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Acoustic emission estimation of crack formation in aluminium alloys

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ABSTRACT

In the paper a problem on the radiation of waves of acoustic emission (AE) during formation of penny-shaped crack in aluminium alloy elastic body under tensile and twisting loading is considered. By the method of integral transforms, the problem is reduced to the solving of Fredholm integral equation of the second kind. The dependences of component of displacement vector on time and distance to the viewpoint as well as amplitudes of the AE signals on the area of the crack and its spatial orientation are obtained.

1. Introduction

Aluminium and its alloys are widely used in modern engineering mainly in aviation and space industry. Various units, structural elements, etc. are made of them. During their operation under action of physical and chemical factors crack-like defects can form. They are especially dangerous for the structural integrity of these elements. For non-destructive testing of crack nucleation and propagation the phenomenon of acoustic emission (AE) is used. Quantitative application of AE as a method of non-destructive testing needs to find the relationships between AE signals and crack parameters (its size, spatial position, etc.). For this purpose we consider a problem of sudden formation of a penny-shaped crack in homogeneous elastic body under tensile and twisting loading (mode I and mode III, respectively). We will try to find the displacement vector components caused by this crack formation directly from equations of motion with appropriate boundary conditions corresponding to abrupt formation of the rupture without any additional conditions. We restricted our analysis to consideration of penny-shaped cracks of mode I and mode III because solving of the problem for mode II crack is more complicated and not completed yet.

2. Problem formulation and solving

2.1. Nucleation of a penny-shaped crack of mode I

According to approach proposed in [1] we replace an arbitrary shaped crack with a penny-shaped crack of the same area. Suppose that a penny-shaped crack nucleates when the tensile stresses in certain region of elastic body achieve the certain critical value σ_0. The crack formation is accompanied by the instant drop of normal stresses on its surfaces from an initial level σ_0 to zero.

Let us consider a system of cylindrical coordinates $Or\theta z$. The origin O coincides with the center of the crack of radius r_0 and the axis Oz is normal to the crack plane (see Fig. 1). At infinity tensile stresses σ are applied along Oz axes. At the time

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Nomenclature

b, m parameters of approximation
c_1, c_2 velocity of longitudinal and shear wave, respectively
r, θ, z cylindrical coordinates
r_0 radius of crack
t time
s parameter of Laplace integral transform
u_r, u_θ, u_z components of a displacement vector
V amplitude of the electric signal
λ, μ Lame's constants
v Poisson's ratio
ρ material density
σ_0, τ_0 the integral characteristics of material breaking strength
σ_{zz}, $\tau_{z\theta}$, τ_{rz} components of a stress tensor
φ, ψ scalar potentials
χ_1, χ_2 parameters of approximation
$E(k)$, $K(k)$ complete elliptic integrals of the first and second kind, respectively
$J_0(\cdot)$ and $J_1(\cdot)$ is the zero and first order Bessel functions of the first kind
$F(\cdot)$, $E(\cdot)$ elliptic integrals of the first and second kind, respectively
$H(t)$ the Heaviside function

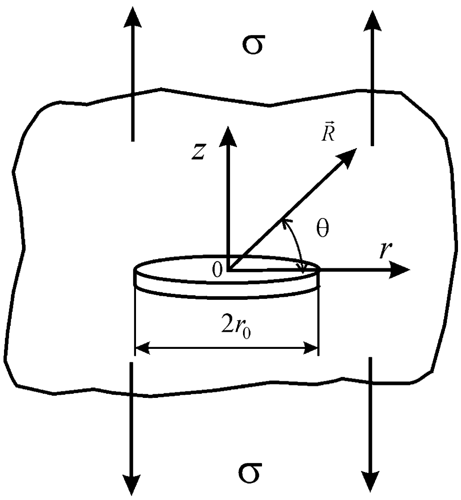

Fig. 1. A penny-shaped crack in an elastic body (mode I).

$t = 0$ they achieve certain critical value σ_0, resulting in a penny-shaped crack nucleation. Using known approaches [2–4] this problem can be reduced to the wave equations

$$\Delta\varphi - \frac{1}{c_1^2}\frac{\partial^2\varphi}{\partial t^2} = 0, \quad \Delta\psi - \frac{\psi}{r} - \frac{1}{c_2^2}\frac{\partial^2\psi}{\partial t^2} = 0, \tag{1}$$

with respect to unknown scalar potentials $\phi(r, z, t)$ and $\psi(r, z, t)$.

Eq. (1) should satisfy the boundary conditions for half-space $z > 0$

$$\begin{aligned} &\sigma_{zz}(r, 0, t) = -\sigma_0 H(t), \quad r \leqslant r_0, \\ &u_z(r, 0, t) = 0, \quad r > r_0, \\ &\tau_{rz}(r, 0, t) = 0, \quad 0 < r < \infty, \end{aligned} \tag{2}$$