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CAVITATION EROSION RESISTANCE OF FeAl INTERMETALLIC ALLOYS AND AL_2O_3 – BASED CERAMICS

ODPORNOŚĆ NA EROZJE KAWITACYJNĄ INTERMETALI FeAl I CERAMIKI NA BAZIE AL_2O_3

The problem of the devastation of fluid-flow machinery components is very complex, because it consists of processes of erosion and corrosion. The most dangerous factor is the cavitation phenomenon, which is very difficult to eliminate through the use of design solutions. Usage of materials with greater resistance to cavitation erosion seems to be an obvious effective method of prevention. Such materials as FeAl intermetallic alloys and ceramic materials may be considered as reasonable candidates for this purpose. In the presented work, cavitation erosion resistance of FeAl intermetallic alloys and Al_2O_3 – based ceramic materials, was investigated and compared.

Keywords: cavitation, cavitation wear, intermetallic alloys, Al_2O_3-based ceramics

Problem niszczenia elementów maszyn przepływowych jest bardzo złożony, ponieważ składa się z procesów erozyjnych i korozyjnych. Najbardziej niebezpiecznym czynnkiem jest zjawisko kawitacji, które bardzo trudno jest wyeliminować poprzez stosowanie rozwiązań konstrukcyjnych. Skutecznym rozwiązaniem jest stosowanie materiału o większej odporności na erozję kawitacyjną. Takimi materiałami mogą być stopy intermetaliczne FeAl lub materiały ceramiczne. W pracy przedstawiono porównanie odporności na erozję kawitacyjną stopów intermetalicznych FeAl i materiałów ceramicznych na bazie Al_2O_3.

1. Introduction

Cavitation is caused by the repeated nucleation, growth, and violent collapse of clouds of bubbles within the liquid. Microstreams of liquid developed during the implosion of cavitational bubbles as well as the action of pressure waves from disappearing bubbles are the main causes of destructions on swilled surfaces leading to a loss of material, i.e. to cavitational erosion. On the surface of material exposed to acting of liquid, the cavitation phenomenon induces local destruction of the surface layer as a consequence of the resultant effect of liquid micro-stream blows with high hydrodynamic parameters as well as pressure waves. Due to the nature of loading, destruction of material surface can be compared to the fatigue process [1-3].

The process of cavitational erosion induces destruction of the material, which consists in plastic strain, material losses, microstructure changes and surface micro- and macrogeometry changes. Diversity of this process causes the destruction of solid body in result of cavitation to be hardly predicted. The apart from the intensity of cavitational phenomenon, the course of cavitational destruction depends also on properties of the material itself. The carried out analyses of many materials showed that cavitational resistance does not depends one strength parameter only. The process of cavitational destruction, having a fatigue character, causes that materials with larger resistance to cavitational erosion are first of all characterised by high hardness and micro-hardness as well as fine-grained one-phase structure having internal compressive stresses [4-6].

One of the methods of counteracting the destructive effect of cavitational erosion is selected of construction materials of the greatest resistance to this type of erosion. Up to now, cavitation erosion of a lot of metallic materials, such as steels, copper alloys, ect., has been investigated. The work devoted to the test of resistance to cavitation erosion of ceramics materials is little.

The aim of this work was to comparison the resistance to cavitation erosion of FeAl intermetallic alloys and ceramic materials such alumina (Al_2O_3) and particulate composites prepared on its base.

2. Investigated materials

Detailed examinations of the resistance to cavitational resistance covered five FeAl intermetallic alloys (in the as-cast state) with aluminium fraction from 36 to 48% at. and ceramic materials – alumina (Al_2O_3) and composites with alumina matrix containing inclusions of other ceramic phases (zirconia and yttria-aluminium garnet – (Al_2O_3/ZrO_2, Al_2O_3/YAG).

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FeAl intermetallic alloys system are modern construction materials, which in recent decades have found application in many branches of the power, chemical and automotive industries. Alloys are being obtained by classical methods of melting in crucible induction furnaces. The most frequently used methods are: air induction melting and vacuum induction melting. The production of FeAl intermetallic alloys by these methods allows obtaining the materials of high purity, homogeneous and coarse-grained structure with minimum porosity and without internal and wear resistant. The FeAl intermetallic alloys are characterized by relatively low density, high mechanical properties, large high-temperature resistance as well as corrosion and abrasive wear resistance [7-8]. 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 jet-impact test bed [9].

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

TABLE 1
The chemical composition (at %) and mechanical properties FeAl intermetallic alloys

Element	FeAl intermetallic alloys				
	FeAl36	FeAl39	FeAl42	FeAl45	FeAl48
Al	36.35	40.08	42.89	46.27	50.30
Mo	0.08	0.08	0.08	0.08	0.08
Zr	0.40	0.39	0.32	0.22	0.18
Fe	63.25	59.52	56.79	53.51	49.52
Density [kg/m^3]	6255	6068	5982	5797	5687
Hardness HV0,1	297	311	330	347	385

The FeAl intermetallic 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. Alloys had the α-state one-phase structure, the grain number ranging 100-200 μm.

Alumina (Al_2O_3) is the most widely used material in the family of engineering ceramics. With an excellent combination of properties and an attractive price, alumina has a very wide range of applications. The alumina is characterised: high strength and stiffness, high hardness, high wear resistant, good thermal conductivity and very good resists high temperature and strong acid. The composition of the alumina body can be changed to enhance particular desirable material characteristics, on to improve hardness and change color.

The investigation of resistance of cavitation erosion have been also performed on three ceramic materials:
1 – Al_2O_3 – ceramics obtained from a commercial powder Al_2O_3 (TM-DAR, TAIMEI Chemicals, Japan);
2 – Al_2O_3/ZrO_2 – particulate composite made of alumina powder (TM-DAR) containing 10 vol. of zirconia (ZrO_2) inclusions (TZ-3Y TOSOH, Japan). Composite powder was prepared by rotation-wibration milling of starting alumina and zirconia powders in ethyl alcohol.
3 – Al_2O_3/YAG – particulate composite made of alumina powder containing 10 vol. % of yttria-alumina garnet (YAG) inclusions. Composite powder was prepared by wet-chemical method described in [10].

Cylindrical samples were uniaxially compacted under 50 MPa and isostatically repressed under 300 MPa and sintered in air atmosphere at 1600°C. The mechanical properties ceramic materials are presented in Table 2.

TABLE 2
The mechanical properties ceramic materials

Ceramics	HV_5 [GPa]	E [GPa]	σ [MPa]	K_{IC} [MPa m $^{0.5}$]
Al_2O_3	15.8±1.0	380±12	700±40	4.3±0.5
Al_2O_3/ZrO_2	15.0±0.8	365±7	600±50	5.5±0.4
Al_2O_3/YAG	19.0±1.1	370±8	580±45	6.0±0.7

3. Experimental methods

The examination of cavitational erosion was carried out on a jet-impact device. Samples for the examination were of the cylindrical shape, 20 mm in diameter and 6±0.5 mm height. Sample surface roughness, measured by means of PGM-1C profilometer, ranged 0.01÷0.02 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 four samples, examined for the total time of 3000 minutes.

4. Results and discussion

The course of cavitational erosion in the examined FeAl intermetallic alloys was very similar for all tested samples. In the initial period, the water stream induces the strengthening of surface layer (observed as a prominent increase of micro-hardness). Effects of plastic strain were also noted on the surface of samples as a uplifting and collapsing of the adjoining grains. In the initial stage of analysis, the following features were observed on the surface of examined samples:
– cavities formed due to implosion of cavitational bubbles near the sample surface or by impact of very small impurities originating from the water stream (Fig. 1a),
– cracks on the material surface along the grain boundaries (Fig. 1b),
– first single losses of material on the grain boundaries (Fig. 1c).

Further exposition to cavitation erosion conditions leads to development of clearly visible cracks on the material surface. Craters are formed along the cracks as a result of grain edge crushing (Fig. 1d). As the erosion of sample surface increases, grain boundaries are hardly detected, but the loss of

a) b) c) d)

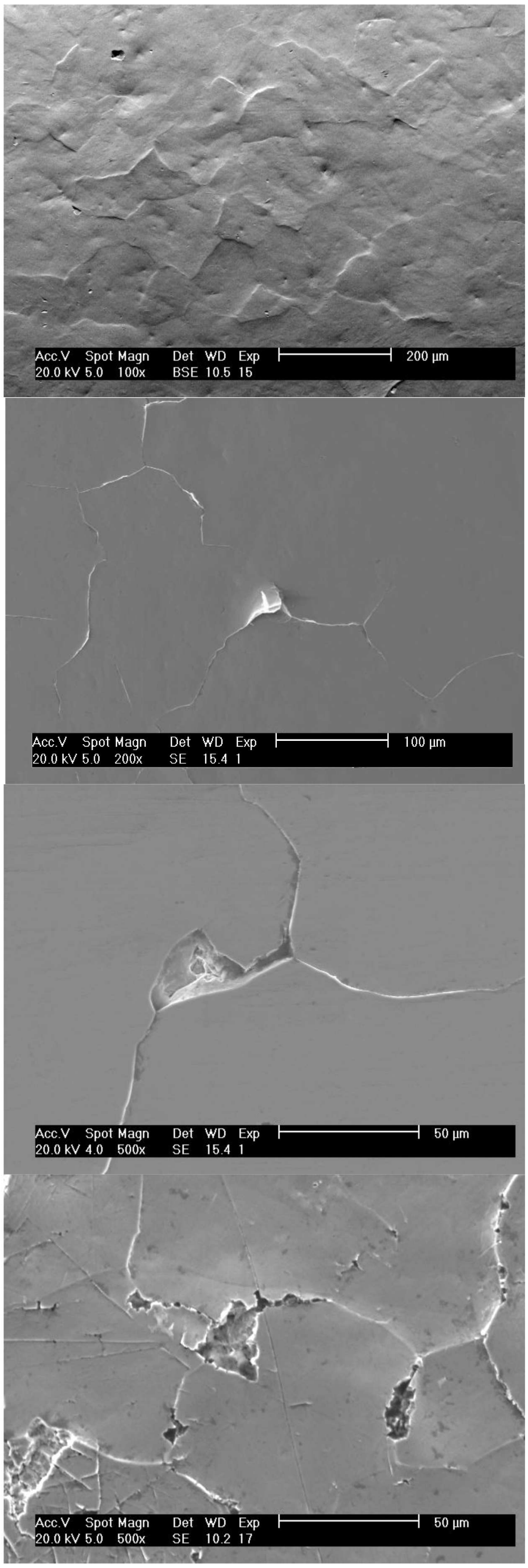

Fig. 1. A typical effects of cavitational erosion observed on surface of FeAl42; effect of plastic deformation on the surface (a); cracks on the material surface along the grain boundaries (b); first single losses of material on the grain boundaries (c); craters on the surface (d)

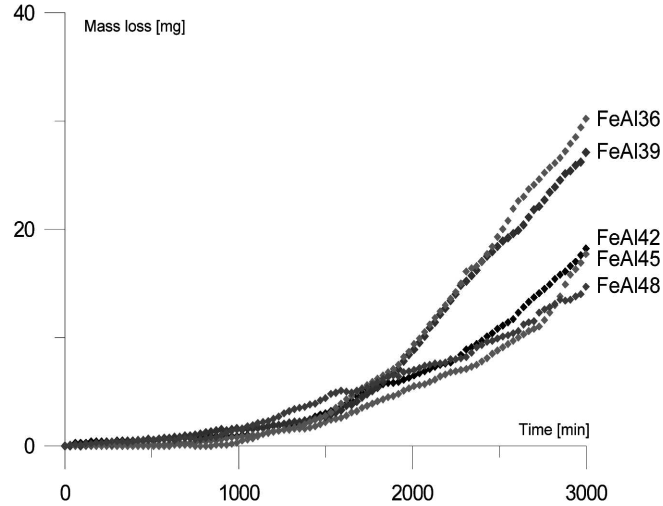

Fig. 2. Mass change kinetic curves of FeAl intermetallic alloys samples during cavitation test

material is still very small (only 10-20 mg after 3000 minutes). Kinetic of mass loss of FeAl intermetallic alloys samples during cavitation test are presented in Figure 2.

The ceramic materials samples are destroyed mainly in limited areas around previously formed small cracks or defects originated during fabrication. The greatest resistance to cavitation erosion was exhibited by Al_2O_3/ZrO_2 sample. Throughout the test, it did not developed beyond the first damage period (incubation). The mass loss of Al_2O_3/ZrO_2 samples after 3000 minutes exposition was only 0.4 mg. Not much bigger loss was measured for Al_2O_3/YAG samples. Their average result was approximately 1.3 mg. In other hand, the lowest cavitation erosion resistance among all tested ceramics was found for Al_2O_3 samples. A acceleration cavitation erosion period started after 1800 minutes of testing and was characterized by a small erosion rate of approximately 0.16 mg/h. The effects of the damage of cavitation erosion of ceramics samples after 3000 minutes are shown in Figure 3.

The detail observation of ceramic samples surfaces after test suggests that dominant mechanism of damage is tearing out of whole grains without any plastic deformation of polycrystalline microstructure (see Fig. 4a-c). The final effect of cavitation wear is connected with the grain size of ceramic material. Alumina showed the biggest wear, the lowest one was measured for alumina-zirconia composite with the smallest matrix grain.

Mass change kinetic curves of ceramic samples during cavitation test are presented in Fig. 5.

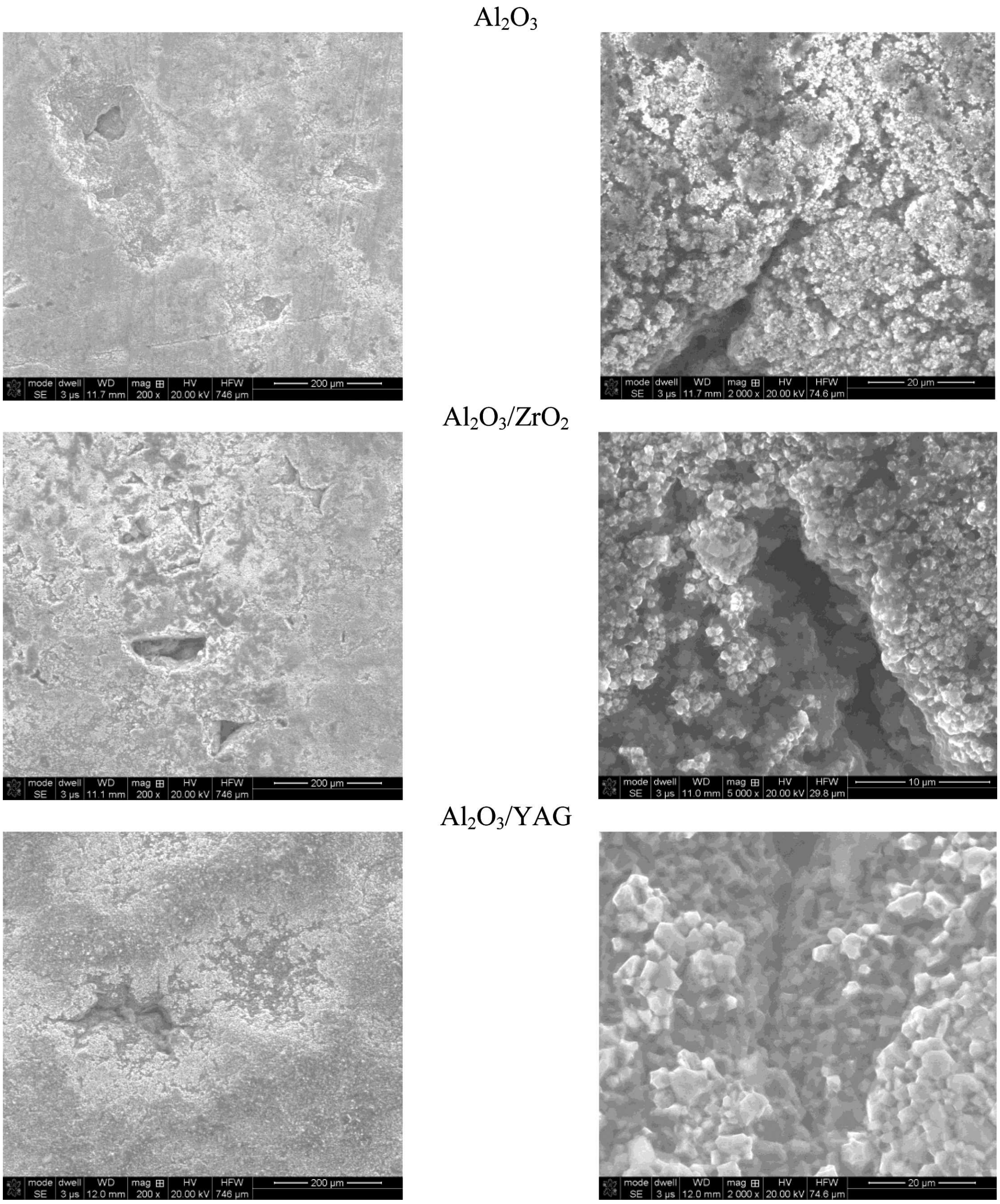

Fig. 3. Effects of cavitational erosion of ceramic materials after 3000 minutes, alumina (a), alumina-zirconia (b) and alumina-YAG composite (c)

a)

b)

c)

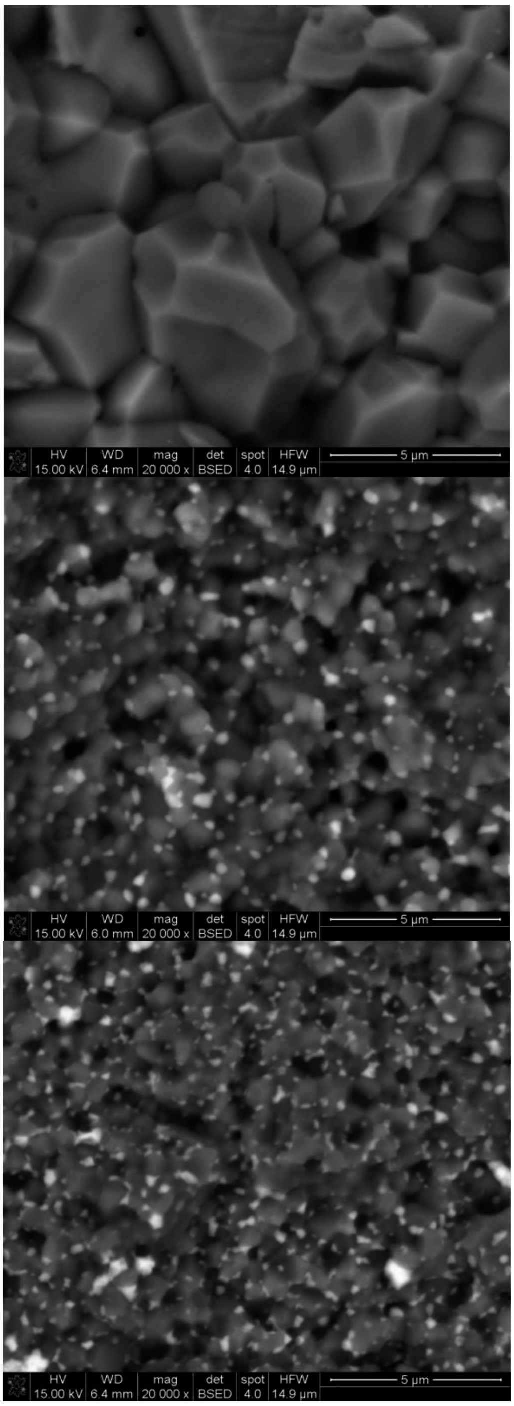

Fig. 4. A typical images of ceramic samples after cavitation test – alumina (a), alumina-YAG composite (b) and alumina-zirconia (c)

5. Summary

Investigated ceramic materials showed higher resistance to cavitation erosion than FeAl intermetallic alloys. Al_2O_3/ZrO_2 and Al_2O_3/YAG ceramics were found to be the most resistant on proposed cavitation erosion conditions. They exhibited about 15 times larger resistance on cavitation erosion than FeAl intermetallic alloys. Reasons of so large difference between ceramic materials and FeAl intermetallic alloys originate from their mechanical and structural properties. Ceramic materials posses very good resistance to cavitation erosion due to high hardness, fine-grained structure and the lack of internal defects. High resistance on corrosion in aggressive environments coupled with very good resistance on cavitation erosion allow to suppose, that ceramic materials can be successfully applied on fluid-flow machinery elements.

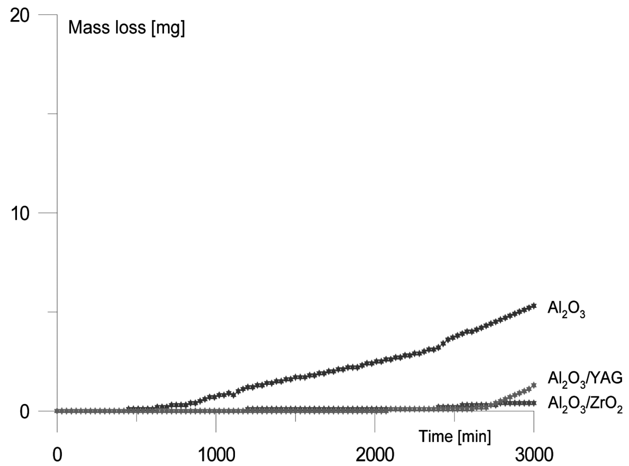

Fig. 5. Mass change kinetic curves of ceramic samples during cavitation test

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