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Correlation of cavitation erosion resistance and mechanical properties of some engineering steels

CHEN WENGE*, GU CHENQING, ZHAO KANG, SHEN FUSAN
School of Materials Science and Engineering, Xi'an University of Technology, Xi'an, Shaanxi 710048, People Republic China

Cavitation and cavitation erosion are often observed in mechanical parts such as hydraulic turbines, water pumps, and ship propeller parts. The destruction, due to cavitations erosion, results in enormous financial expense. Former research results [1–4] have shown that the mechanical action caused by strong pulsating pressure plays the major role in the cavitation erosion failure. In the very early state of detecting the cavitations, the hardness of material was employed to predict its cavitation erosion resistance. However, it is known later that materials with the same hardness may have different mechanical behaviors [5, 6]. This makes the application of such prediction methods less favorable. To resolve the issue, the strain energy was introduced to evaluate the cavitations erosion resistance of materials. The examples of strain energy are (i) engineering strain energy, (ii) limiting tensile strain energy and (iii) elastic strain energy. Later research results showed that its applicability still has room for improvement.

In recent years, the fatigue mechanism of cavitations erosion has been introduced [7]. The cavitations erosion resistance of some alloys has shown to be increased linearly with the increase of composite fatigue parameter $\sigma_f \cdot n'$, where σ_f is the fatigue strength coefficient and n' is the recycling strain strengthening exponent. Apparently, using the composite parameter to evaluate the cavitation erosion resistance of material is a profound methodology. The mathematical model reflects the complexity of cavitation erosion mechanism.

Based on the past research work mentioned above, it is seen that the cavitation erosion resistance of material would need more than one strength parameters to model. Here, we introduce new parameters to form the correlation.

Parameter T is raised from the point of view that cavitations erosion is the result of strain fatigue failure. Here, it is clearly shown that strain-hardening ability at the stage of uniform strain is an important factor which enhances the cavitations erosion resistance of materials. T is the uniform deformation strengthening modulus of material and it is defined as

$$T = \frac{\delta_b - \delta_{0.2}}{\varepsilon_f}$$

where ε_f is true strain obtained in static tensile test. $\varepsilon_f = \ln(1 - \Psi)$, σ_b, $\sigma_{0.2}$ and Ψ are the tensile strength, the yield strength and the reduction of cross-sectional area, respectively.

The parameter N is considered as the impact load property. This is because the cavitations erosion is an impact failure under micro-shooting flow and pulsating wave [8]. This also applies in both high cavitations erosion resistance of material and low one as it depends on the material's ability in absorbing the impact energy. Cavitations erosion takes place only at local areas, so the ability of material in absorbing impact working through local coordination deformation appears to be more important. Therefore mechanical property parameter N is introduced as absorbed impact energy per unit deformation volume.

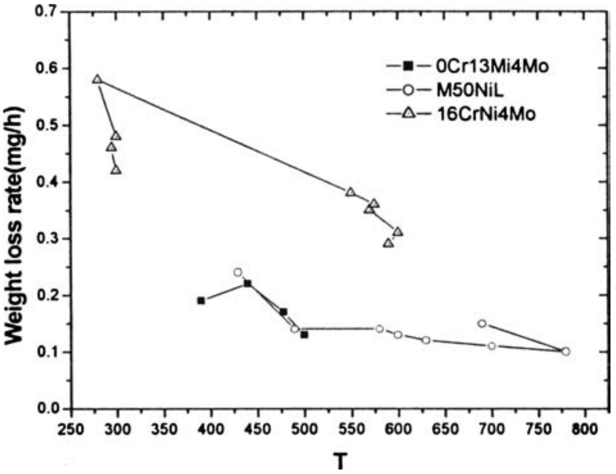

Figure 1 Weight–loss rates of cavitation erosion as a function of parameter *T*.

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* Author to whom all correspondence should be addressed.

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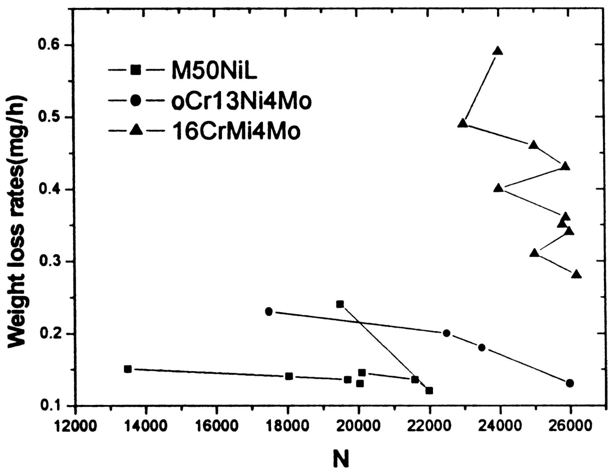

Figure 2 Weight–loss rates of cavitation erosion as a function of parameter *N*.

The parameter *N* is defined as

$$N = \frac{E\mathrm{i}}{S\mathrm{i}} + \frac{E\mathrm{p}}{S\mathrm{p}}$$

where *E* is the total energy (work) that the specimens absorbed during fracture. *E*i and *E*p are crack formation work (including elastic and plastic strain work) and crack extension work, respectively. *S* is the maximum offset at the point of fracture. *S*i and *S*p are the respective offset corresponding to *E*i and *E*p.

The curves of the composite property *T* of the steels and parameter *N* and weight-loss rates of the steels are shown in Figs 1 and 2. From the Figs 1 and 2, it can be seen that the weight-loss rates of cavitation erosion with either *N* or *T* alone is not well regularized.

At the same time cavitations intensity factor is introduced, according to its relation to water-current speed [9] i.e. $I = A.V^{\mathrm{n}}$ (where *I* is the cavitation erosion extent, *V* is water-current speed across the machine; *n* is a constant which is 1–5 for rotating disc apparatus, and *A* is an invariant coefficient). Here, water-flow speed (which is relative to the water flow) is chosen to represent cavitations intensity.

As individual mechanical parameter can not well explain the complexity of cavitation-erosion mechanism, the authors, by analyzing the experimental data with statistic and generalization methods, find out the relationship of cavitation erosion resistance with the uniform deformation hardening modulus of material, the maximum absorbed impact work by unit deformation volume, and cavitation intensity (speed relative to the water flow). That is

$$W\mathrm{c} = \alpha \frac{V^2}{\sqrt{NT}}$$

where *W*c is the average weight loss rate of cavitations erosion of steel (mg/h); *V* is water current speed across the machine (m/s); *N* is the maximum absorbed impact work per unit deformation volume while the material is fractured (J/m); *T* is the uniform deformation hardening modulus of materials (MPa); and α is dimension constant (it varies with materials).

We show the empirical study from the correlation equation that we introduce, the results are shown in Fig. 3. Fig. 3 shows the relationship between *W*c and $V^2/(NT)^{1/2}$ under different cavitations intensity. Obviously, the calculated values match well in straight line with the experimental data.16CrNi4Mo steel has two sets of experimental values, the left-side values belong to the low temperature tempered specimens, while the right-side values belong to the high temperature tempered ones. M50NiL has a strange point (see Fig. 3 the right-side point), which is the experimental result data after two quenching (oil quenching and water quenching) and low temperature. The cavitations erosion resistances of four steels are evidently divided into two classes, one is M50NiL and 0Cr13Ni4Mo steels and the other is 16CrNi4Mo and Q235 steels. This difference shows that cavitation erosion is also related to other properties of material, which is affected by parameter α in the formula. It is obvious that when α is low, cavitation erosion resistance of material is high.

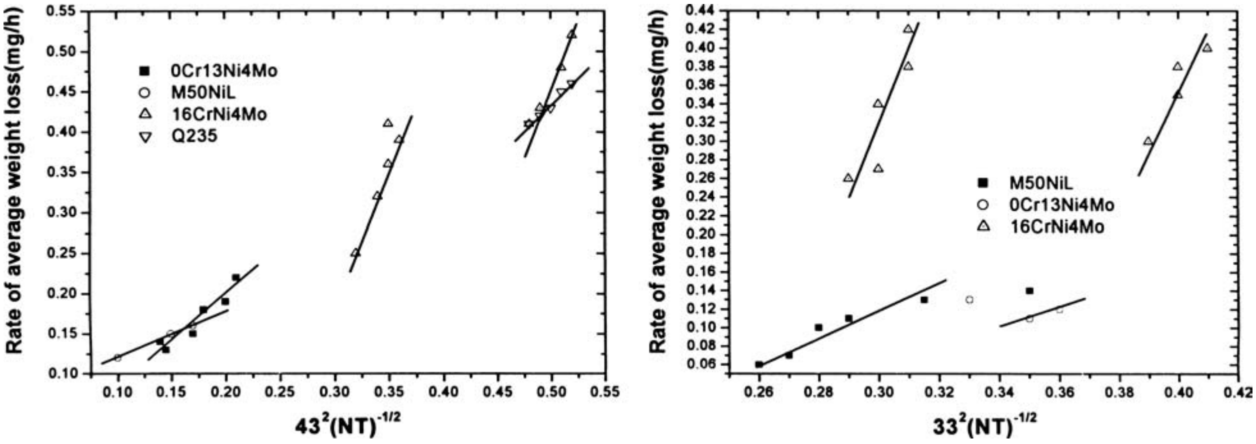

Figure 3 Comparison between the calculated and experimental results of cavitation erosion.

This paper presents a novel method in predicting the cavitations erosion resistance. We introduce new parameters and formulate an equation relating them with cavitations erosion resistance. The results of the presented method is worse than the existing methods as shown in the experimental result section. The yielded result determines the properties of materials. According to the theories of cavitation erosion formation [3, 4], the value of α can be determined by the physical–chemical property and thermal stability of materials. This is also shown in this paper. In the paper, physical–chemical property of stainless steel 0Cr13Ni4Mo is the best. M50NiL steel has the highest thermal stability and belongs to the secondary-hardening steel type. 16CrNi4Mo and Q235 steels are worse in these two properties than the other two steels.

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References

1. NIE, RONGSHENG, in "Cavitation and Cavitation Erosion of Hydraulic Turbine" (Hydraulic and Electric Publishers, China, 1985).
2. A. SHINA, K. TAKAYAMA and Y. TOMITA, *High Speed Mech.* **48** (1984) 77.
3. H. JITANG, in "The Principle and Application of Cavitation Erosion-Corrosion" (Qinhua University Publishers, China, 1991).
4. H. G. FELLER and Y. KHARRAZI, *Wear* **93** (1984) 249.
5. B. VYAS and L. H. HANSSON, *Corrosion Sci.* **30** (1990).
6. Z. KANG, G. CHENQING and S. FUSAN, *Wear* **162** (1993) 811.
7. R. H. RICHMAN and W. P. MCNAUGHTION, *ibid.* **140** (1990) 63.
8. C. S. RAO and D. H. BUCKLEY, *Mater. Sci. Eng.* **67** (1984).
9. R. T. KNAPP, J. W. DAILY and F. G. HAMMIT, in "Cavitation" (McGraw-Hill, New York, 1970).

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