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The method for determination of the beginning of cavitational wear through comparison of mass decrement and destroyed surface increment on the example of FeAl36 alloy

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Abstract

Cavitational erosion is the phenomenon of mechanical destruction of a material due to the implosion of cavitational bubbles. Cavitational resistance is the ability of material to oppose the effect of cavitation being determined most frequently by analysing the kinetics of destruction of a material being examined on a given device. Materials with the highest resistance to cavitational destruction are characterised by the longest incubation period and smaller destruction rate. The carried out laboratory tests of resistance to cavitational erosion showed that determination of the beginning of cavitational wear is very difficult because the kinetics of cavitational destruction depends on: test bed type, tested material and test time.

The aim of presented study was to propose a method for determination of the beginning of cavitational wear through comparison of mass decrement and destroyed area increment curves on the example of FeAl36 intermetallic alloy subjected to the cavitational wear on a flux-impact test stand.

Key words: cavitation, cavitational wear, intermetallic alloys.

1. Introduction

The kinetics of cavitational destruction reflecting the effect of cavitation phenomenon on the surface of material, i.e. strengthening of surface layer, changes in surface micro-geometry, development of micro-cracks, detachment of single grains or grain agglomerations, and formation of pitting. Experimental examinations carried out on the kinetics of cavitational destruction showed that the curves of mass decrement or volume decrement of the material exposed to the cavitation phenomenon over time are the best and the simplest indicator of cavitational erosion. Other measures of the resistance to cavitational erosion being applied can be: maximum erosion rate, mean erosion penetration rate, changes in surface roughness, maximum depth of cavitational erosion, mean depth of cavitational erosion, and eroded material area [1].

The diagram of the kinetics of cavitational destruction most frequently adopted is that one presented by A. Thiruvengadam and H.S. Preiser [2] in the form of mass decrement rate curves. The model (Fig. 1) has been confirmed and interpreted much broader by other researchers: J.W. Tichler [3], M.S. Plesset and R.E. Devine [4] or K. Steller [5].

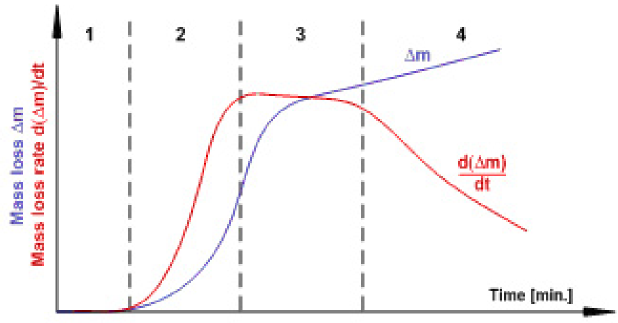

Fig. 1. Kinetics of the destruction of cavitation

When analyzing the kinetics of cavitational destruction, it is possible to distinguish its four stages:

- incubation period (1) – initial period of destruction during which there are no mass decrement, whereas fatigue processes and plastic strain effects occur and micro-cracks develop on the surface exposed to cavitational destruction;
- mass decrement rate increase period (2) – a rapid increase of mass decrement rate appears, from zero to maximum value, induced by development of micro-cracks and chipping of material particles due to the exceedance of fatigue strength threshold on the material surface;
- mass decrement rate decrease period (3) – is being characterised by a gradual decrease of material loss rate on the surface where no accumulation of internal stresses has occurred yet. Reduction of the destruction is caused, among others, by partial absorption of cavitational blows by the liquid filling cavities in the material;
- constant mass decrement rate period (4) – it is a time when a balance between the amount of accumulated energy and that of the energy lost together with material particles being removed is achieved.

Development of cavitation examinations contributed to the emergence of various testing equipment, for which respective destruction periods present themselves differently than in Fig. 1. They depend of test stand, tested material, cavitation intensity and exposure time. The studies carried out by G.P. Thomas and J.H. Brunton [6] on a flux-impact test allowed isolation of three periods of destruction induced by the mechanical effect of water stream: incubation period, mass decrement rate increase period, and mass decrement decrease period (Fig. 2).

R. Canavelis, when obtaining the similar kinetics of cavitational destruction, isolated however two stages in the incubation period:

τ_0 – stage without material mass loss, and

τ_1 – stage with small mass decrement and minimum erosion rate (Fig. 3).

Analysis of the results of metal material examinations carried out on twenty laboratory test beds within the International Cavitation Erosion Test showed that only few cases succeeded to confirm a classical course of destruction kinetics presented in Fig. 1 or 2 [8]. In most cases of the tests being carried out, cavitational destruction kinetics curves were obtained which contained only first two periods, i.e. incubation period and mass decrement rate increase period. The main reasons of differences in the kinetics of cavitational destruction were:

- material properties; in case of materials with low plasticity boundary (aluminium alloys), mass decrement occurred during a short-term loading (lack of incubation period);
- too short test time (lack of mass decrement rate decrease period);
- changes in the cavitational loading due to changes in material surface geometry induced by cavitational erosion on flow test beds or withdrawal of the surface being eroded from the impact zone of cavitational cloud on vibration test beds (lack of mass decrement rate decrease period);
- carrying out tests until the maximum value of mass decrement rate d(Δm)/dt was obtained (lack of mass decrement rate decrease period).

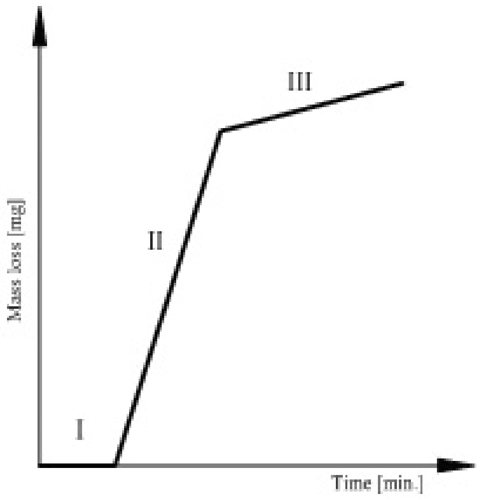

Fig. 2. Kinetics of the destruction of cavitation by G.P. Thomasa i J.H. Bruntona [6]

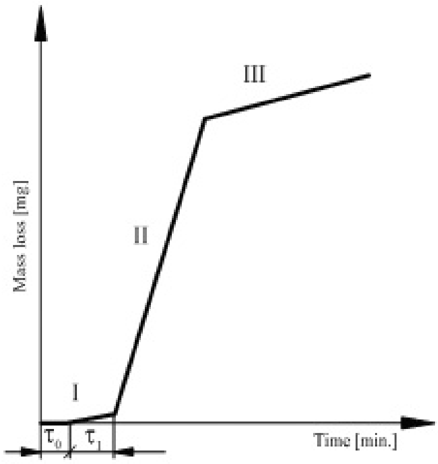

Fig. 3. Kinetics of the destruction of cavitation by R. Canavelisa [7]

The results of ICET (International Cavitation Erosion Test) tests confirmed the theses presented by H. G. Feller and Y. Kharrazi [9] that the longer incubation period and the smaller maximum destruction rate, the larger is resistance of material to cavitational erosion. Determination of the beginning of cavitational wear based on the results of laboratory tests is very difficult. The methods most frequently applied in determination of the end of incubation period include:

- a method for determination of point A, i.e. of the end of incubation period through intersection of two straight lines: a line y_1 tangential to the curve in the incubation period and a tangent line y_2 in the period of mass decrement rate increase (Fig. 4); and
- calculation methods which are based on phenomenological models of cavitational erosion kinetics [11].

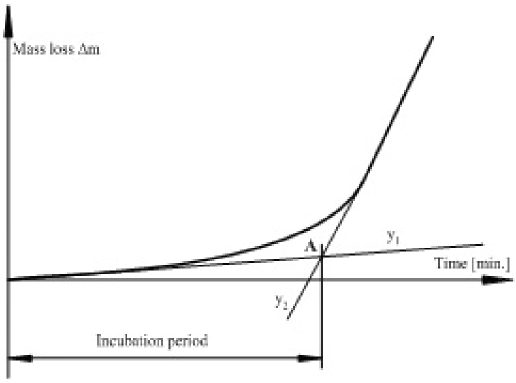

Fig. 4. The method for determination of the end of incubation period [10]

The kinetics of cavitational destruction depends on the type of laboratory test bed and the material being tested, which causes a difficulty in selecting a universal method allowing determination of the beginning of cavitational wear.

The aim of presented study was to propose a method for determination of the beginning of cavitational wear through comparison of mass decrement and destroyed area increment curves on the example of FeAl36 intermetallic phase-based alloy subjected to the cavitational wear.

2. Materials and research methods

The study covered two samples with the FeAl36 intermetallic alloy with molybdenum, boron, zirconium and carbon microadditions. The chemical composition of the examined material and the selected mechanical properties are presented in Table 1.

Table 1. FeAl36 intermetallic alloys subjected to cavitation erosion

FeAl36							
Element						Density [kg/m^3]	Hardness HV0,1
Al	Mo	Zr	B	C	Fe		
36,0	0,22	0,10	0,01	0,13	63,54	6255	297,34

The intermetallic FeAl36 alloy is in the cast state and had the α-state one-phase structure of the solid aluminium solution in iron (Fig. 5).

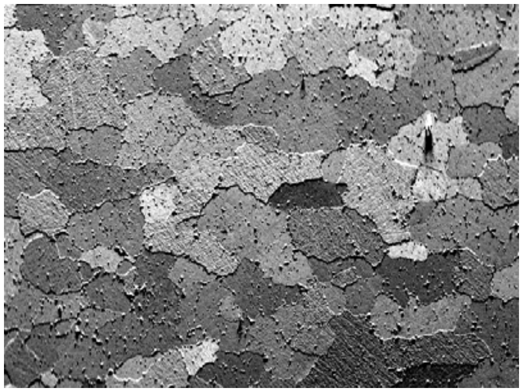

Fig. 5. Typical microstructure of FeAl36 alloy after cast

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 2 samples of each alloy, examined for the total time 3000 minutes.

The area of destroyed surface in result of cavitational destruction was calculated in mm^2 in eight time intervals by means of Analysis computer software, being part of Philips XL30LaB6 electron microscope equipment. Calculations were made based on macroscopic photographs enlarged fourteen times.

3. Study results and their analysis

The area of destroyed surface in result of cavitational destruction FeAl36 intermetallic alloy presented in Figure 6.

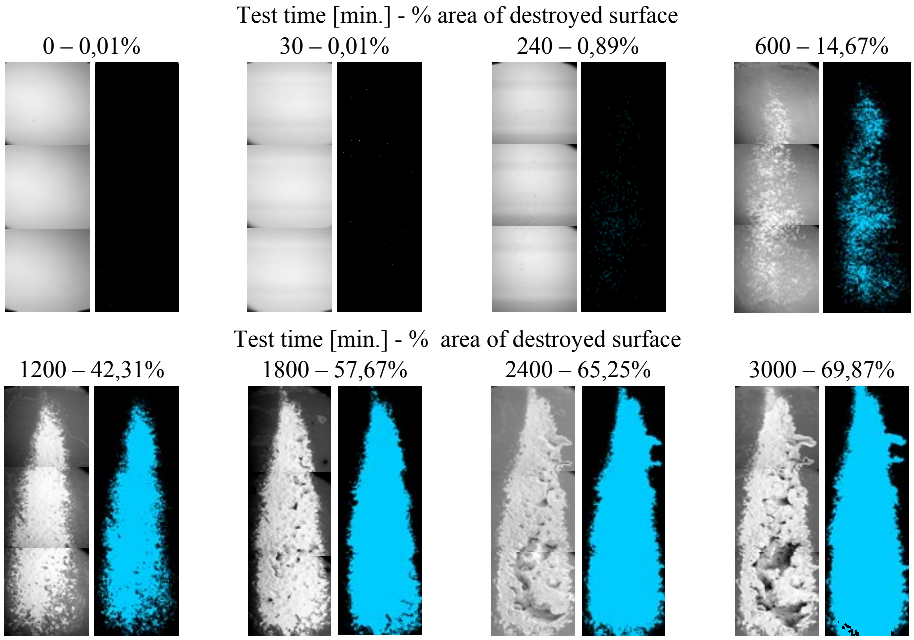

Fig. 6. The area of destroyed surface in result of cavitational destruction FeAl36 intermetallic alloy

When analysing the results of tests of resistance to cavitational wear of the FeAl36 alloy (Fig. 7), it is possible to isolate two destruction stages τ_0 and τ_1, being components of the incubation period. The end of period τ_0 amounts approximately to 240 minutes of testing. The destroyed surface of samples is about 0.9%. On the surfaces, numerous plastic strains and small quantity of very small material losses, amounting to about 0.1 mm, are visible. Submission of the tested samples to cavitational loading to 600 minutes leads to development of cracks along the grain boundaries and grain crushing, which induces a fast increment of the surface being destroyed (ok. 14%) with a small increase of mass decrement (0.2 mg). Further tests of cavitational wear resistance induce a rapid increase of the area of surface under destruction and a small increase of mass decrement rate. Such a course of cavitational destruction proceeds up to 1800 minutes. The percentage of damaged area amounts then to about 60%, while mass decrement to about 4 mg. On the sample surfaces, it is possible to observe development of deeper craters. When analysing the course of curves for the increment of surface being destroyed in the time of about 1550÷1600 minutes, a change in the rate of increment for the surface being destroyed and the rate of mass decrement in the tested samples occurs. This point can be defined as the end of incubation period, while the beginning of second cavitational destruction period kinetics as the end of mass decrement increase rate. This period is characterised by a higher rate of material erosion induced by the loss of whole grains or their clusters, causing the development of deep craters on the surface samples [12, 13].

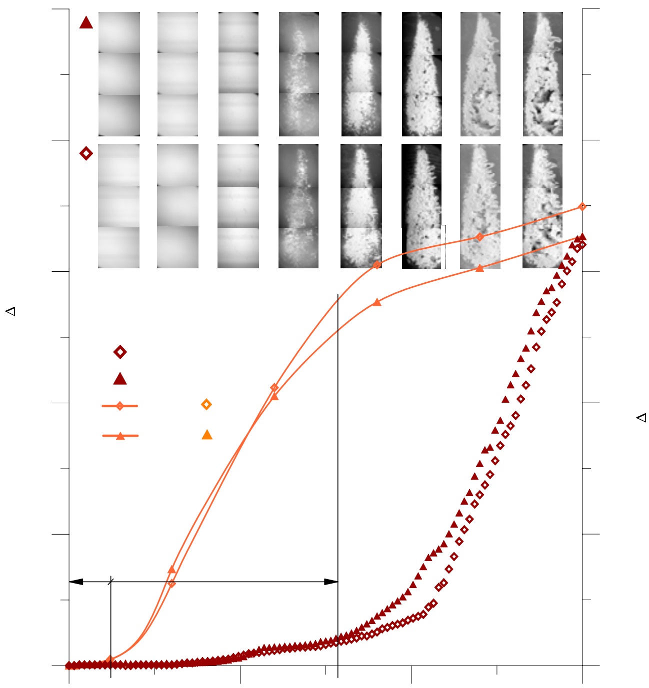

Fig. 7. Comparison of mass decrement and destroyed area increment curves on FeAl36 intermetallic alloy

In this period, a phenomenon of cavitational erosion progression deep into the material occurs, the evidence of which is the slope of curves in Fig. 7, i.e. a rapid increase of mass decrement and a minimum increase of the surface being destroyed.

4. Conclusion

The course of cavitational destruction of metal materials is very complex and depends first of all on the intensity of cavitation phenomenon and the mechanical properties of material, especially the resistance to fatigue effects of cavitation pulses. Unpredictability of the process of cavitational erosion induces different kinetics of destruction, in which it is possible to distinguish two periods: incubation period and mass decrement rate increase period. The carried out tests of the resistance to cavitational erosion of metal materials showed a difficulty in determining the beginning of cavitational wear. The presented method allows detailed determination of the end of first destruction period through additional tests of destroyed surface increment and comparison of their curves with those of mass decrement. The usefulness of the developed method should be verified on other types of laboratory equipment for testing the resistance of materials to cavitational destruction, which will be the subject of further studies.

Acknowledgements

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