THE GRÜNEISEN COEFFICIENT FOR UPV-1 PYROLYTIC CARBON

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Recently there have been vigorous developments in research on the mechanical parameters of materials subject to rapid energy deposition from laser beams, electron or ion beams, etc. [1-3]. Energy is absorbed in a time much less than the mechanical lag in the material, which gives rise to thermoelastic stresses. One can use sources with various spectra and energy transfer rates and materials with various absorptivities to examine the stress wave propagation and to measure the thermodynamic and elastic parameters, and also to research spalling if the absorbed energy is sufficient [4, 5].

The relation between the thermoelastic stress σ and the absorbed energy E is [6] $\sigma = \Gamma(T, V)\rho E$, in which Γ is the Grüneisen coefficient and ρ the density.

For most homogeneous isotropic bodies at temperatures above about 0.3 Θ (Θ is the Debye temperature), Γ is only slightly dependent on temperature [7] and can be expressed as [6]

$$\Gamma = \beta c_0^2/c_V,$$

in which β is the bulk expansion coefficient, c_V the specific heat, and c_0 the speed of sound, which is governed by the compressibility.

Γ is not a constant for an anisotropic material and varies with direction.

Pyrolytic graphite is convenient for examining the dependence of Γ on the anisotropy, which is made by pyrolyzing methane at hot graphite [8]. It is a fine-grained polycrystalline material having a preferred axial orientation for the crystallites, which is dependent on the mode of preparation and the treatment [9].

Measurements have been made on Γ in two perpendicular directions with a pulsed electron beam [9, 10] for PG1, PG2, and PG3 pyrolytic graphites as well as for highly anisotropic CAPG graphite. Only the values of Γ varied parallel and perpendicular to the deposition plane for PG1, PG2, and PG3, whereas the sign also varied for CAPG.

The Grüneisen coefficient for UPV-1 pyrolytic carbon made in this country was measured; the measurements were made with equipment similar in type and principle to [11], with the electron beam brought into the atmosphere. The pulse length at half height was about $1.3 \cdot 10^{-7}$ sec, maximum energy about 1 MeV, mean energy 0.3-0.5 MeV.

Two specimens 60 mm in diameter and 10 mm thick with differing orientations for the planes in relation to the deposition direction were made: perpendicular and parallel to it. The specimen thickness exceeded the electron range at the maximum energy, which was about 2 mm. The initial pyrocarbon plate was about 7 mm thick, so the specimens were prepared from separate plates cut in the necessary direction, which were cemented together with a 30-40 μm layer of epoxide resin.

The specimens 1 (Fig. 1) were cemented to 6 mm quartz plates 2 with diameter 50 mm, which were in turn cemented to the piezoelectric plate 3 (TsTS-19 ceramic, diameter 30 mm and thickness 13 mm). The fused-silica plate is necessary to improve the noise immunity. The electron beam was incident on the free front surface.

The energy transfer and the amplitude of the mechanical stress at the sensor were recorded.

The energy transfer was measured from the heating of steel complete-absorption calorimeters: the annular one 4 with outside diameter 57 mm and inside diameter 45 mm and the central one 5 with diameter 6 mm.

The electron range in the UPV-1 was substantially less than the thickness, so a bipolar stress pulse propagates towards the sensor containing compression and expansion phases.

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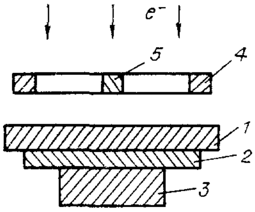

Fig. 1

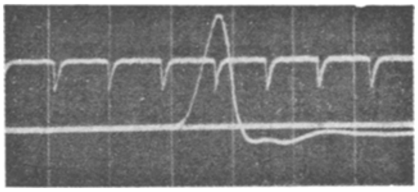

Fig. 2

TABLE 1

Material	Direction			
	c		a	
	Γ	v, cm/μsec	Γ	v, cm/μsec
UPV-1	0,26±0,04	0,36±0,04	0,17±0,03	0,53±0,05
PG1	0,3±0,03	0,33±0,05	0,3±0,03	0,65±0,05
PG2	0,29±0,02	0,35±0,05	0,32±0,03	0,55±0,05
PG3	0,3	0,36	0,2	0,61
CAPG	0,48±0,03	0,38±0,05	−0,99±0,15	2,2±0,1

Information is contained on the sign and magnitude of Γ in the phase of the leading bipolar pulse, since the second phase is due to reflection from the free irradiated surface.

The stress amplitude in the first phase of the bipolar pulse σ_1 is

$$\sigma_1 = \frac{\sigma_3}{4}\frac{(z_3+z_2)(z_2+z_1)}{z_3 z_2},$$

in which σ_3 is the stress acting at the tensor, while z_3, z_2, and z_1 are the acoustic impedances of the sensor material, the fused silica, and the specimen correspondingly, $z = \rho v$, and v is the speed of sound.

The speed of sound in the a and c directions (a along the deposition plane and c perpendicular to it) during the pulse transit were measured; Fig. 2 shows the characteristic waveform. The mark length is 0.4 μsec. The positive signal is the thermoelastic stress.

The Grüneisen coefficient was determined by comparison with that for a standard material with identical electron energy transfer, for which purpose a specimen-fused silica-piezoceramic assembly was prepared where the specimen consisted of AMG6 alloy (γ for aluminum is 2.09 [6]). That alloy was chosen because the average atomic number of the elements composing it and the density are close to those for carbon, so the energy deposition profile should be similar (the mean energy loss in inelastic collisions in a 1 cm path at 0.5 MeV would differ by less than 10%). The energy deposition did not exceed 6-8 J/cm^2. The maximum temperature rise in the carbon was a few degrees, i.e., the temperature hardly altered and was close to the room value (about 300 K).

Table 1 gives the measured Grüneisen coefficient and speed of sound for UPV-1 together with the analogous data [9, 10] for 300 K; UPV-1 is close to PG2 and PG3 but differs considerably from CAPG. CAPG has a structure that is closest to that of crystalline graphite. The crystallite sizes attain 10-40 μm in the a direction in a material made in the same way as CAPG [9], and the orientation is most highly ordered. According to [12], the crystallites in UPV-1 are about 0.19 μm in size. Pyrolytic graphite UPV-1T is the most similar to CAPG as regards mode of production amongst materials made in this country.

There are no published data on the Grüneisen coefficient and speed of sound for it.

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STABILITY OF A VISCOELASTIC ROD ON DYNAMIC LOADING

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There are fairly numerous papers on the dynamic loading in the elastic range for rods, which have been surveyed in [1, 2]; however, comparatively little is known about the dynamic stability of rods on the viscoelastic range.

Here we show that one can examine the dynamic stability of such a rod under increasing compression from nonlinear integrodifferential equations containing variable coefficients, which can be solved numerically by means of quadratures. We consider how the major factors affect the behavior.

1. Many aspects of nonlinear oscillations and dynamic stability can be considered by means of nonlinear integrodifferential equations with variable coefficients [3-7] for rods and beams composed of composite materials with viscoelastic behavior:

$$\ddot{T}_k+\omega_k^2[1-\mu_k P(t)]\,T_k=X_k\left\{t,\ T_1,\ \ldots,\ T_N,\ \int_0^t \varphi_k(t,\tau,T_1(\tau),\ \ldots,\ T_N(\tau))d\tau\right\},$$
$$T_k(0)=T_{0k},\ \dot{T}_k(0)=\dot{T}_{0k},\ k=1,\ldots,N, \tag{1.1}$$

in which $T_k = T_k(t)$ are time functions to be determined, P, X_k, and φ_k are given continuous functions in the argument range, and ω_k =, μ_k = const.

A numerical method has been proposed [8, 9] based on the quadrature formulas for integrodifferential equations; here that method is extended to (1.1), for which the system is written in integral form. We put $t = t_m$, $t_m = mh$ (h = const, m = 1, 2,...) and replace the integrals by certain quadrature formulas to get a recurrent formula for $T_{mk} = T_k(t_m)$:

$$T_{mk}=T_{0k}\cos\omega_k t_m+\frac{\dot{T}_{0k}}{\omega_k}\sin\omega_k t_m+\frac{1}{\omega_k}\sum_{r=0}^{m-1}A_r^{(k)}\Big\{\mu_k\omega_k^2P_rT_{rk}+$$
$$+X_k\Big(t_r,\ T_{r1},\ \ldots,\ T_{rN},\ \sum_{s=0}^{r}B_s^{(k)}\varphi_k(t_r,t_s,T_{s1},\ \ldots,\ T_{sN})\Big)\Big\}\sin\omega_k(t_m-t_r),$$
$$m=1,2,\ \ldots,\ k=1,\ \ldots,\ N \tag{1.2}$$

in which $A_r^{(k)}$, $B_s^{(k)}$ are numerical coefficients independent of the form of the integrand functions and which take various values in accordance with the quadrature formulas [10].

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