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Mathematical description and evaluation of cavitation erosion resistance of materials

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Abstract: This work presents mathematical model describing cavitation erosion of materials. The model of cavitation erosion is based on Weibull's distribution. The model describes influence of material properties i.e. relative resistance to plastic deformation and stress intensity factor of hardened surface layer under cavitation loading on the cavitation erosion of materials. Moreover new factor describing of cavitation erosion resistance of materials was proposed. New coefficient of cavitation erosion resistance R is a function of incubation time, maximum volume loss rate v_{max} and time replying of v_{max} rate. The factor lets to evaluate of materials according to their cavitation resistance. In additional there is possibility to define influence of mechanical properties to cavitation resistance making use this new factor.

Keywords: Cavitation erosion, Evaluation, Mathematical model

1. INTRODUCTION

Cavitation erosion is a progressive loss of material from a solid due to the impact action of the collapsing bubbles or cavities in the liquid near the material surface. The failure of pipelines, pumps, water turbine blades and other hydraulic sets can often be attributed to cavitation erosion.
Because there is no mathematical model of cavitation erosion, which describes this kind of wear in precisions way [3, 5,6], assessment of cavitation erosion resistance of materials can be done only by comparison of erosion curves (volume loss in time and volume loss rate of erosion) for different materials [1, 2, 4]. However investigations of materials, to determine such relationships, are labour-consuming. These investigations are carried out in the lab field and they are very expensive, too.
This work proposes mathematical model which will permit to define volume loss of material and volume loss rate of cavitation erosion taking into account of exposure time under cavitation loading, or to define time of exposition after assumption of volume loss limit.

2. CAVITATION EROSION OF MATERIALS

Typical cavitation erosion curve determined in lab field is presented in Fig. 1. Four periods can be defined on this curve. First, incubation period, is an initial period of damage in which volume loss of material is non-measurable. In this time material accumulates energy, plastic

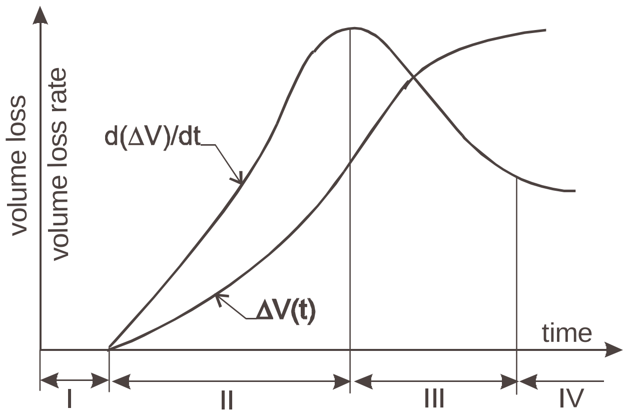

Figure 1. Cavitation erosion curves

deformation start (Fig. 2). Fatigue processes and strain hardening can occur during this time. Intensification of damage is observed in second period of cavitation erosion. This period is distinguished by violent increase of volume loss rate of erosion. In this time volume loss rate reaches maximal value. In third period weakening of damage is observed. Volume loss rate decreases. This course of material failure is explained by decrease of cavitation intensity caused by filling of pits with water. Last, fourth period, is characterized by almost constant volume loss rate of erosion.

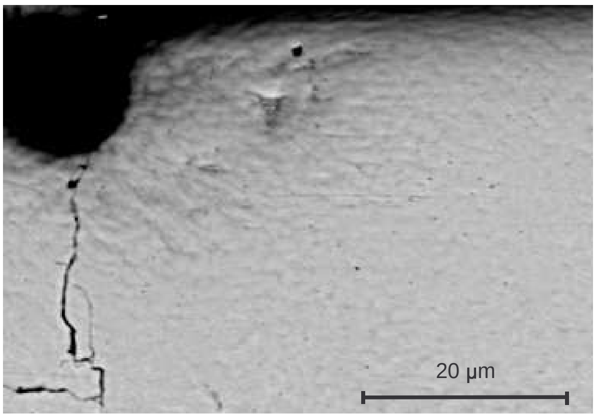

Figure 2. Plastic deformation and cracks due to cavitation loading in laser formed clad

3. MATHEMATICAL MODEL OF CAVITATION EROSION

Model describing of cavitation erosion of materials assumes that:

- intensity of cavitation erosion is constant on eroded surface,
- cavitation erosion is a phenomenon which can be described by distribution function,
- probability of volume loss depends on relative intensity of cavitation I, dimensions of material, (A – surface area and H – height of sample) and properties of material i.e.:
    - resistance to plastic deformation under cavitation loading - $1/W_{pl}$, where W_{pl} is a relative work of plastic deformation on the eroded surface,
    - relative stress intensity factor under cavitation loading - K_{cd},
    - depth of strain hardening or max. length of cracks on the end of incubation period – h,
- $P(V_0)$ i.e. probability of cumulative volume loss for elementary volume V_0 is described by Weibull's function:

$$P(V_0)=1-\exp\left\{-I\cdot V_0\cdot\left(\frac{t}{K_{c_d}}\right)^{\frac{1}{W_{pl}}}\right\} \tag{1}$$

where: V_0 – elementary volume $V_0 = A\cdot h$,
Cumulative probability of volume loss for arbitrary eroded volume $V=n\cdot V_0$ is equalled $[P(V_0)]^n$ i.e.

$$P(V)=[P(V_0)]^n=[P(V_0)]^{V/V_0} \tag{2}$$

and after transformations

$$P(V)=\exp\left\{\frac{V}{V_0}\ln\left[1-\exp\left(-I\cdot V_0\left(\frac{t}{K_{c_d}}\right)^{\frac{1}{W_{pl}}}\right)\right]\right\}. \tag{3}$$

Volume loss of material is a product of initial volume and cumulative probability of volume loss P(V) i.e.

$$V(t)=V\cdot\exp\left\{\frac{H}{h}\ln\left[1-\exp\left(-I\cdot A\cdot h\cdot\left(\frac{t}{K_{c_d}}\right)^{\frac{1}{W_{pl}}}\right)\right]\right\} \tag{4}$$

4. EVALUATION OF MATERIALS

In literature the single-value parameters defined on the base of adduced curves (Fig. 1) are met [2-6]. Among factors characterising the cavitation erosion resistance of materials have been proposed such as:

- incubation time t_{inc}
- total volume loss after defined time,
- maximum volume loss rate v_{max},
- maximum damage penetration rate MDPR,
- mean erosion depth after defined exposition period,
- mean durability δ_{cav} defined as:

$$\delta_{cav}=\frac{1}{T}\int_0^T\left(\frac{d(\Delta V)}{dt}\right)^{-1}dt \tag{5}$$

where: T - exposition period,

This last factor in the best way reflects cavitation resistance of materials because it is representing the results of the whole erosion test. But this coefficient is difficult to calculate.

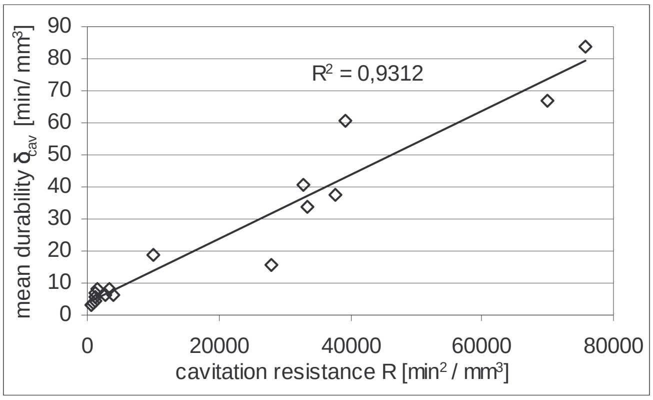

Figure 3. Mean durability as a function of R rate

New factor of cavitation erosion resistance of materials R can be defined as:

$$R = \frac{t_{inc} + t_{v\max}}{v_{\max}} \tag{6}$$

where t_{vmax} - time replying of v_{max}

On Fig. 3 relationship between mean durability δ_{cav} and R rate is presented. How results from this figure there is very good correlation between those coefficients. However R rate has one advantag. It is easier to calculation than mean durability. Investigation of influence of mechanical properties of materials on the cavitation erosion resistance will be easier when R coefficient will be considered.

4. CONCLUSION

The role of the mechanical properties of materials in the cavitational damage resistance can be easier to define if we will separately determine influence of these parameters on the incubation time, maximal volume loss rate and time replying of maximal volume loss rate (t_{vmax}).

REFERENCES

1. ASTM Standard G32-85, Standard method of vibratory cavitation erosion test.
2. CSN 015082-76, Cavitation Erosion, Polish Standards.
3. J. Noskievič, Vergleich verschiedener mathematischer Modelle der durch Kavitation verursachten Werkstoffzerstörung, Prace IMP, z. 90-91, 1989.
4. PN-86/H-04427, Cavitation Erosion, Polish Standards.
5. L. Sitnik, Mathematical description of the cavitation erosion process and its utilization for increasing the materials resistance to cavitation, Proceeding of Cavitation in Hydraulic Structures and turbomachinery, Albuquerque, New Mexico, 1985.
6. K. Steller, On prediction of durability of structural materials subjected to cavitation, Proceeding of Second Int. Conf. On Cavitation, I Mech. E Publ. 1983.