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Application of strain-controlled fatigue testing methods to polymer matrix composites

P. B. S. Bailey*, M. Higham

Instron Dynamic Systems, Coronation Road, High Wycombe, HP12 3SY, UNITED KINGDOM

Abstract

This paper presents a short investigation of the benefits of non-contact strain measurement for monitoring and control of fatigue tests on composites. Recent developments in measurement technology offer the means to effectively measure both axial and transverse strain, instantly, throughout cyclic and highly dynamic tests. Several test scenarios are examined which demonstrate potential benefits of current state-of-the-art video extensometry, for strain controlled fatigue tests on thermoplastic composites.

Live extensometry enables continuous monitoring and live calculations throughout the test and provides the option to automatically collect additional data for loading cycles with anomalous behaviour. It also allows a good control system to safely apply accurately strain-controlled loading of specimens. Digital image correlation techniques can offer complimentary information on the full-field strain behaviour of a specimen, but the data processing and storage requirements are considerably too large for live or continuous measurements during fatigue tests.

Composites fatigue investigations, to date, have generally been focused on high cycle fatigue, typically under sinusoidal stress-controlled conditions. The authors propose that there is a growing need to understand composite behaviour, at well-defined strain-rates and under conditions of occasional, non-catastrophic, overload; furthermore that non-contact extensometry is an important enabling technology for such investigations.

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* Corresponding author. Tel.: +44 7880 187716.
E-mail address: peter_bailey@instron.com

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1. Introduction

Contacting extensometers are a well-established method of strain measurement for materials testing which have been used since very early in the history of modern metallurgy and materials science [Kirkaldy (1866), Huston (1897), Ewing (1899)]. The object is to obtain a good measure of the strain in the material, by determining the average extension of a representative length, which is subject to the intended loading conditions. The worker must accept that in tests to characterise bulk material performance, the point of load introduction is never subject to the same loading conditions as they are trying to evaluate. Likewise, for bulk mechanical measurements, it is important to take measurements from a sufficiently large volume of material that any local effects of microstructure are averaged appropriately.

Contacting extensometers can be self-supporting on a bracket or mounting, or be specimen mounted with their weight and resistance contributing to the stress applied to the specimen. In both cases a well-chosen device will provide the most precise, reliable, repeatable data possible. A wide variety of designs have been developed over some 140 years, transitioning to electronic reading devices from the 1950s onwards with the pioneering work of researchers such as Burr and Hindman [Hindman (1945), Hindman (1942)]; that particular collaboration lead to the birth of Instron [Hindman (1949)]. Although the industry continues to make incremental improvements every few years, this is largely associated with the electronics and computer systems used; mechanical and electrical performance of the physical device largely plateaued by the 1990s and new designs are mostly created to improve ergonomics or meet specific trends in customer demand.

Fig. 1. Extensometers ancient and modern. (left) one of the earliest contacting extensometers produced by J. A. Ewing in Cambridge, c1890; (right) Instron AVE2 video extensometer for dynamic measurement, released 2015.

Video extensometry is also now a moderately well-established option, the earliest systems coming into service in the late 1970s. Video extensometry (as distinct from digital image correlation) tracks a simple set of marks (dots or lines) on the specimen, either by image analysis at a software or firmware level, or by digital or analogue hardware. Since the performance of these systems is predominantly governed by the automated imaging and data processing which enables them to work, improvements in this field have been somewhat more impressive. At the time of writing, the authors believe that the measurement technology is approaching practical limits of achievable accuracy and resolution. Although improvements are certain to continue in terms of ease of use and inter-laboratory repeatability, the current camera and processing performance are no longer limiting the measurement performance of systems for quasi-static test; rather the optical effects of specimen and environment are most significantly affecting measurement uncertainty.

2. Background

At the time of writing, the most rapidly growing commercial demand to implement composite materials is coming from the automotive industry. For many years this industry has used injection moulded polymers for a wide variety of non-critical components, for either cosmetic or only semi-structural purposes. However, with an urgent and legally imposed necessity to reduce carbon dioxide emissions from vehicles, one seemingly simple initiative for automotive manufacturers is to reduce vehicle mass. In consequence a vast array of schemes are being proposed and