Strain rates for three- and four-point flexure tests

The literature on flexture tests of strength or of stress versus strain frequently contains a displacement rate for a ram, the loading configuration, and the sample dimensions, but no explicit strain or stress rate [1, 2], and in some papers strain-rate dependent properties are given without sufficient information to determine the strain rate [3–7]. In others the stress rate is given but not the strain rate [8, 9]. Data extracted from the above references and the elastic strain rates, where apparent, are tabulated in Table I. Clearly the inclusion of elastic strain rate in such papers should be desirable since the results are rate dependent and since the comparison of results and conditions are easiest with respect to $\dot{\epsilon}$.

Although the derivation of formulae relating the maximum strain and the ram speed is straightforward, explicit equations were not found in the textbooks consulted. There is, however, a paper by Hollenberg *et al.* containing calculations of stress and strain in symmetric four-point bending creep test which gives, as a special case, the strain rate versus ram speed for elastic behaviour [10]. It is suggested that authors use this or a similar expression to determine the initial elastic strain rate for flexure tests and include the information in their papers.

The expression developed by Hollenberg *et al.* for small deflections, $\epsilon \leqslant 0.02$ is

$$\epsilon_{max} = \frac{2h\,(N+2)}{(L-a)\,[L+a\,(N+1)]}\,Y_L \quad (1)$$

where ϵ_{max} is the maximum strain rate, h is the bar thickness, L and a are the outer and inner load span, respectively, Y_L is the ram displacement and N is the creep exponent. The deformation rate (which may result from viscous creep or cracking or both) may take the form

$$\dot{\epsilon} = C\sigma^N$$

with σ as the stress. Important special cases are $N = 1$, where Equation 1 reduces to the result for an elastically deflected beam,

$$\epsilon_{1,max} = \frac{6h}{L^2 + aL - 2a^2}\,Y_L, \quad (2)$$

and $N = \infty$, where

$$\epsilon_{\infty,max} = \frac{2h}{a(L-a)}\,Y_L. \quad (3)$$

The rate equations are the first time derivative of Equations 2 and 3. Note that $\dot{\epsilon}_1$ varies linearly with h and $\dot{y}_L$ and quadratically with the span.

The ratio of Equation 1 to Equation 2 varies with N, between 1 and 4/3, 5/3 or ∞ for a/L equal to 1/2, 1/3 or 0 (ideal three-point bending), respectively. The initial elastic strain rate is a lower limit on the strain rate, and if $a/L \geqslant 1/2$ and $\epsilon \leqslant 0.02$, the strain rate will not deviate from the elastic strain rate by more than 34%. This result, along with the fact the volume of material subject to the maximum elastic stress increases with a, argues for the use of $a/L \gtrsim 1/2$.

There are some papers which treat the relationship between creep and subcritical crack growth, and fracture stress [11–14]. In those cases it turns out that the value of N in Equation 1, which is associated with cracking, is between 11 and 14 for

TABLE I

Reference	L	a	h	$\dot{y}_L$	$\dot{\epsilon}_1$	$\dot{\sigma}$
[1]	1.75 in.	0.875 in.	0.125 in.	0.02 in. min^{-1}	0.004 99 min^{-1}	
	1.0 in.	0.5 in.	0.125 in.	0.02 in. min^{-1}	0.001 5 min^{-1}	
[2]	1.906 cm	0.953 cm	0.318 cm	0.005 cm min^{-1}	0.000 44 min^{-1}	
[3]	1.905 cm	0	0	–		
[4]	0.642 cm	–	0.14 cm	0.01 cm min^{-1}		
[5]	1.9 cm	0	0.3 cm	–		
[6]	–	–	–	–		
[7]	–	–	–	–		
[8]	0.875 in.	0.375 in.	0.118 in.			1000 NM m^{-2} min^{-1}
[9]	0.875 in.	0.375 in.	0.125 in.	0.02 in. min^{-1}	0.018 4 min^{-1}	2.3 × 10^5 psi min^{-1}
	0.875 in.	0.375 in.	0.125 in.	0.002 in. min^{-1}	0.001 84 min^{-1}	2.3 × 10^4 psi min^{-1}
	0.875 in.	0.375 in.	0.125 in.	0.0002 in. min^{-1}	0.000 184 min^{-1}	2.3 × 10^3 psi min^{-1}

0022–2461/79/112760–02 $02.20/0

Si_3N_4 tested in the range 1000 to 1400° C and 17 and 32 for soda-lime glass and alumina, respectively, tested in the presence of water. The referenced papers shown that the variations in the fracture stress σ_f with $\dot{\sigma}$ or $\dot{\epsilon}$ is in the neighbourhood of 10 to $<20\%$ per decade and that the variations increase with decreasing N and with decreasing average initial flaw size. These analyses also appear to indicate that when the deformation is entirely a result of a process involving cracking as the rate-limiting step in deformation, $N \simeq n + 1$; where n is the exponent relating the crack growth rate, V, to the stress intensity factor K_I

$$V = AK_I^n \tag{4}$$

Lange [9] and Hollenberg *et al.* [10] give expressions of the form

$$\sigma_f = C_1\dot{\epsilon}^{1/(m+1)} = C_2\dot{\sigma}^{1/(n+1)} \tag{5}$$

and since

$$\dot{\sigma} \leqslant \dot{\sigma}_1 = E\dot{\epsilon}_1 < E\dot{\epsilon},$$

where E is the elastic modulus, it is clear that $n > m$. Thus the variation of σ_f with $\dot{\epsilon}$ is greater, although not appreciably greater, than that with $\dot{\sigma}$. This is illustrated in Fig. 1 which contains the data points, without error bars, and the curves of σ_f versus $\dot{\sigma}$ for Si_3N_4 from [9]. To this are added curves and data points for σ_f versus $E\dot{\epsilon}$ obtained from Equation 1 with $N = 10$ which gives $\epsilon/\epsilon_1 = 1.29$. (This limit for $N = \infty$ is $\epsilon/\epsilon_1 = 1.35$.) These curves show only a slight difference in dependence of σ_f on $\dot{\sigma}$ and $\dot{\epsilon}$.

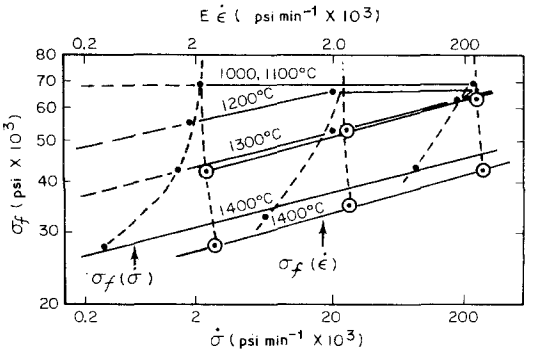

Figure 1 The variation of hot-pressed Si_3N_4 fracture stress with stress rate [9] or strain rate. The dashed curves join points obtained at the same ram speed.

References

1. D. C. LARSON, S. A. BORTZ and R. RUH, Paper 77-WA/GT-4, presented at ASME Annual Meeting, Atlanta, GA, 27 November to 2 December (1977).
2. R. R. WILLS, R. W. STEWART and J. M. WIMMER, *J. Amer. Ceram. Soc.* 60 (1977) 64.
3. D. P. ELIAS and M. W. LINDLEY, *J. Mater. Sci.* 11 (1976) 1278.
4. G. R. TERWILLIGER, *J. Amer. Ceram. Soc.* 57 (1974) 48.
5. H. LARKER, J. ADLERBORN and H. BOHMAN, "Fabrication of Dense Silicon Nitride Parts by Hot Isostatic Pressing", Society of Automotive Engineers International Automotive Engineering Congress and Exposition, Detroit, Mich. 28 February to 4 March (1977).
6. G. G. DEELEY, J. M. HERBERT and N. C. MOORE, *Powder Met.* 8 (1961) 145.
7. W. J. ARRAL, "Ceramics for High Performance Applications", edited by J. J. Burke, A. E. Gorum and R. E. Katz (Brookhill, Chestnut Hill, MA, 1974).
8. J. L. ISKOE, F. F. LANGE and E. S. DIAZ, *J. Mater. Sci.* 11 (1976) 9080.
9. F. F. LANGE, *J. Amer. Ceram. Soc.* 57 (1974) 84.
10. G. W. HOLLENBERG, G. R. TERWILLIGER and R. S. GORDEN, *ibid* 54 (1976) 196.
11. A. G. EVANS, *Int. J. Fracture* 10 (1974) 251.
12. A. G. EVANS and H. JOHNSON, *J. Mater. Sci.* 10 (1975) 214.
13. F. F. LANGE, *Int. J. Fracture* 12 (1976) 739.
14. S. M. WIEDERHORN, A. G. EVANS, E. R. FULLER and H. JOHNSON, *J. Amer. Ceram. Soc.* 57 (1974) 319.

Received 15 January
and accepted 19 April 1979.

PETER L. LAND
Air Force Materials Laboratory,
Wright-Patterson AFB,
Ohio 45433, USA

Preparation and characterization of thin films of FeS_2

Iron pyrite (FeS_2) is a semiconductor with a zero-temperature band gap of about 0.84 eV [1]. In a series of experiments, the various physical properties of FeS_2 have been investigated recently [1]. These studies have been carried out on natural single crystals. To the best of our knowledge, a study on the preparation and characterization of thin films of FeS_2 has yet to appear in the literature. In this letter we report such a study. The films were prepared by evaporation of FeS_2 and they were characterized by the techniques of

0022–2461/79/112761–03 $02.30/0