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The effect of structure on the cavitational wear of FeAl intermetallic phase-based alloys with cubic lattice

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Abstract

The process of cavitational erosion induces destruction of a material which consists of plastic strains, mass decrements, phase changes, grain fragmentation and surface micro- and macro-geometry changes. Heterogeneity of this process causes the destruction of a solid body due to cavitation to be hard to predict. Examinations of many materials showed that the course of cavitation wear is basically affected by structure which allows for orientation and size of grains and their shape, fraction of small and large angle boundaries, type of phases (in multi-phase materials), interposition of their grains, grain volume fraction as well as distribution of impurities and possible defects of materials, such as cracks, pores and non-metallic inclusions.

The aim of this study was to examine the effect of structure on the cavitational wear of FeAl intermetallic phase-based alloys with cubic lattice.

Key words: cavitation, cavitational wear, intermetallic alloys, structure.

1. Introduction

Intermetallic phase-based alloys (so called intermetals) of the Fe-Al system are modern construction materials, which in recent decades have found application in many branches of the power, chemical and automotive industries [1-3]. From among intermetallic alloys of the Fe-Al. system, due to unique technological properties, those based on the FeAl intermetallic phase of the B2-type structure deserve particular attention. This phase is being found in a wide range of aluminium fraction (36÷51% at.), the content of which directly affects the mechanical properties of the alloys under consideration. The increase of aluminium content is reflected in their density, oxidation resistance, hardness and the course of crystallisation. Intermetallic alloys of the Fe-Al system are being obtained by classical methods of melting in crucible induction furnaces. The most frequently used methods are: AIM – Air Induction Melting and VIM - Vacuum Induction Melting [4,5]. The production of intermetals by these methods allows obtaining the materials of high purity, homogeneous and coarse-grained structure with minimum porosity and without internal and surface cracks. The FeAl intermetallic phase-based alloys are characterised by low density, high mechanical properties, large high-temperature resistance as well as corrosion and abrasive wear resistance. These alloys show also several times larger resistance to cavitational erosion, slightly increasing together with aluminium fraction, when compared to the Fe, Cu and Al alloys examined on a flux-impact test stand (Fig. 1).

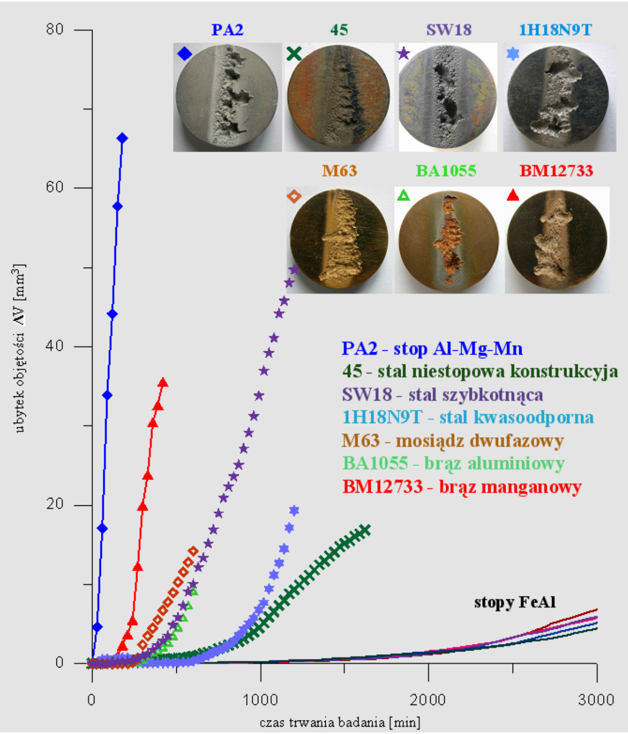


Fig. 1. Comparison of the test results of cavitational wear of intermetallic FeAl alloys with Rother materials [6-7]

Higher resistance of FeAl based alloys to cavitational erosion results first of all from their high hardness in the as-cast state, large compressive stresses in the material, as well as homogeneous structure.

The aim of examinations being shown at present was to determine the effect of structure of alloys with FeAl intermetallic phase matrix on their resistance to cavitational erosion.

2. Materials and research methods

Detailed examinations of the resistance to cavitational resistance covered five FeAl intermetallic phase-based alloys (in the as-cast state) with aluminium fraction from 36 to 48% at. and mono-phase structure of the solid solution of aluminium in α-iron (B2-type structure), containing the following alloy-forming micro-additions: molybdenum, zircon, boron and carbon. The alloys were produced by stage meting in a Leybold-Heraeus vacuum induction furnace of the IS-5/III type, at a temperature of 1500÷1550°C and in a vacuum of approximately 0.001 Torr.

The chemical composition of the examined materials and the selected mechanical properties are presented in Table 1.

In order to fix the phase structure of the examined materials and to determine explicitly the crystallographic lattice, and the same to confirm the occurrence of long-range order which is typical for the B2-type superstructure, a qualitative X-ray analysis was carried out. Measurements were made by a Seifert XRD 3003 diffractometer using the Cu lamp with a radiation length $\lambda K_{\alpha 1}$=0.15418 nm. Identification of the received diffractograms was made by means of manufacturer's software using the ASTM-PDFZ cards database. The obtained results confirm that the alloys under examination are the secondary ordered solid aluminium solutions in the α-state iron.

Table 1. FeAl intermetallics alloys subjected to cavitation erosion

Element	Intermetallics FeAl alloys				
	FeAl36	FeAl39	FeAl42	FeAl45	FeAl48
Al	36,00	39,00	42,00	45,00	48,00
Mo	0,22	0,22	0,22	0,22	0,22
Zr	0,10	0,10	0,10	0,10	0,10
B	0,01	0,01	0,01	0,01	0,01
C	0,13	0,13	0,13	0,13	0,13
Fe	63,54	60,54	57,54	54,54	51,54
Density [kg/m^3]	6255	6068	5982	5797	5687
Hardness HV0,1	297,34	311,47	330,47	347,64	385,30

Examination of the grain orientation in respective alloys was made with the EBSP method using a Phillips XL30LaB6 scanning microscope. Detailed examination covered each of the FeAl alloy samples with the grain number ranging 100÷200.

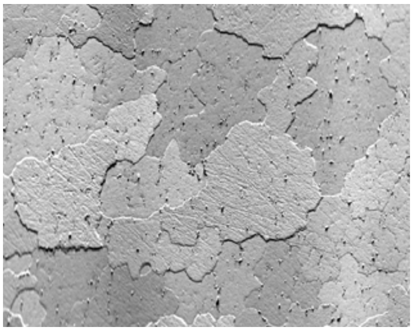
The examination of cavitational erosion was carried out on a streaming-blowing apparatus. Samples for the examination were of the cylindrical shape, 20 mm in diameter and $6^{\pm 0,5}$ mm height. Sample surface roughness, measured by means of PGM-1C profilographometer, ranged 0,010÷0,015 μm. The samples were mounted vertically in rotor arms, parallel to the axis of water stream pumped continuously at 0,06 MPa through a nozzle with a 10 mm diameter, 1,6 mm away from the sample edge. The rotating samples stroke against the water stream. Water flow intensity was constant and amounted to 1,55 m^3/h. The samples were examined for the period of 30 minutes, took out from the fixtures, degreased in an ultrasonic washer for 10 minutes at 30°C, dried in a laboratory drier for 15 minutes at 120°C and weighed, than mounted again in the rotor arms, maintaining the initial position in relation to the water stream. The analyses included 5 samples of each alloy, examined for the total time 3000 minutes.

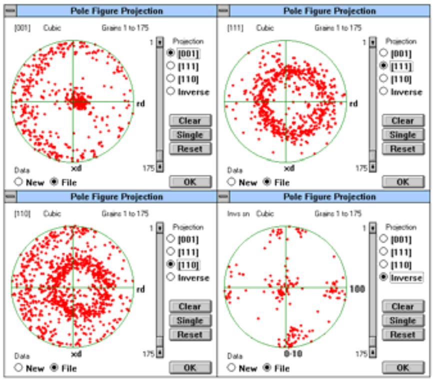
3. Study results and their analysis

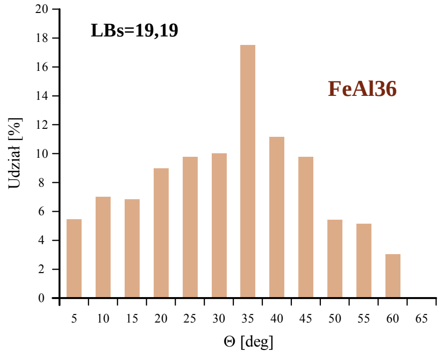
Results of the examination of grain orientation in different planes are presented in Fig. 2. The grain orientation examinations show to a strong fibre texture in <100> direction in FeAl36 sample (Fig. 2a). As aluminium content in the FeAl alloys under examination increases, their strong texture disappears. This is induced by a change in alloy properties being determined by larger aluminium content which results in higher thermal conductivity and the same in better heat dissipation, i.e. in faster crystallisation from liquid phase to solid phase which takes place at a temperature of approximately 1300°C.

FeAl36

a)

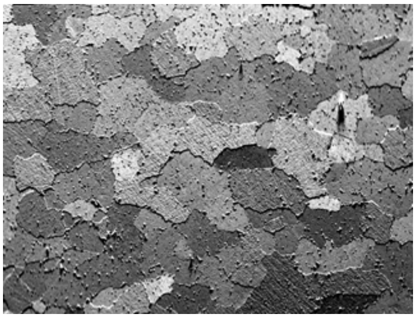


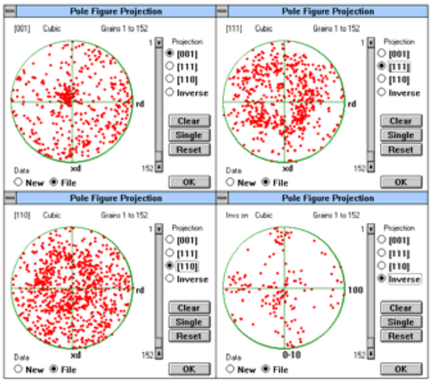


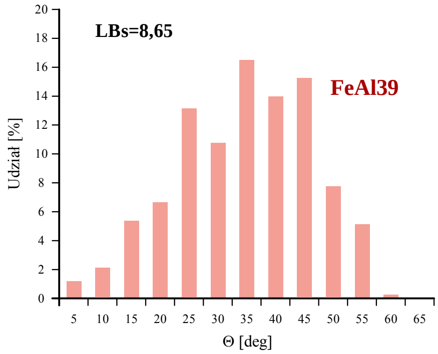


FeAl39

b)

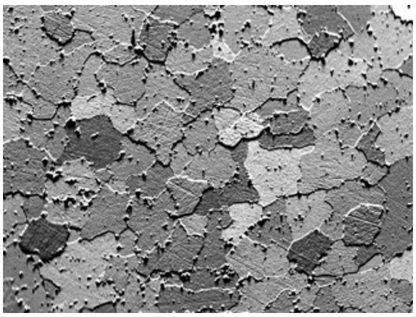


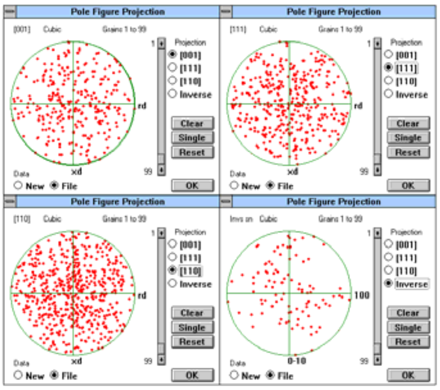


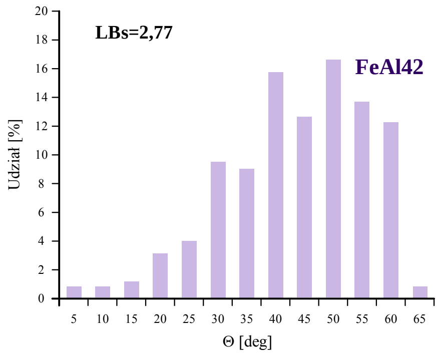


FeAl42

c)







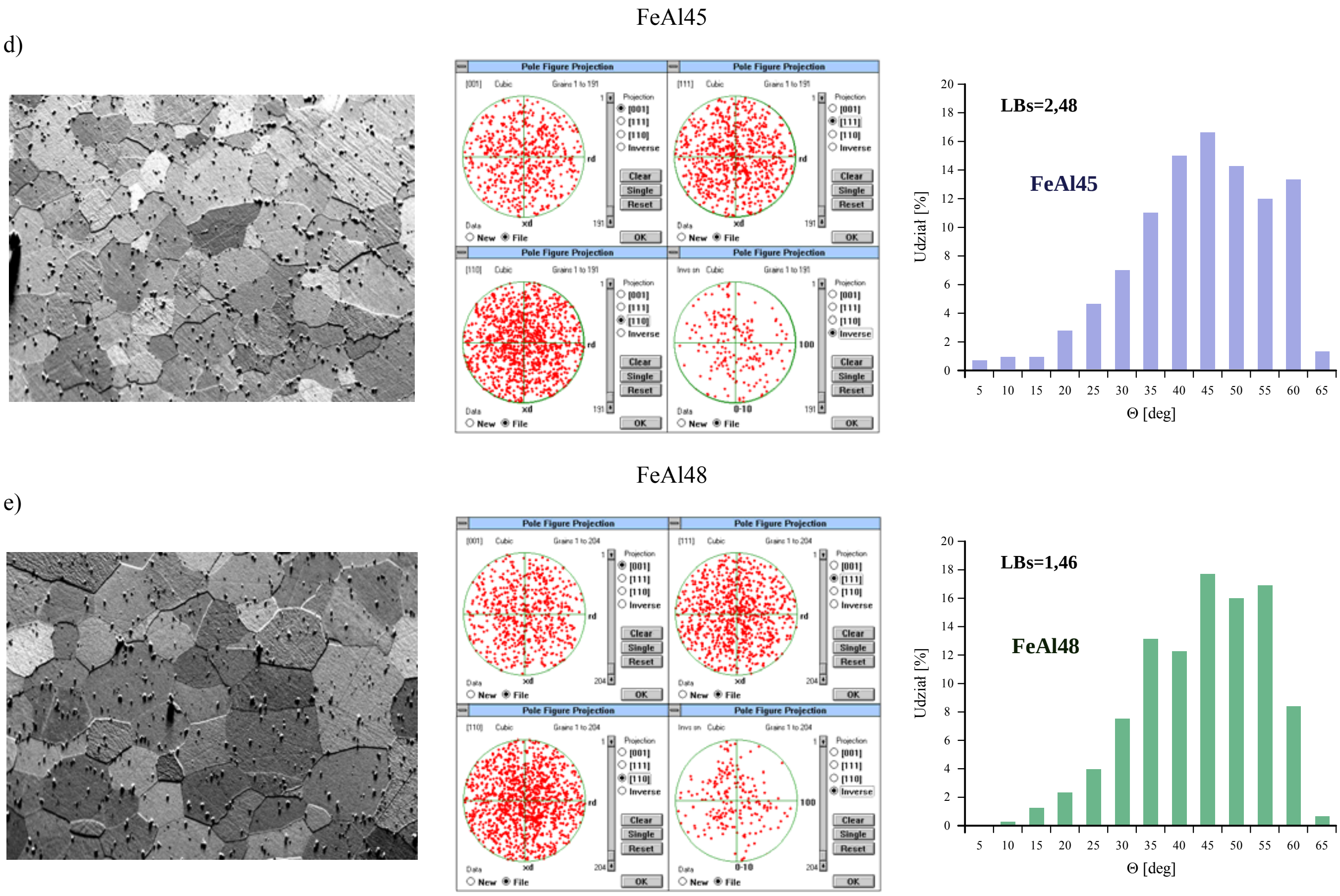


Fig. 2. Microstructure, pole figures and small angle boundaries histogram (LBs) intermetallic FeAl alloys after cavitational wear a) FeAl36, b) FeA139, c) FeAl42, d) FeAl45, e) FeAl48

In the areas covered by grain orientation examinations, a crystallographic evaluation of the state of grain boundaries was also carried out. It was found that the fraction of large angle boundaries increases with the increase of aluminium content, while that of small angle decreases. The presented histograms of the FeAl alloys subjected to resistance to cavitational erosion show that a drop in the fraction of small angle boundaries (marked as LBs) counted for $\Theta \leq 15^{o}$ follows according to exponential function (Fig. 3).

The course of cavitational erosion in the examined FeAl alloys is very similar to each other. In the initial period, the water stream action on the surface of samples induces the strengthening of surface layer and the increase of micro-hardness.

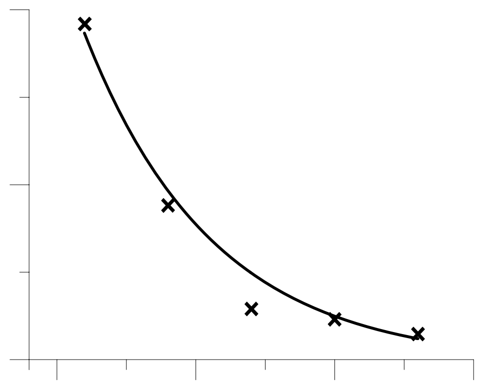


Fig. 3. Participation of small angle boundaries (LBs) as a function of Al content in FeAl intermetallic alloys

a) b) c)

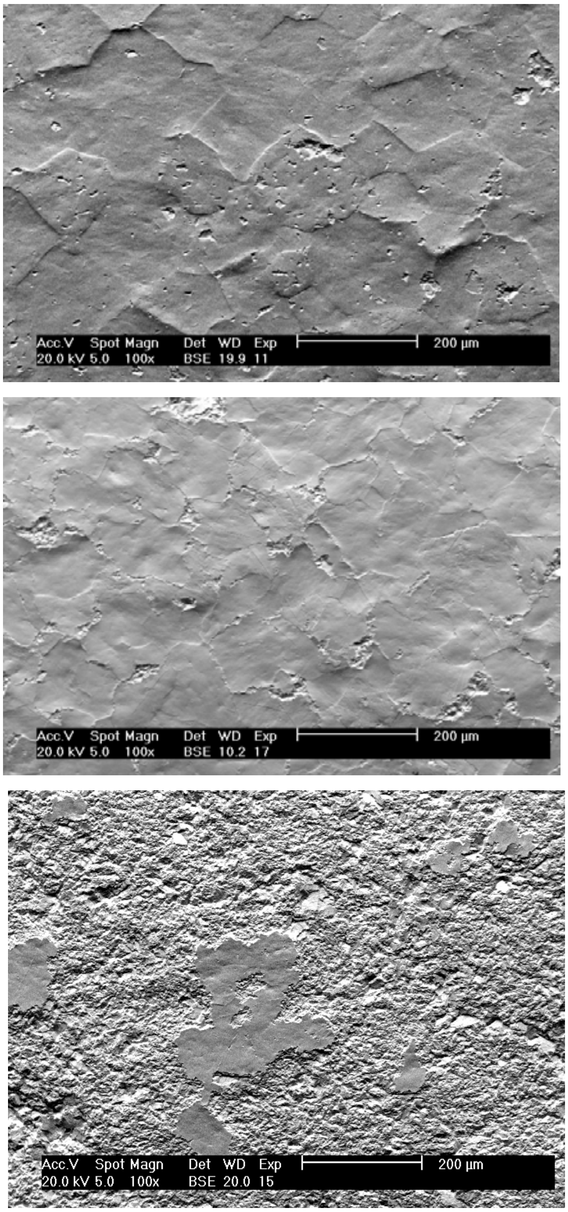


Fig. 4. Effects of cavitational erosion of intermetallics FeAl alloys: a) uplift and collapse of the grain, b) craters edgewise of the grain, c) state of FeAl sample surface after 1200 min.

Also the plastic strain was observed on the surface of samples, manifested in the uplift and collapse of the adjoining grains (Fig. 4a). In the initial stage of analysis, the following effects were observed on the surface of examined samples:

- cavities induced by the implosion of cavitational bubbles to be found near the sample surface or by the blow of very small impurities to be found in the water stream,
- cracks on the material surface along the grain boundaries,
- first single losses of material on the grain boundaries (Fig. 4b).

Further exposure of the material surface to cavitational loading leads to development of cracks on the material surfach. Craters form in result of grain crushing along the crack networks, which leads further to development of larger and deeper irregularities in the examined surface on which the grain boundaries are harder and harder to see (Fig. 4c).

Analysis of the obtained results allows statement that the highest resistance to cavitational resistance is showed by FeAl48 sample, i.e. an alloy with the highest Al content (Fig. 5). Cavitational destruction curves are being presented only by two destruction periods from among the three ones [8-9]:

- long incubation period amounting approximately for all alloys to about 1500-1600 minutes; and
- accelerated destruction period, being characterised for the alloys with larger aluminium content (FeAl45 and FeAl48) by uniform mass decrement on the surface of samples under examination.

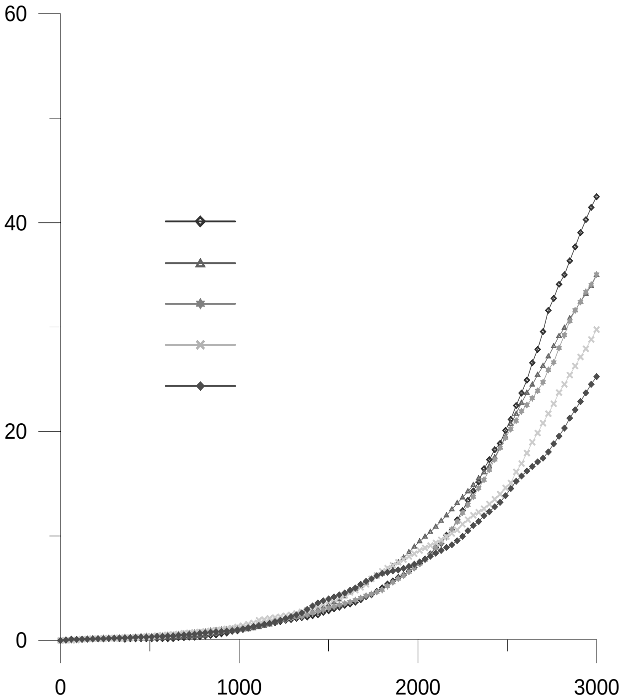


Fig. 5. Comparison of the test results of cavitational erosion of intermetallic FeAl alloys

4. Conclusion

The alloys based on FeAl intermetallic phase owe their high cavitational resistance first of all to a very favourable set of material features (large hardness, large corrosive resistance) and structure (mono-phase structure of a similar grain size without micro-cracks, pores and non-metallic inclusions). The mechanism of cavitational destruction of FeAl intermetallic alloys is initiated at the triple points of grain boundary contact, i.e. within the area where first decrements appear. In the incubation period, a plastic strain of the surface layer occurs as well as the phenomenon of grain upheaval and collapse. The elongated shape of grains with a large fraction of small angle LBs, amounting to about 20% for alloys with aluminium content below 40% at. Al, induces in these alloys a faster development of cracks at the boundaries of these grains when compared to those with larger Al fraction. The further course of erosion is the appearance of craters along the cracks developed at the grain boundaries, which later increase their area in result of slow grain crushing. The highest resistance is being showed by the alloy with the largest aluminium content – FeAl48, i.e. the alloy with straight grain boundaries forming the crystallites in the form of pentagons and hexagons (small fraction of small angle boundaries LBs = 1.46%) when compared to other alloys examined. Analysis of the results of grain orientation examinations carried out with the EBSP (Electron Backscatter Patterns) method, a SEM based electron diffraction method, does not show any effect of grain orientation on the course of cavitational destruction. Random orientation of grains in alloys with larger aluminium content causes that elements of machine parts exposed to cavitational destruction can be obtained by any technique of melting in induction furnaces, without the need for expensive heat treatment processes in order to achieve a specific structure.

Acknowledgements

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