Threshold erosion fracture of aero engine blades

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Abstract

A model of erosion wear of blades at threshold velocities of incidence of abrasive particles is presented. In the model the Hertzs classical impact theory is used for modeling the contact interaction of a particle with an elastic half-space. The incubation time fracture criterion is applied for predicting surface fracture.

1 Introduction

Foreign object damage (FOD) is a significant threat on aero engine components. Sources of FOD can be sand particles of various size [1]. However, this particles are small and their impacts will not lead to immediate failure, but may reduce the service life of the component.

The impact speed of dust particles to the surface of the blade greatly affects the magnitude of wear. Obviously, the greater speed of the particle and/or the greater particle size lead to greater wear of the blade. However, the theoretical dependences of blade erosion on a velocity of impact and a particle size are undetermined.

In this work we consider erosion damage of blades by combination of the Hertz problem solution and the incubation time criterion [2]. The aim of the work is to construct a model to predict the threshold erosive wear of blades at different speeds and sizes of abrasive particles.

2 Problem Formulation

Assume that the aircraft is on the ground with running engines. Sand and dust particles are sucked into the engine and falling to the turbine blades. Assume that the particles are identical and have a spherical shape and fall perpendicularly to the blade surface.

The interaction of the particle and the blade can be modeled by solving the contact problem of an impact of a spherical particle of radius R and initial velocity V with a half-space (Hertz problem) [2, 3] . According to the second law of Newton, the equation of particle displacement is as follow:

$$m\ddot{x} = F \tag{1}$$

where m is particle mass; F is determined by the elastic response of the blade. Let us use the Hertzian theory to find it:

$$F = -kx^{3/2}, k = \frac{4}{3}\frac{\sqrt{R}E}{(1-\nu^2)} \tag{2}$$

where E and ν are the Young modulus and the Poisson ratio of the blade.

Assume the initial conditions are the following:

$$x(0) = 0; \dot{x}(0) = V. \tag{3}$$

Hertz solution for the contact problem give the following expression for radial stress:

$$\sigma(t, V, R) = \frac{1-2\nu}{2\pi}\frac{k}{R}\sqrt{x_0 \sin\frac{\pi t}{t_0}} \tag{4}$$

where x_0 is the maximum depth and t_0 is impact duration.

To assess the possibility of fracture in conditions of an erosion process we use the incubation time criterion:

$$\max_t \int_{t-\tau}^{t} \sigma(s)ds \leq \sigma_c\tau \tag{5}$$

where $\sigma(t)$ is the current tearing stress; σ_c is the material static strength, and τ is the brittle fracture incubation time. The incubation time is considered as a physical constant of the material describing the duration of preparation of the medium to fracture or a phase transition, which can be determined experimental or theoretically.

The application of the criterion (5) allow to analyze the behavior of threshold (the minimal external effects causing fracture) characteristics of fracture, such as threshold speed V^* of particle impact.

The determining criteria relation has the form of following equality:

$$f(V, R, \tau) = \max_t \int_{t-\tau}^{t} \sigma_r(V, R, s)ds - \sigma_c\tau \tag{6}$$

where σ_r is the maximal (radial) tearing stress at the surface points adjoining the contact area.

After simplification (6) takes the form

$$\frac{1-2\nu}{2\pi}\frac{k}{R}\sqrt{x_0}\int_{\frac{\lambda-1}{2}}^{\frac{\lambda+1}{2}} \sqrt{\sin\frac{\pi}{\lambda}[H(\tilde{t}) - H(\tilde{t}-\lambda)]d\tilde{t}} = \sigma_c \tag{7}$$

where λ is dimensionless parameter, and it can be expressed through V and R:

$$\lambda = \frac{t_0}{\tau} = \left(\frac{5\pi(1-\nu^2)}{4}\right)^{\frac{2}{5}} \frac{\rho^{\frac{2}{5}} R}{\tau E^{\frac{2}{5}} V^{\frac{1}{5}}}$$

and

$$\frac{1-2\nu}{2\pi} \frac{k}{R} \sqrt{x_0} = \frac{1-2\nu}{2\pi} \left(\frac{5}{3}\pi\right)^{\frac{1}{5}} \left(\frac{4}{3(1-\nu^2)}\right)^{\frac{4}{5}} V^{\frac{2}{5}} \rho^{\frac{1}{5}} E^{\frac{4}{5}}$$

The incubation time of fracture for a material can be found by solving (7) for τ if threshold impact speed V^* of the particle with the radius R is known. Thus, having determined τ, we can predict the impact threshold speeds for particles of an arbitrary size.

3 Results

Figure 1 shows the dependence of the threshold speed of erosion fracture for martensitic steel EI736 [4] on the diameter of erodent particles. This dependence has static and dynamic branches. The static (horizontal) branch has a weak dependence of the threshold speed on the particles diameter. The dynamic branch shows a rapid growth of the threshold speed upon a decrease in the particle size.

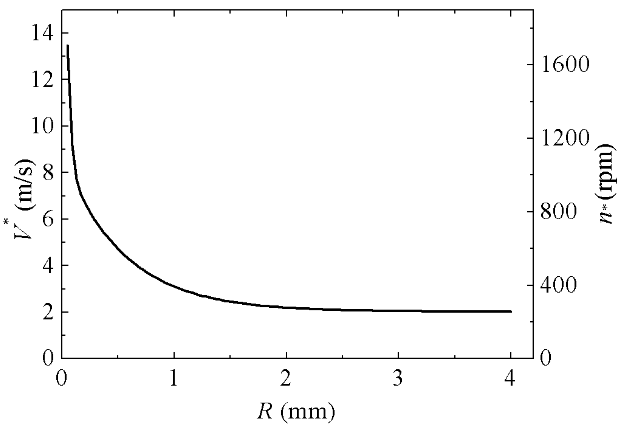

Figure 1: Dependence of the threshold particle (turbine) speed on the particle radius. The speed calculated for points in the centre of the 50 mm blade. The calculated parameters are $\sigma_c = 932$ MPa, $\tau = 10$ μs.

4 Conclusions

This work deals with the problem of erosion damage of engine blades when a blade surface is impacted with abrasive sand particles at the right angle. The Hertzs classical impact theory is used for modeling the contact interaction of a particle with an elastic half-space. To determine the threshold velocity of the particles at which the blade surface does not incur erosive fracture, the incubation time dynamic fracture criterion is applied. The constructed model allows to predict the threshold erosive wear of blades at different speeds and sizes of abrasive particles.

For the development of this work it is expected to consider the influence of different angles of impact and temperature on the threshold velocity of erosion damage of aero engine blades.

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