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TIME-DEPENDENT PROPERTIES OF FIBER COMPOSITES FOR ENERGY-STORAGE FLYWHEELS

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DISCLAIMER

TIME-DEPENDENT PROPERTIES OF FIBER COMPOSITES FOR ENERGY-STORAGE FLYWHEELS*

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ABSTRACT

Time-dependent deformation and time-dependent strength are being characterized for several candidate polymeric composites for flywheels. This presentation highlights the motivation and the philosophy of the characterization adopted by the authors in establishing the ongoing programs at LLL. This overview is intended to provide a basis for inferring the type of engineering data being generated for different aspects of flywheel design. The details of these data can be obtained from the published reports and articles. Two aspects of flywheel design data are addressed: those dealing with time-dependent statistical strength, and those dealing with deformation and strength under time-varying history.

DISCUSSION

Time-dependent statistical strength data are needed to predict failure probabilities for a flywheel operating under various stresses associated with input, storage, and output of energy. Stress-rupture tests at constant load levels are used as baseline benchmarks. Such tests are required because even a nominal variation in static strength (typically less than 5%) can lead to large scatter in stress-rupture life (in excess of 100%), as shown in Fig. 1 To provide the necessary statistical parameters for reliability design, large data samples from long-term testing are now being accumulated in testing facilities capable of simultaneous testing of 100 samples (Fig. 2). The type of data being generated is typified in Fig. 3. From curves such as these, we can determine the amount of derating in stress level that is required to attain

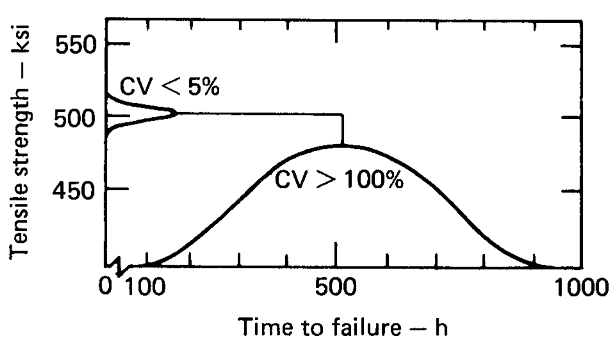

Fig. 1. Nominal scatter in static strength data which can result in large scatter of lifetime predictions.

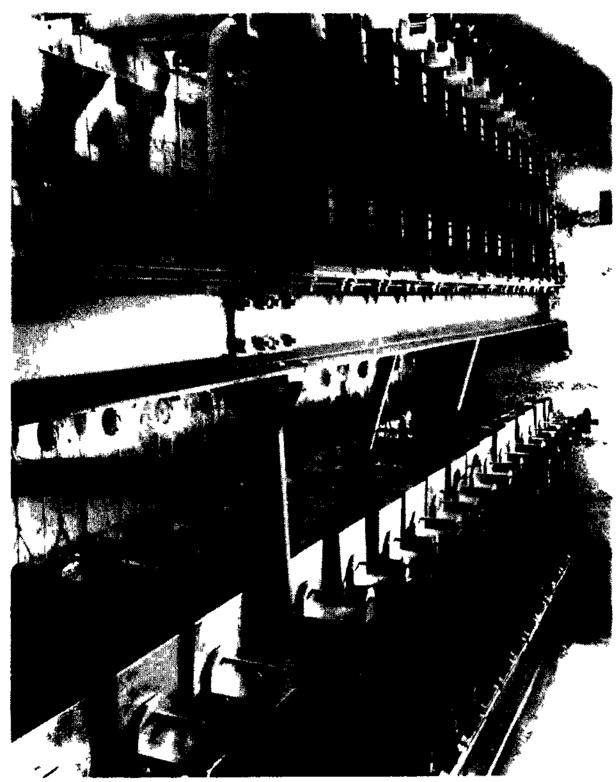

Fig. 2. Stress-rupture test for facilities; 100 stations are available for simultaneous testing of many samples.

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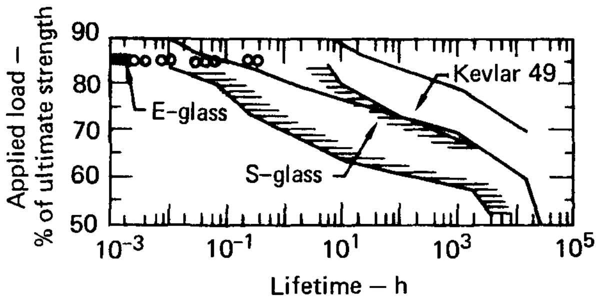

Fig. 3. Stress-rupture lifetime data for several composite materials being considered for flywheels. For S-glass and Kevlar 49 composites,* 2 to 100% failure bands are displayed.

the desired degree of reliability in the operating life.

Deformation and strength under time-varying history are pertinent in assessing the dimensional stability and fatigue sensitivity of materials employed in flywheel application. For a flywheel, dimensional stability is directly related to the hub attachment and containment design; it is also indirectly related to strength augmentation through prestressing and hybrid designs. Deformation under time-varying history can be estimated from load-deformation constitutive relations. We are adopting the convolution integral form for such reactions:

$$\varepsilon(t) = \int_0^t J(t - \tau) \frac{d\sigma}{d\tau} d\tau .$$

In this program, we record the time-varying stress-history $\sigma(t)$ and the time-varying strain history $\varepsilon(t)$. With these data, we establish the limits of linearity and qualitatively determine the creep compliance $J(t)$.

The characterization of strength under time-varying load history depends on the identification of damage parameters which provide meaningful engineering sensitivity. A damage parameter may be regarded as a failure criterion in time. For example, under stress-rupture conditions, the creep strain $\varepsilon(t)$ may be used as a damage criterion (Fig. 4a). However, creep strains for polymeric composites often approach an asymptotic limit and this, combined with the usual material scatter, leads to a large uncertainty, Δt, in life prediction (Fig. 4a). Hence, we seek a damage function Ψ of the form,

$$\Psi = \int_{t_0}^{t} f(\sigma,\varepsilon,t,\theta)dt ,$$

such that Ψ would exhibit the property depicted in Fig. 4b, providing a higher sensitivity or a smaller uncertainty of life prediction. The exploratory effort to identify such damage function requires comprehensive instrumentation for recording the multitude of time-varying parameters, i.e., $\sigma(t)$, $\varepsilon(t)$, t, θ(environment). The comprehensive instrumentation and mechanical testing are provided by five servo-hydraulic testers and 44 creep and program-interruptable creep machines serviced by three computers for data acquisition and data processing. A sample of the data being recorded is shown in Fig. 5; some intermediate cycles are expanded in Fig. 6.

The overall objective of these programs is to provide time-dependent deformation and material strength data in sample sizes that are large enough to be statistically meaningful as well as to present data in quantitative forms amenable to design applications.

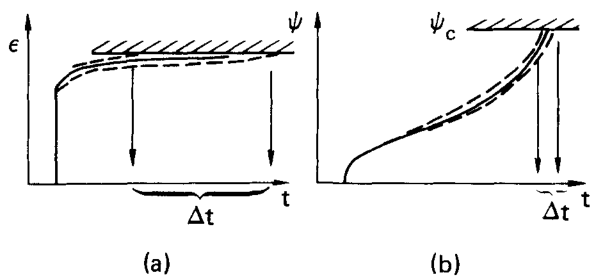

Fig. 4. Damage parameters: (a) use of creep strain as a damage parameter may result in a large uncertainty in the lifetime prediction; however, in (b) a damage parameter is being constructed to reduce the uncertainty in the lifetime predictions.

*Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Department of Energy to the exclusion of others that may be suitable.

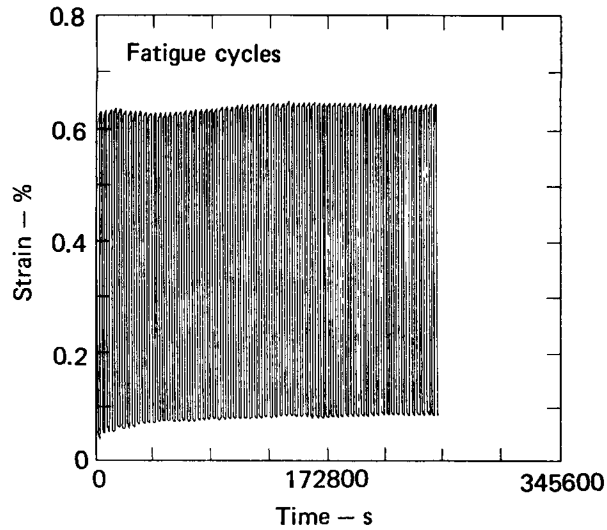

Fig. 5. Time-dependent strain history in fatigue of an aramid fiber strand composite exhibiting accelerated creep strain.

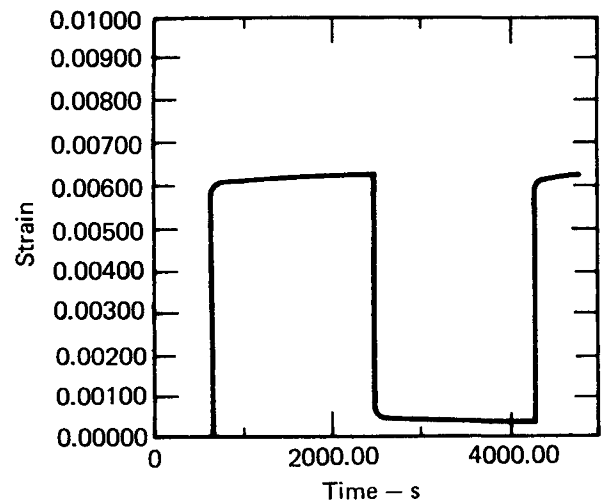

Fig. 6. Expanded plot of the strain history in fatigue of Kevlar 49 strand composite exhibiting creep and recovery within each stress-cycle.