielski, Characterization of the structure of FeAl alloy after hot deformation, Journal of Achievements in Materials and Manufacturing Engineering 18 (2006) 107-110.

[4] D. Kuc, G. Niewielski, M. Jablonska, I. Bednarczyk, Deformability and recrystallisation of Fe-Al intermetallic phase - base alloy, Journal of Achievements in Materials and Manufacturing Engineering 20 (2006) 143-146.

[5] D. Kuc, I. Bednarczyk, G. Niewielski, The influence of deformation on the plasticity and structure of $Fe_3Al$ - 5Cr alloy, Journal of Achievements in Materials and Manufacturing Engineering 22/1 (2007) 27-30.

[6] P. I. Ferreira, A. A. Couto, J. C. C. de Paola, The effects of chromium addition and heat treatment on the microstructure and tensile properties of Fe-24Al (at. %), Materials Science and Engineering A192/193 (1995) 165-169.

[7] J.W. Lee, C.C. Wu, T.F. Liu, The influence of Cr alloying on microstructures of Fe–Al–Mn–Cr alloys, Scripta Materialia 50 (2004) 1389-1393.

[8] A.O Mekhrabov, et al. Effect of ternary alloying elements addition on atomic ordering characteristics of Fe-Al intermetallics, Acta Materialia 47 (1999) 2067-2075.

[9] Y.D. Huang, W.Y. Yang, Z.Q. Sun, Effect of the alloying element chromium on the room temperature ductility of $Fe_3Al$ intermetallics, Intermetallics 9 (2001) 119-124.

[10] A. Chanda, H. Pal, M. De, S. Kajiwara, T. Kikuchi, Charcterisation of microstructure of isothermal martensite formed at low temperature in powder of Fe-23Ni-3.3Mn alloy by Rietveld method, Materials Science and Engineering A265 (1999) 110-116.

[11] A. Chanda, M. De, X-ray characterization of the microstructure of α-CuTi alloys by Rietveld's method, Journal of Alloys and Compounds 313 (2000) 104-114.

[12] L. Pająk, B. Formanek, G. Dercz, Rietveld analysis of intermetallic phases from Ni-Al system, Proceedings of the 11th International Scientific Conference "Achievements in Mechanical and Materials Engineering", AMME`2002, Gliwice – Zakopane, 2002, 405-408.

[13] L. Pająk, B. Formanek, G. Dercz, Dispersion analysis of NiAl-TiC-$Al_2O_3$ composite powder, Proceedings of the 12th International Scientific Conference "Achievements in Mechanical and Materials Engineering", AMME`2003, Gliwice – Zakopane, 2003, 723-726.

[14] G. Dercz, B. Formanek, K. Prusik, L. Pająk, Microstructure of Ni(Cr)-TiC-$Cr_3C_2$-$Cr_7C_3$ composite powder, Proceedings of the 13th Scientific International Conference "Achievements in Mechanical and Materials Engineering", AMME'2005, Gliwice – Wisła, 2005, 99-102.

[15] G. Dercz, K. Prusik, L. Pająk, Sructure investigations of commercial zirconia ceramic powder, Journal of Achievements in Materials and Manufacturing Engineering 18 (2006) 259-262.

[16] R. Nowosielski, R. Babilas, G. Dercz, L. Pająk, Microsructure investigations of Co-Si-B alloy after milling and annealing, Journal of Achievements in Materials and Manufacturing Engineering 23/1 (2007) 59-62.

[17] R. Nowosielski, R. Babilas, G. Dercz, L. Pająk, J. Wrona, Structure and properties of barium ferrite powders prepared by milling and annealing, Archives of Materials Science and Engineering 28/12 (2007) 735-742.

[18] A. Hanc, J.E. Frąckowiak, G. Dercz, L. Pająk. F. Binczyk, Structural Studies on metallic powders from Fe-Al-X (X = Fe, Ni, Cu, Cr) type obtained by the self-decomposition method and electro-magneto-mechanical mill, Solid State Phenomena 130 (2006) 181-184.

[19] B. Szczucka-Lasota, B. Formanek, A. Hernas, L. Pająk, Corrosion resistance of composite HVOF sprayed coatings with FeAl and NiAl intermetallic phases in aggressive environment, Proceedings of the 12th International Scientific Conference "Achievements in Mechanical and Materials Engineering", AMME`2003, Gliwice – Zakopane, 2003, 889-894.

[20] J. Kansy, A. Hanc, D. Gieblel, M. Jabłońska, Vacancy formation in Fe-Al of B2 and $DO_3$ alloys, Acta Physica Polonica A (2008) (in press).