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Technical Comments

Comments on "Transient Stresses in Solids Induced by Radiant Surface Heating"

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Nomenclature

z = direction of propagation
α = coefficient of linear expansion
K = thermal diffusivity
ν = related to the compressional wave velocity by $\nu = \nu_0(1 + \epsilon)^{-1/2}$
S = specific heat at constant strain
τ = a dummy variable, $U(t - z/\nu) = \begin{cases} 0, t < z/\nu \\ 1, t > z/\nu \end{cases}$
ϵ = thermoelastic coupling coefficient given by $\epsilon = \dfrac{\alpha^2 T_0 E}{\rho S}$
ρ = density
E = isothermal Young's Modulus
T_0 = reference equilibrium temperature

In a recent note Lindholm[1] describes an experiment in which he observes the stress resulting from the rapid heating of one end of a bar. The purpose of this note is to indicate the expected peak value for the thermally induced propagating stress wave in this experiment.

The exact solution of the time dependent thermoelastic equations, under conditions almost identical to those occurring in Lindholm's experiment, was obtained by Measures[2] who obtained the following expression for the thermally induced stress wave:

$$p(z,t) = -\frac{\alpha}{S}\left\{\frac{K}{\pi}\right\}^{1/2}\int_0^t\left[\frac{\exp\{-(z^2/4K\tau)\}}{(\tau)^{1/2}} - \frac{U(t - z/\nu)}{\{\tau - z/\nu\}^{1/2}}\right]\left[\frac{dQ}{d\tau}(t-\tau)\right]d\tau$$

The only assumptions made were that the changes in the properties of the body are negligible, so that a linear theory may be employed, and that the thermoelastic coupling coefficient ϵ is small as compared to unity. For lead $\epsilon = 2.4 \times 10^{-2}$, so that the latter assumption is justified.

The stress wave is seen to comprise two components: the first is diffusive in nature and extends only as far as the thermal penetration depth $(Kt)^{1/2}$, whereas the second represents a propagating stress wave and is the component of interest. An estimate for the peak value of this thermally induced propagating stress wave can be written as

$$p_{\max} = -G(\alpha/S)\{K/T\}^{1/2}Q_{\max}$$

where T is the time for Q, the thermal flux, to maximize; and G is a numerical factor (or order unity) depending on the particular form of $Q(t)$. The negative sign indicates a compressive stress.

If we use the experimental values used by Lindholm

$$Q_{\max} = 600 \text{ cal cm}^{-2}\text{ sec}^{-1} \quad T = 10^{-3}\text{ sec}$$

then for lead, the peak value of the thermal induced stress is 7.7 dynes cm^{-2}, which is very small when compared to the measured stress of 2×10^4 dynes cm^{-2}. Thus it would appear that Lindholm's suggestion that the observed stress is due to vaporization is reasonable.

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Erratum: Alternative Proposal Concerning Laminar Wakes Behind Bluff Bodies at Large Reynolds Number

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