



Logistic curve model of cavitation erosion progress in metallic materials

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ABSTRACT

The authors previously found that the change in volume loss rate with the exposure time can be expressed by a logistic curve. In this study, the validity of this model is examined for various materials such as pure aluminum, carbon steels, stainless steels, cobalt alloys, and so on. The MDE (mean depth of erosion) d as a function of the exposure time can be expressed by three parameters α , β and c as in the following equation:

$$d = \frac{\alpha}{\beta} t - \frac{1}{\beta} \ln \frac{1+c}{1+ce^{-\alpha t}}$$

The parameters α , β and c are derived from the relation between the nominal incubation period and the slope of the maximum rate stage, from the average thickness of the removed layer when the nominal incubation period is terminated, and from an arbitrary point (t_0 , d_0) of the MDE in the maximum rate stage. We conclude that the calculated curve based on this model is in good agreement with the MDE data points for various materials, test conditions and test methods.

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1. Introduction

One of the major issues of cavitation erosion is the difficulty of predicting cumulative erosion during in-service conditions. Cavitation erosion is a fatigue phenomenon that is caused by a large number of cyclic impact loads that are generated by bubble collapses near a material surface in a very short time. It is very important to describe cavitation erosion behavior in order to predict the amount of erosion. Kato [1] reported a method for estimating the amount of erosion by using the energy generated in a bubble collapse on a hydrofoil in a flow system. Moreover Rao and Buckeley [2] reported a long-term prediction model and an analytical method for a rotating disk facility. However, it is not clear how far the methods of both researches can be applied for the other test methods as well. Karimi et al. [3–5] determined the cavitation erosion rate by a model based on mechanical properties such as proof stress, rupture stress and work hardening, and the frequency distribution of impact loads. This model can be applied to various types of cavitation but it cannot express in a single equation the erosion over the whole period. Meged proposed the modeling of vibratory cavitation erosion test results by a Weibull distribution [6,7]. But, his model needs the drawing of Weibull plot to obtain the Weibull parameters.

One of the present authors [8] reported that the cavitation erosion process can be expressed with a logistic curve. In the previous study [8], only aluminum oxide and pure copper were used as test materials, and vibratory apparatus with a double amplitude of 50 μm was used for the tests.

In our present study, we try to reduce the number of parameters of the erosion process equation proposed in the previous study [8]. Moreover, the applicability of the erosion process equation is now discussed for various materials, test conditions and test methods.

2. Previous study of logistic curve model

Fig. 1 shows the erosion process model proposed in our previous study [8]. Existing pits are considered as nucleuses to generate new erosion pits. The process of pit creation is retained in the erosion process. The variation in the number p of erosion pits per unit time is given by

$$\frac{dp}{dt} = \alpha p \quad (1)$$

If the volume of the erosion particles is almost the same, the volume loss per unit time (volume loss rate) u can be expressed as:

$$\frac{du}{dt} = \alpha u \quad (2)$$

Moreover, the number and volume of the annihilated pits at any time increment is proportional to the actual pit number, and therefore to u . The probability of annihilating a specific pit is proportional to pit concentration, and therefore to u/F , with F denoting the

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Nomenclature

A	the constant of the relation between the slope of MDE curve in the maximum rate stage and the inverse of incubation period (μm)
t	exposure time (h)
u	volume loss rate (mm^3/h)
u_0	initial volume loss rate (mm^3/h)
V	volume loss (mm^3)
α	multiplication factor in pit number per unit time ($1/\text{h}$)
β	annihilation factor in pit number per unit time ($1/\mu\text{m}$)
α/β	maximum erosion rate ($\mu\text{m}/\text{h}$)
c	constant given by the product of α/β and u_0
d	MDE (mean depth of erosion) (μm)
t_i	exposure duration associated with nominal incubation period (h)
d_i	MDE at t_i (μm)
t_0	arbitrary time in the maximum rate stage (h)
d_0	MDE at t_0 (μm)

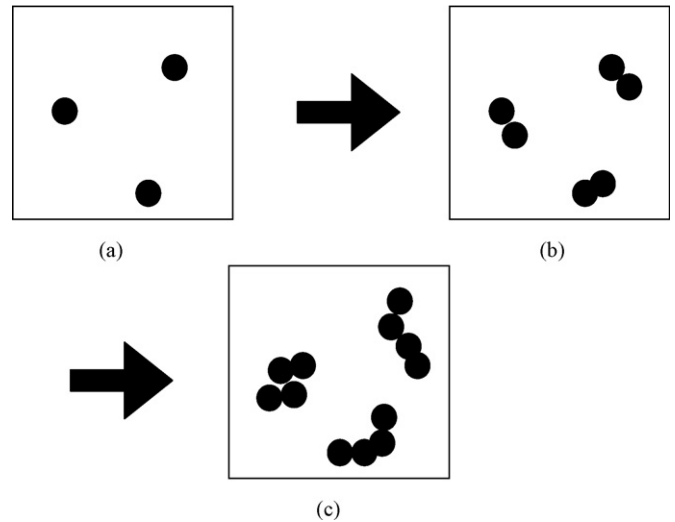


Fig. 1. Erosion process model.

eroded surface area:

$$\frac{du}{dt} = -\frac{\beta}{F}u^2$$

$$(3) \quad \frac{du}{dt} = \alpha u - \frac{\beta}{F}u^2 \quad (4)$$

Table 1

Chemical composition in mass %.

	Si	Fe	Cu	Mn	Mg	Cr	Zn	V	Ti	Al
A1050	0.09	0.14	0.01	0.01	0.01	0	0.01	–	0.01	Bal
A1070	0.09	0.15	0.01	0.01	0.01	0	0	0.01	0.01	Bal
C1020	–	–	99.96	–	–	–	–	–	–	–
C1100	–	–	99.90	–	–	–	–	–	–	–
	C	Si	Mn	P	S	Cu	Cr	Ni	Fe	
S15C	0.15	0.25	0.47	0.015	0.013	0.14	0.18	0.04	Bal	
S55C	0.54	0.27	0.82	0.016	0.017	0.14	0.18	0.04	Bal	
SS400	0.14	0.25	0.46	0.21	0.013	–	–	–	–	
	C	Si	Mn	P	S	Ni	Cr	Mo		
SK95	0.94	0.23	0.73	0.027	0.063	0.12				
	C	Si	Mn	P	S	Ni	Cr	Mo		
FC200	3.38	2.19	0.58	0.021	0.016	–	0.038	–		
	C	Si	Mn	P	S	Cr	Ni	Mo	Cu	
SUS304	0.05	0.37	1.19	0.026	0.004	18.17	8.16	–	–	
SUS316	0.05	0.24	1.36	0.033	0.027	16.94	10.21	2.06	–	
SUS630	0.05	0.3	0.89	0.039	0.004	15.66	4.29	–	3.35	
	C	Si	Mn	P	S	Ni	Cr	Mo		
SCS3	0.1	0.73	0.55	0.037	0.005	1.38	12.75	0.7		
SCS5	0.06	1	1	0.04	0.04	4	13.5	–		
SCS16	0.03	1.5	2	0.04	0.04	14	18.5	2.5		
	Co	Fe	Cr	W	Ni	C	Mn	Si		
Pure-Co	100	–	–	–	–	–	–	–		
Co–2 wt%Fe	98	2	–	–	–	–	–	–		
Co–4 wt%Fe	96	4	–	–	–	–	–	–		
Co–10 wt%Fe	90	10	–	–	–	–	–	–		

A1050 and A1070 are pure aluminum. C1020 and C1100 are pure copper. S15C is a carbon steel with a carbon of 0.15%. S55C is a carbon steel with a carbon of 0.55%. SS400 is a rolled steel for general structure with a tensile strength of 400 MPa. SK95 is a high carbon steel. FC200 is gray cast iron. SUS shows a rolled stainless steel. SCS shows a cast stainless steel.

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