MEASUREMENT OF LONG-TERM STRESS-RELAXATION IN CARBON-CARBON COMPOSITES

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Introduction

The factors which contribute to the phenomena of creep and stress-relaxation in carbon/carbon composites are not fully understood but it is reasonable to assume that such processes as fibre fracture, fibre/matrix debonding and matrix cracking are involved. Knowledge of creep and stress-relaxation behaviour is important in any long term engineering uses of these relatively new materials.

The measurement of flexural stress-relaxation in thin carbon composites is more complex than the related measurement of creep, due to absence of easily measured stress-dependent parameters. In particular the condition of constant strain prohibits the measurement of non-elastic movement, and methods of detecting stress-relaxation depend on either (a) measuring the change in some other physical property which varies with internal stress or (b) the direct measurement of internal stress, keeping the change in strain to as small a value as possible.

A number of possible methods of measuring stress-relaxation are described and reviewed.

Methods Using the Instron Universal Testing Machine

The specimen is stressed in flexure, either directly or by use of a removable jig in which the specimen can be locked at a pre-determined stress. Both methods enable a stress history of the specimen to be obtained, but the first monopolises the Instron and the second involves handling difficulties which gave rise to unacceptable errors. Neither method involves appreciable creep, but both are dependent on the stability of the Instron load-cell.

Direct Loading Method

The specimen is stressed in flexure by means of a weight hung at its mid-point and the deflection is measured by means of a micrometer mounted above the specimen. To measure stress-relaxation, small increments are periodically removed from the original weight, sufficient to bring the deflection of the specimen back to its original value. Equipment requirements are minimal, but removal of weights is difficult without disturbing the assembly. Automated versions are expensive and elaborate. The specimen is also subject to unlimited creep between stress checks.

Cantilever Method

The specimen is contained in a special jig in which it is stressed in flexure by means of a load hung on a cantilever acting on the specimen at its mid-point. At a pre-determined load, the specimen can be locked in position by means of screws operating an electrical circuit, and the load can be removed. When a stress reading is taken, one screw is unlocked slightly and a load is gradually applied until contact with the second screw is broken. The difference in the two loads gives the stress-relaxation.

Development of this method is still proceeding, but precision construction may be necessary for the production of accurate data.

Electrical Resistance Method

This method depends on the assumption that the electrical resistance of a material varies with its internal stress. Periodic resistance measurements are made on a specimen locked at a pre-determined stress.

Experiments have shown that any resistance changes are comparable with errors in measurement, and therefore assessment of stress changes by this method is not feasible.

Hydraulic Method

In this method stress is applied to the specimen by means of a hydraulically operated piston. Any relaxation of stress in the specimen will be communicated to the hydraulic fluid and can therefore be measured. The main disadvantages are (1) the possibility of fluid leakage (2) the possibility of creep of the specimen. In addition, a pressure gauge would be required, capable of measuring very small pressure changes at the standing pressure changes at the standing pressure in the fluid.

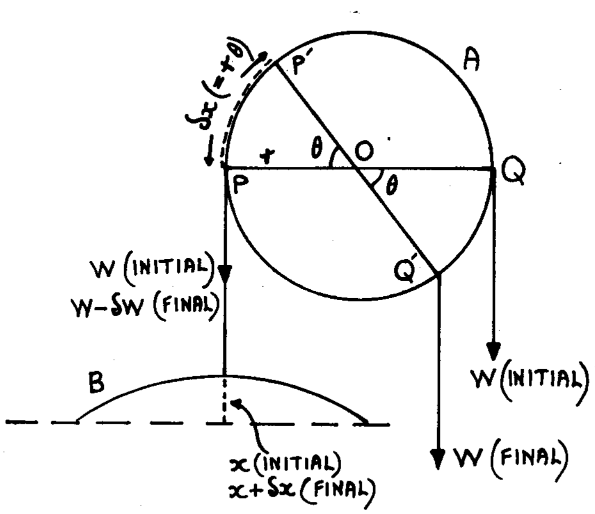
Piezoelectric Method

Stress is applied to the composite via a piece of piezoelectric material in compression, and is measured by a voltage generated in the piezoelectric. The charge on the piezoelectric leaks away after a short time, however, and thus the method has no long-term value. Use of the piezoelectric material in a capacitative mode offers no advantages over other capacitative systems. Stray capacitance in the vicinity would obscure small changes in stress-related capacitance.

The resonant frequency of piezoelectric material is lowered if the material is suitably loaded. Use of the material to stress composites might be considered to constitute such a loading, enabling the applied stress to be measured from the resonant frequency, and hence loss of stress to be found from the subsequent rise in resonant frequency.

Simultaneous Measurement of Creep and Stress-Relaxation

Stress-relaxation may be regarded as creep occurring under variable stress. Thus a material under stress, free of any constraint which would restrict changes either in its internal stress or in strain, is assumed to undergo simultaneous creep and stress-relaxation. This situation is partially obtained in the arrangement shown below:



In the diagram, A is a weightless disc of radius r, pivoted at its centre O on frictionless bearings. Initially, the specimen B, of modulus E, is flexurally strained by a load W to a deflection x. W is initially attached to the circumference of the disc at Q and can move to any point Q' on the circumference as the disc turns. B is attached to the circumference by a theoretical string initially at P. As the disc turns, the point of attachment of the string moves round the circumference to P' in such a way as to always apply the stress to the specimen from P.

Free of constraint, the specimen will undergo simultaneous creep and stress-relaxation. At time t, the point of attachment of the string moves to P' such that PP' (and QQ') both subtend an angle θ at O. The modulus of the specimen B is now E_t. The stress in the specimen falls by δW (load equivalent) and the deflection increases by δx. The following equations can be derived for δW and δx:

Setting $\delta x = 0$ (the stress-relaxation condition of constant strain)

$$\delta W = W\ 1 - \frac{E_t}{E} + W\ 1 - \frac{x \cos\theta}{x + r\theta}$$

Setting $\delta W = 0$ (the creep condition of constant stress) gives:

$$\delta x = x\frac{E}{E_t} - 1 = x\frac{x + r\theta}{x \cos\theta} - 1$$

Thus the only quantity which is required to be measured at time t is the angle θ, which would be probably $< 1^{o}$. The practical realisation of the arrangement is likely to be difficult. A degree of constraint exists on the free movement of stress and strain (ie if $\delta x = r\theta$ then $\delta W = W(1 - \cos\theta)$, but it is possible to calculate either (1) stress-relaxation at zero creep, or (2) creep at zero stress-relaxation.

Acoustic Transducer Method

Stress is applied to a carbon composite specimen in flexure, by means of a thin steel wire in longitudinal tension. The stress in the wire is related to that in the carbon and can be measured by means of the acoustic frequency emitted when the wire is suitably excited. Since the system must always be in equilibrium, any loss of stress in the carbon will be accompanied by a loss of stress in the wire (assumed to be behaving elastically), and hence by a lowering of the emitted frequency. Since the longitudinal extension of the wire is very much less than the flexural extension of the carbon, small losses of stress of the carbon-wire system will result in very small contractions of the wire. The system thus exhibits a close approximation of that of zero creep of the carbon.

This is the principle method which is being used at the present time. Excitation of the wire is carried out by means of short electro-magnetic pulses, causing the wire to vibrate in its fundamental mode and generate a current of identical frequency in the sensing/excitation head. The frequency is given as a digital read-out of the period of 100 oscillations. Stress-relaxation of the wire is minimised by prior heat-treatment under tension. It has been found that readings of freq-uency tend to vary with atmospheric conditions ie temperature and humidity. The precise relation-ships and the reasons for them have not yet been established.

Direct Acoustic Method

This method depends on the possibility that the frequency emitted by a flexurally strained bar is related to the internal stress in the bar. Excitation would probably be carried out by passing a variable frequency alternating current through the bar, which would be located between the poles of a permanent magnet. The main attraction of this method would be the elimination of the wire transducer.

Conclusions

(a) An acoustic method, using a wire trans-ducer (Sect 9), has been adopted for the measure-ment of flexural stress-relaxation in carbon-carbon composites.

(b) A mechanical method using cantilever load-ing is under development with a view to adoption as a standard means of measurement.

(c) A piezoelectric method is under considera-tion for development.

(d) A method of simultaneous measurement of creep and stress-relaxation appears promising theoretically, but is likely to be very difficult to realise in practice.