

# Assessment of corrosion resistance in liquid media of FeAl intermetallic phase based alloys with varied aluminium content

J. Cebulski\*, R. Michalik, S. Lalik

Department of Material Science, Silesian University of Technology,  
ul.Krasińskiego 8, 40-019 Katowice, Poland

\* Corresponding author: E-mail address: janusz.cebulski@polsl.pl

Received 15.11.2005; accepted in revised form 15.04.2006

## Properties

### ABSTRACT

**Purpose:** The paper presented results of corrosion resistance investigations with FeAl intermetallic phase matrix and different aluminium content (38%, 40% and 42%).

**Design/methodology/approach:** In the corrosion research electrolyser, potentiostat „Solartron 1285” and computer with „CorrWare 2” software were used. Results of the research were worked out with „CorrView” software. The potential’s values were determined in relation to normal hydrogen electrode (NEW). The temperature of the solutions was kept on 21°C level. The recording of potential/density of current - time curve was conducted for 300 s. Sample polarization ranges from potential smaller by 300 mV from normal potential to 0 mV in case of the test in 0.2% HCl solution as well as to 1500 mV in case of 3% H<sub>2</sub>SO<sub>4</sub> solution. Rate of changing the potential amounted 10 mV/min in each case. Observations of the surface state were conducted using scanning electron microscope (JSM – 35) with magnifications from 30 to 1000.

**Findings:** The results were showed that electrochemical corrosion conducted in 0,2% HCl and 3% H<sub>2</sub>SO<sub>4</sub> solution depend on aluminium content. The best electrochemical corrosion resistance in 0,2%HCl have samples of Fe-38Al intermetallic phase based alloy and in 3% H<sub>2</sub>SO<sub>4</sub> have Fe-40Al. It was confirmed by the lowest value of corrosion current density, low value of passive current density, pitting corrosion resistance much higher than in other samples.

**Research limitations/implications:** The results of potentiodynamic research of alloy examined in 0.2% HCl solution are presented in table 1, these for 3% H<sub>2</sub>SO<sub>4</sub> in table 2. Results of the potentiostatic and galvanostatic tests are presented in table 3. In figures 1, 2 the potentiodynamic curve are presented. Table 4 presents results of the surface state after corrosion tests. Figures 3 - 8 present surface state of the samples after corrosion research, which was observed using the scanning electron microscope.

**Originality/value:** Corrosion resistance in liquid media of FeAl intermetallic phase.

**Keywords:** Corrosion; Metallic alloys; Intermetallic

## 1. Introduction

Searching for new structural materials in the area of alloys with FeAl intermetallic phases matrix is mainly concentrated on solving technological problems. Restrictions connected with putting into practice arise mainly from large brittleness of these

materials [1-4]. One of basic advantages of this group of materials is higher corrosion resistance in comparison with typical structural materials. Corrosion resistance of alloys on the matrix of FeAl intermetallic phases was determined in gas mediums [5,6]. Review of the investigated intermetallic phase alloys structures and properties has led to the following remarks:

- physical-chemical and mechanical properties of intermetallic compounds, at present knowledge stage, are difficult to predict on basis of their components physical-chemical parameters;
- unique properties, which determine their practice application, are possible to achieve only through correct selection of chemical composition as well as exact and precise conducting of manufacturing processes (plastic working and heat treatment);
- co-operation between materials science expert with process engineers is indispensable to produce alloys with intermetallic compounds matrix useful as structural materials or functional materials.

Intermetallics in particular FeAl, are characterized by high corrosion and oxidation resistance in media, containing not only oxygen but also sulphur, good abrasion resistance and small density. In the literature there is lack of studies about concerning determination of electrochemical corrosion resistance of these materials. Evaluation of corrosion resistance of Fe40Al15Cr0.2TiB alloy was performed in corrosive medium, containing HCl and H<sub>2</sub>SO<sub>4</sub> [7-14]. During the research susceptibility this material for surface activation was proved. It seems usefulness to take comparative research of alloys with different Al contents in order to obtain passive layer on material surface. This work presents results liquid media of corrosion tests of alloys with different aluminium contents [14-17].

## 2. Research course and the results

The goal of this research was to determine corrosion resistance of the alloys with the matrix of FeAl intermetallic

phase in 0.2% HCl and 3% H<sub>2</sub>SO<sub>4</sub>. The research were conducted on alloys vacuum melted. Using components: ARMCO iron of technical purity and aluminium ARO (purity of 99,995% mass). To homogenize chemical composition annealing at temperature of 1050° for 72h was conducted. The following alloys were obtained and examined: Fe 38Al, Fe40Al 5Cr0,2TiB, Fe42Al. The research programme included:

1. Potentiostatic examinations.
2. Galvanostatic examinations.
3. Potentiodynamic examinations.
4. Evaluation of surface condition after corrosion tests.

In the corrosion research electrolyser, potentiostat "Solartron 1285" and computer with "CorrWare 2" software were used. Results of the research were worked out with "CorrView" software. The potential's values were determined in relation to normal hydrogen electrode (NEW). The temperature of the solutions was kept on 21°C level. The recording of potential/density of current - time curve was conducted for 300 s. Sample polarization ranges from potential smaller by 300 mV from normal potential to 0 mV in case of the test in 0.2% HCl solution as well as to 1500 mV in case of 3% H<sub>2</sub>SO<sub>4</sub> solution. Rate of changing the potential amounted 10 mV/min in each case. Observations of the surface state were conducted using scanning electron microscope (JSM – 35) with magnifications from 30 to 1000.

The results of potentiodynamic research of alloy examined in 0.2% HCl solution are presented in table 1, these for 3% H<sub>2</sub>SO<sub>4</sub> in table 2. Results of the potentiostatic and galvanostatic tests are presented in table 3. In figures 1, 2 the potentiodynamic curve are presented. Table 4 presents results of the surface state after corrosion tests. Figures 3 - 8 present surface state of the samples after corrosion research, which was observed using the scanning electron microscope.

Table 1.  
Results of potentiodynamic research in 0.2% HCl

material/ symbol	E <sub>cor</sub> [mV]	I <sub>cor</sub> [μA/cm <sup>2</sup> ]	E <sub>pas</sub> [mV]	i <sub>pas</sub> [μA/cm <sup>2</sup> ]	E <sub>punc</sub> [mV]	E <sub>rep</sub> [mV]
Fe38Al	-823.05	94.57	-560.0	18.70	-360.0	-633.4
Fe40Al5Cr	-862.57	300.0	-700.0	275.0	-561.6	-650.0
Fe42Al	-832.20	180.16	-562.7	54.21	-470.0	-642.1

Table 2.  
Results of potentiodynamic research in 3% H<sub>2</sub>SO<sub>4</sub>

symbol	E <sub>cor</sub> [mV]	I <sub>cor</sub> [mA/ cm <sup>2</sup> ]	prepassive			peak 1		passive			peak 2		E <sub>rep</sub>
			E <sub>1</sub> [mV]	E <sub>2</sub> [mV]	i <sub>p1</sub> [μA/ cm <sup>2</sup> ]	E <sub>cp1</sub> [mV]	i <sub>cp1</sub> [mA/ cm <sup>2</sup> ]	E <sub>1</sub> [mV]	E <sub>2</sub> [mV]	i <sub>p2</sub> [μA/ cm <sup>2</sup> ]	E <sub>cp2</sub> [mV]	i <sub>cp2</sub> [mA/ cm <sup>2</sup> ]	
Fe38Al	-546.2	1.34	-	-	-	-454.3	5.23	-250.0	283.0	143.0	-	-	-186.5
Fe40Al5Cr	-591.0	1.70	250.5	323.6	19.39	-478.4	7.87	758.5	845.2	31.6	500.0	0.12	400.0
Fe42Al	-564.3	1.71	-	-	-	-460.3	7.57	-268.0	195.7	139.1	-	-	0.0

where: E<sub>cor</sub> - corrosion potential; i<sub>cor</sub> - density of corrosion current; E<sub>1</sub>, E<sub>2</sub> - beginning and the end of prepassive and passive range, i<sub>p1</sub> - density of current in prepassive range, i<sub>p2</sub> - density of current in passive range, E<sub>cp1</sub> - critical potential of passivation for first peak, i<sub>cp1</sub> - critical current density of passivation for first peak, E<sub>cp2</sub> - critical potential of passivation for second peak, i<sub>cp2</sub> - critical current density of passivation for second peak, E<sub>rep</sub> - potential of repassivation

Table 3.  
Results of potentiostatic and galvanostatic research

Material	Medium	Results of potentiostatic research	Results of galvanostatic research
Fe38Al Fe40Al Fe42Al	3% H <sub>2</sub> SO <sub>4</sub>	increase of current density values with time and then stable state	decrease of current density values with time and then stable state
Fe40Al5Cr Fe42Al	0.2% HCl	continuous increase of current density values with time	decrease of current density values with time and then stable state
Fe38Al		increase of current density values with time and then stable state	continuous decrease of current density values with time

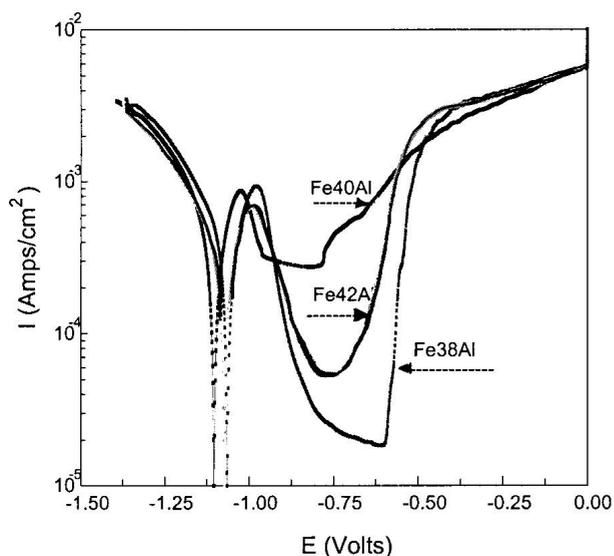


Fig. 1. Potentiodynamic curves in 0.2% HCl solution.

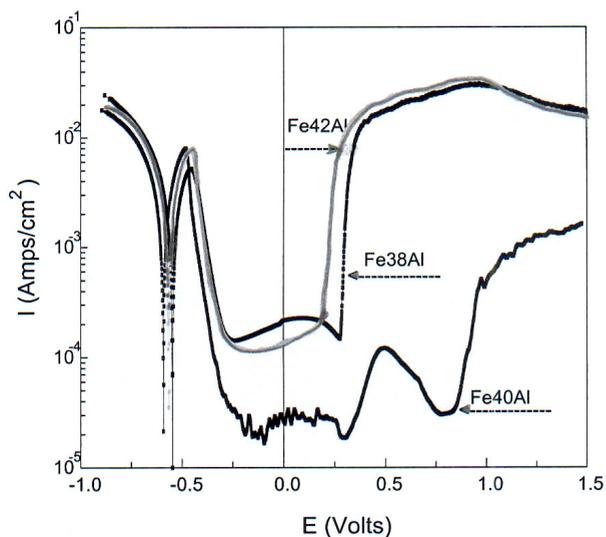


Fig. 2. Potentiodynamic curves in 3% H<sub>2</sub>SO<sub>4</sub> solution.

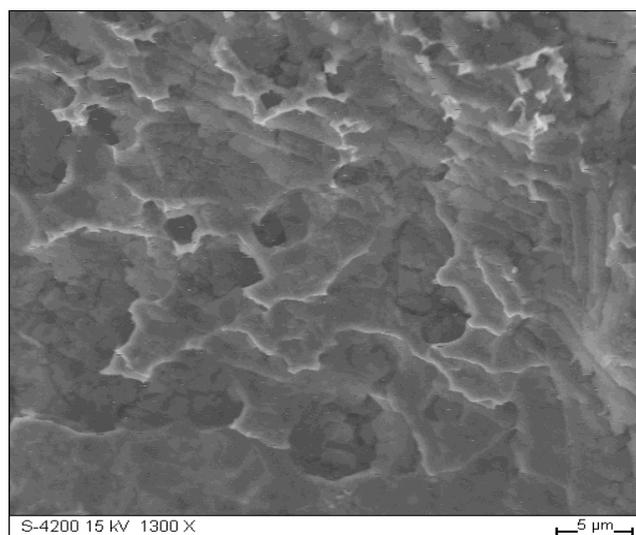


Fig. 3. Surface of Fe38Al alloy after corrosion tests in 3% H<sub>2</sub>SO<sub>4</sub> solution, scanning electron microscope, magn. 1300x.

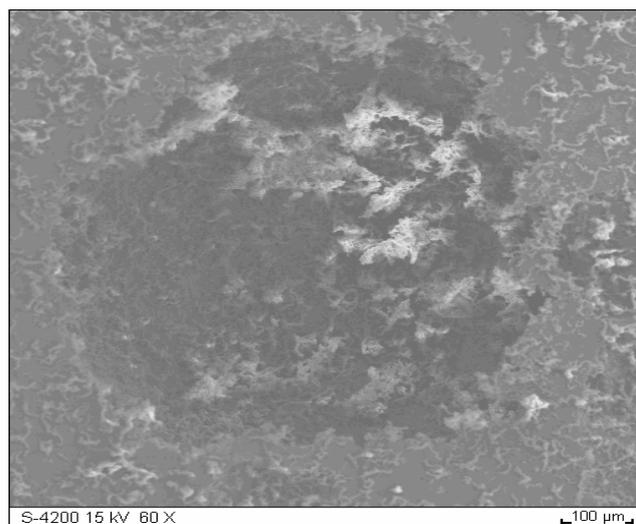


Fig. 4. Surface of Fe38Al alloy after corrosion tests in 0,2% HCl solution, scanning electron microscope, magn. 60x.

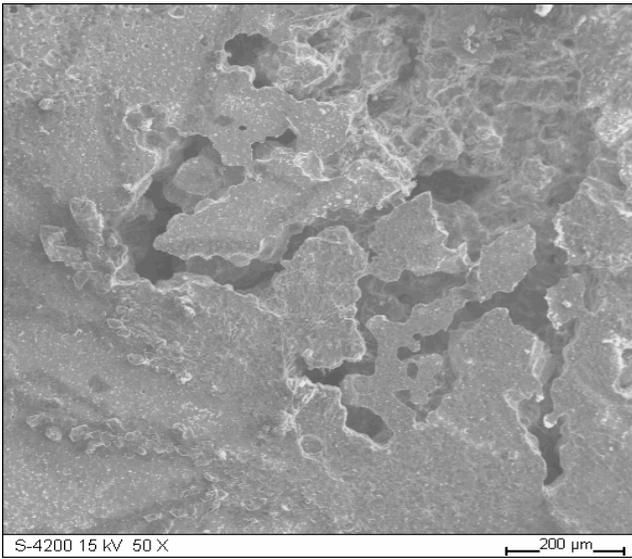


Fig. 5. Surface of Fe40Al5Cr alloy after corrosion tests in 3% H<sub>2</sub>SO<sub>4</sub> solution, scanning electron microscope, magn. 50x.

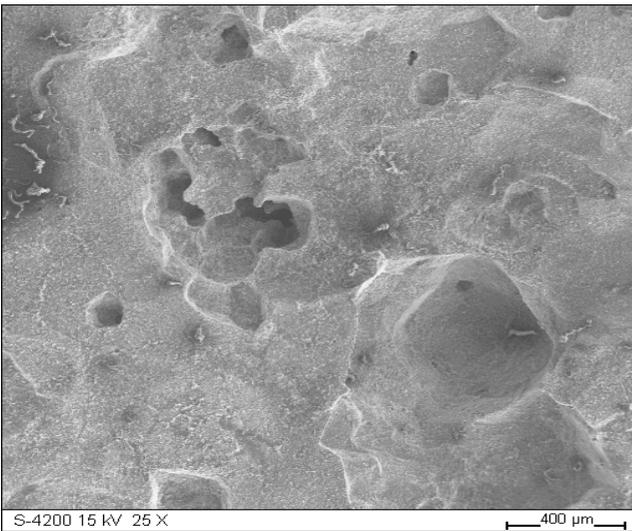


Fig. 6. Surface of Fe40Al5Cr alloy after corrosion tests in 0,2% HCl solution, scanning electron microscope, magn. 50x.

In analysis of the potentiodynamic and galvanostatic research in 0.2% HCl solution attention was paid on high susceptibility to surface activation. So it is possible that every surface damage, in medium containing HCl will lead to considerable acceleration of corrosion processes. On the potentiodynamic curves passive range was observed, the values of passive current density were considerable smaller than the values of corrosion current density. Thus the tested alloys could be protected anodically, which in this case should considerable decrease the rate of corrosion processes. Electrolytic polishing connected with passivation of the tested

materials can be considered as well. Relatively low value of puncture potential testifies high susceptibility of tested alloys to pitting corrosion. The alloy with 38% aluminium content revealed the highest corrosion resistance (low value of the passive current density, the widest passive range and the highest value of puncture potential). The alloy with 40% aluminium content proved to be the worst. Position of repassivation potential for the tested alloys, except alloy with 40% aluminium content, in activation range can testify low stress corrosion resistance in 0.2% HCl solution.

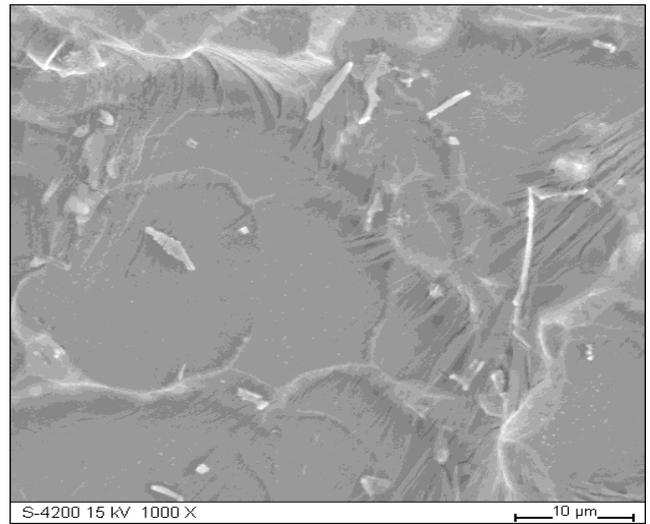


Fig. 7. Surface of Fe42Al alloy after corrosion tests in 3% H<sub>2</sub>SO<sub>4</sub> solution, scanning electron microscope, magn. 1000x.

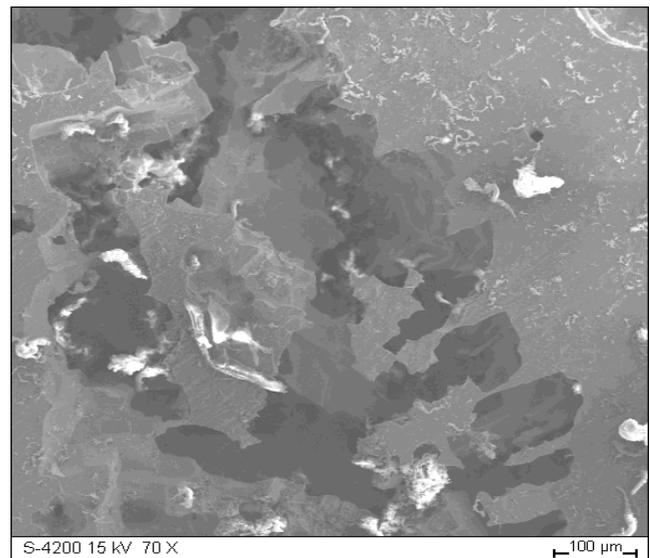


Fig. 8. Surface of Fe42Al alloy after corrosion tests in 0.2% HCl solution, scanning electron microscope, magn. 70x.

Table 4.  
Results of surface observations after corrosion tests

Alloy	3% H <sub>2</sub> SO <sub>4</sub> solution	0.2% HCl solution
Fe38Al	no corrosion pits, quench annealing effects are visible, sulphides are spread evenly	large, pointwise evenly spread corrosion pits, numerous small corrosion pits chlorides spread evenly are present
Fe40Al5Cr	single, deep corrosion pits, corrosion pits have of gutter shape and along grain boundaries, grains boundary visible, sulphides are spread evenly	large numbers of very big, deep corrosion pits, chlorides are spread evenly
Fe42Al	single, deep corrosion pits, quench annealing effects are visible, large numbers of sulphides were spread evenly	single, big pointwise corrosion pits are grouped in samples centre, large numbers of evenly spread small corrosion pits, chlorides are spread evenly

The surface state research of the alloys after corrosion tests in 0.2% HCl solution showed presence of corrosion pits on surface of all the tested samples. It was observed that with increasing of aluminium content for individual alloys, also amount of corrosion pits increase, including ones. Mainly chlorides were the products of corrosion, which were observed on the samples surface. The chemical composition microanalysis of the samples surface after corrosion tests shows the highest aluminium loss in comparison with initial constitution in the alloys with high aluminium content - Fe40Al5Cr and Fe42Al. It can be supposed, that in corrosion processes mainly aluminium takes place and that too high content of this element is not advisable from corrosion resistance in solutions containing chlorides point of view.

The analysis of the potentiostatic and galvanostatic tests of the alloys in 3% H<sub>2</sub>SO<sub>4</sub> solution shows susceptibility to surface activation, which should be considered as disadvantageous property of the investigated material. On the potentiodynamic curve was observed prepassive and passive range as well as two peaks for the 40% of aluminium alloy were observed and only passive range as well as one peak for the alloys with 38% and 42% of aluminium. The highest corrosion resistance was found for Fe40Al5Cr alloy. This alloy is characterized by higher pitting corrosion resistance and considerably lower corrosion rate in passive range in comparison with other alloys. The increase of current density, connected with appearing of second peak, as well as the difference between value of current density in prepassive and passive range are not very high. For all alloys tested in 3% H<sub>2</sub>SO<sub>4</sub> solution considerably lower value of current density in prepassive and passive range was observed than value of corrosion current density. Similarly as in 0.2% HCl in case of 3% H<sub>2</sub>SO<sub>4</sub> the tested alloys can be protect anodically and by electrolytic polishing connected with passivation in oxidizing medium. The repassivation potential is situated in the passive

range of Fe38Al and Fe42Al alloy and prepassive range for Fe40Al5Cr alloy. Therefore resistance for stress corrosion in H<sub>2</sub>SO<sub>4</sub> media can be expected, but it must be confirmed in further investigations. Cyclic voltammetry studies have shown, that corrosion processes accelerate in initial phase then slow down and finally are stable.

The surface state research of the alloys after corrosion tests in H<sub>2</sub>SO<sub>4</sub> solution showed corrosion pits presence on surface of Fe40Al5Cr and Fe42Al alloys, on surface of Fe38Al alloy corrosion pits presence was not confirmed, however there were visible effects of samples quench annealing. On Fe38Al alloy surface corrosion pits have gutter shape and were located on grain boundaries. The research carried out shows, that the corrosion pits expand mainly inside, which can be cause of dropping out of the hole grains. However, more disadvantageous was the surface state of the alloys with high aluminium content, where additionally presence of corrosion pits was observed and in Fe42Al alloy areas, with effects of quench annealing and areas with big, deep corrosion pits were visible. Products of the corrosion were mostly sulphides. Like in the case 0.2% HCl solution chemical composition microanalysis of the samples surface after corrosion showed the highest aluminium loss in alloys with high aluminium content in comparison with initial composition. Summing up the research results in both solutions the highest corrosion resistance revealed alloy with the lowest aluminium content - Fe38Al. The aluminium content in the tested alloys influenced significantly corrosion phenomena in the tested alloys – the increasing aluminium content reduced the alloys corrosion resistance.

### 3. Conclusions

1. The highest corrosion resistance in 0.2% HCl solution was found for the alloy with the lowest aluminium content - Fe38Al.
2. The highest corrosion resistance in 3% H<sub>2</sub>SO<sub>4</sub> solution was registered for the Fe40Al alloy.
3. All the tested alloys have revealed higher corrosion resistance in oxidizing medium than in reducing one.
4. The aluminium content in the tested alloys has influenced considerably their corrosion resistance in sulphuric acid and hydrochloric acid solutions.
5. Corrosion resistance of the tested alloys in sulphuric acid solution can be increased by passivation or application of anodic protection, which requires further research.

### References

- [1] Cebulski J.: The methods of plasticity increasing for FeAl intermetallic based alloy –PhD thesis (1999) (In Polish)
- [2] J. Barcik, J. Cebulski: FeAl intermetallics phase based alloy – structure and technological properties, Materials Engineering nr 1, (1997), p. 24.
- [3] G. Matula, L.A. Dobrzański, A. Várez, B. Levenfeld, J.M. Torralba „Comparison of structure and properties of the HS 12-1-5-5 type high-speed steel fabricated using using the

- pressureless forming and PIM methods” J. Mat. Proc. Tech. 162-163 (2005) 230-236.
- [4] T. Khan, Intermetallics for Struktural Application Proc. Conf. „High Temperature Materials for Powder Engeniering” 1990 hold in Liege, publ. Kluwer Alad. Publ.
- [5] „High- temperature Aluminides Intermetallics” in Mater. Sc. & Eng. A152/A153/(1992)
- [6] J. Cebulski, R. Michalik: The evaluation of alloy on the matrix of intermetallic phase FeAl. Protect from Corrosion. nr 2, (2005) p. 33-36. (In Polish)
- [7] G. Matula, L.A. Dobrzański, A. Várez, B. Levenfeld, J.M. Torralba, Comparison of structure and properties of the HS 12-1-5-5 type high-speed steel fabricated using using the pressureless forming and PIM methods, Journal of Materials Processing Technology 162-163 (2005) 230-236.
- [8] Z. Bojar, Z. Komorek, R. Łyszkowski, M. Wiczorek: Materials Engineering 17 (1997) p. 104.
- [9] H. Garbacz, J.W. Wyrzykowski: Materials Engineering 17 nr 3 (1997) p. 86.
- [10] J. Adameczyk, A. Grajcar “Structural and mechanical properties of DP-type and TRIP-type J. Mat. Proc. Tech. 162-163 (2005) 267-275.
- [11] L.A. Dobrzański, A. Brytan, M.A. Grande, M. Rosso, E.J. Pallavicini “Properties of vacuum sintered duplex stainless steels” J. Mat. Proc. Tech. 162-163 (2005) 286-293.
- [12] H. Paduch, J. Krztoń: Materials Engineering 1-2 (1994) p. 37.
- [13] J. Barcik, Kupka M.: Materials Engineering 5 (1994) p. 112.
- [14] S. Ratchev, S. Liu, A.A. Becker „Error compensation strategy in milling flexible thin-wall parts“ J. Mat. Proc. Tech. 162-163 (2005) 673-682.
- [15] J. Barcik, J. Cebulski: Materials Engineering nr. 5 (1998) p. 901.
- [16] R. Mania: Manufacturing of Mo-Al Intermetallics by SHS, XVth Physical Metallurgy and Materials Science Conference, ed. Sigma NOT, Kraków 1998, p. 921.
- [17] E. Godlewska, S. Koziński, R. Mania M. Wesolek: XVth Physical Metallurgy and Materials Science Conference, ed. Sigma NOT, Kraków 1998, p. 929.