Testing Brief

Testing at High Strain Rates

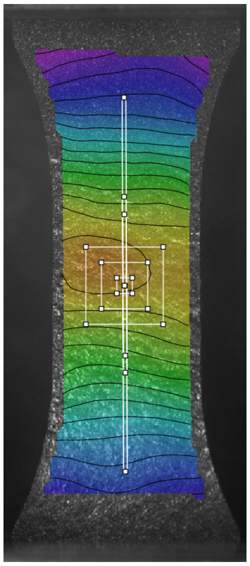

Figure 1, Localized Plastic Deformation at High Strain Rate with Virtual Extensometers (100 s-1)

Introduction

Most tensile, shear and, compression experiments are performed slowly under quasi-static conditions. Quasi-static indicates that the acceleration effect on load measuring devices is insignificant and the stress wave propagation in the test specimen need not be considered. The strain rate of typical quasi-static tensile tests is approximately 0.01 s-1 (1 s-1 = 100%/second). Naturally, materials in service may experience strain rates much higher than this and the physical properties of many materials are sensitive to the strain rate.

This brief will introduce testing issues in the general range of 0.1 s-1 to 1000 s-1. This is the rate of straining generally covered by universal test instruments, standard servohydraulic test instruments, specialized drop towers, and high-speed servohydraulic test instruments. Strain rates above 100 s-1 require other testing solutions which revolve around wave propagation techniques such as the Kolsky bar and the Nolle Wave Propagation Apparatus and these techniques are not addressed herein.

Basic Testing Elements

Tensile, shear, and compression experiments share several common elements that need to be adjusted to achieve higher rates of straining.

Loading System

A loading system is required to deform the test specimen. For quasi-static tests, this is typically an electromechanical test instrument that uses a screw-driven crosshead to apply a constant rate of deformation. To achieve higher strain rates, the loading system needs to move faster. A faster loading system such as a servohydraulic test instrument may be necessary. It is important that the instrument achieves the desired strain rate quickly. If this isn't possible, yet the instrument is still capable of the needed test speed, a slack grip system may be used. A slack grip system allows the needed test speed to be reached prior to engaging the test specimen.

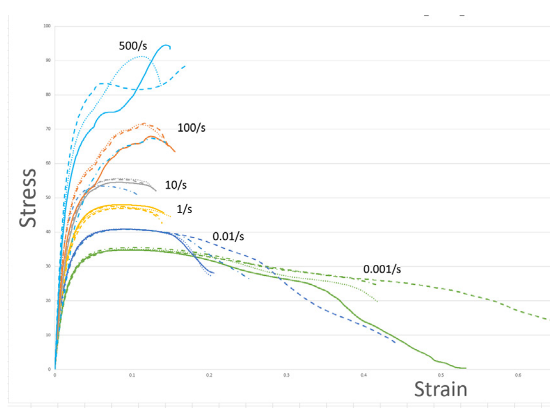

Figure 2, Tensile Tests on Plastic at Multiple Strain Rates (0.001/s to 500/s)

At strain rates above approximately 10 s-1 and below 1000 s-1, the loading system will need to be a drop tower or a specialized high speed servohydraulic system. In addition to achieving the necessary speeds at the test specimen grip, the overall system stiffness and damping must be such that the extraneous vibrations do not degrade the experiment.

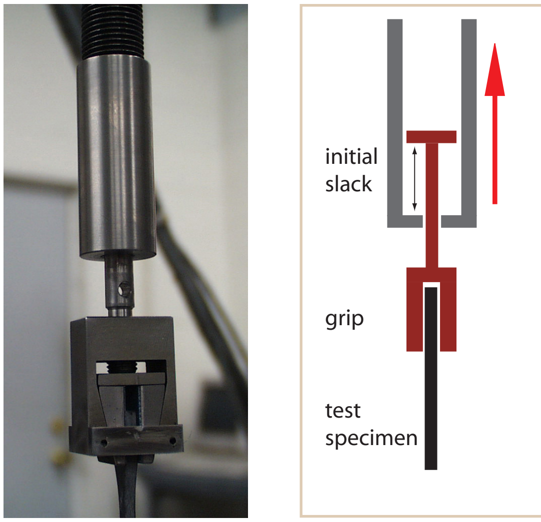

Figure 3, Slack Grip System that Allows the Loading System to Ramp to Speed Prior to Engaging the Test Specimen

Force Measurement

A force measuring transducer is used to measure the force transmitted through the test specimen. For quasi-static tests, this transducer is typically a strain gage based load cell. Strain gage based load cells are too soft at higher strain rates because they introduce inertial effects and free vibrations in the time frame of interest. Piezoelectric force sensors that are significantly stiffer are used. These sensors drift over time and are generally not a good choice for quasi-static tests. In addition to a stiffer load cell, the mass of the test specimen grip that rides on the load cell needs to be minimized to limit inertial loading.

Strain Measurement

A strain measuring transducer is used to measure straining in the test specimen area away from gripping effects. For quasi-static tests, this transducer is typically a strain gage based extensometer that is clipped onto the side of the test specimen. Depending on the clip-on extensometer design, the increased straining rate of the specimen and the initial acceleration required to achieve this may cause the clip-on extensometer to vibrate producing extraneous errors in strain measurement. At Axel, the solution of choice at higher strain rates is a high speed non-contacting strain measuring system. Because the measurement is a non-contacting device, there is no inertia induced-vibration due to the mass of the sensor. However, the non-contacting strain measuring system does require specimen marking and considerable set-up for each experiment.

Figure 4, High Strain Rate Tensile Experiment setup

Figure 5, High Strain Rate Slack Grip apparatus

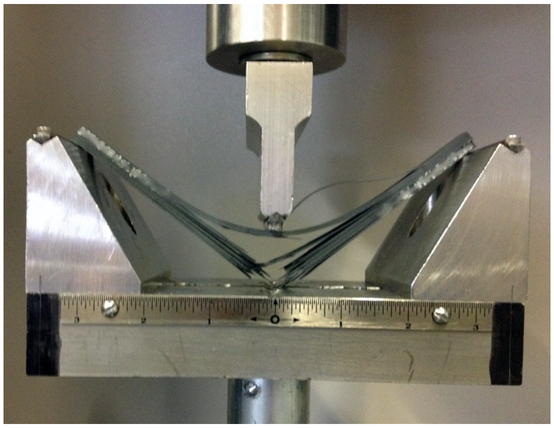

Figure 6, High Speed Bend Test

Even with a non-contacting strain measuring solution, the measurement range of interest must be established. If low strain modulus values are critical the total strain measurement range is typically short. If the total energy under the curve is more critical, larger strain ranges can be measured and the resolution at small strains is compromised.

Data Collection

A data collection system is needed to collect, process, and synchronize data from the force and strain measuring systems. Naturally, the total event duration becomes shorter with increasing strain rates such that higher data collection rates are needed. The data collection system, including transducers, signal conditioners, and the data logger must have sufficiently high frequency response. Because the data rates are high, the specimens small, and the transducers have high frequency measurement capabilities, test data from high strain rate tests often isn't as clean as that from quasi-static experiments.

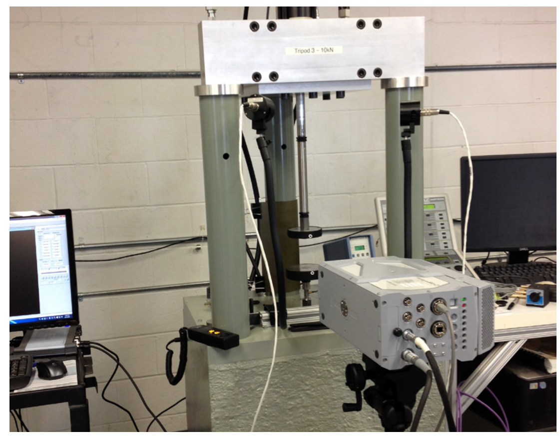

Figure 7, Compression Load-unload Experiment with High Speed (500,000 fps) Imaging

It can be difficult to separate actual specimen stress and strain data from the transducer noise and mechanical vibrations. To do this effectively, it is important to measure and understand the noise and vibrations inherent in the test system so that good judgment can be used when processing experimental data.

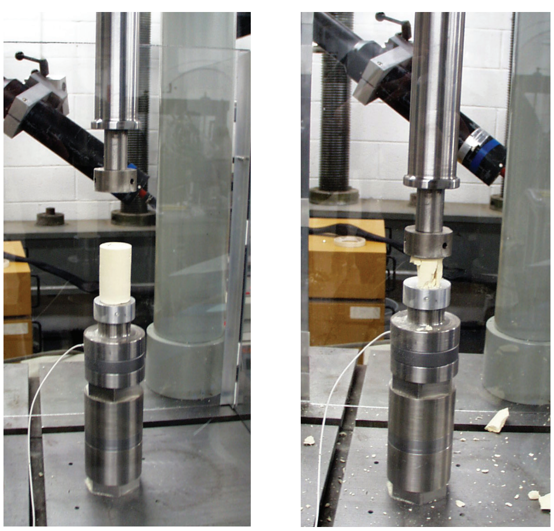

Figure 8, Crushable Foam Specimens Before and After a High Speed Compression Experiment

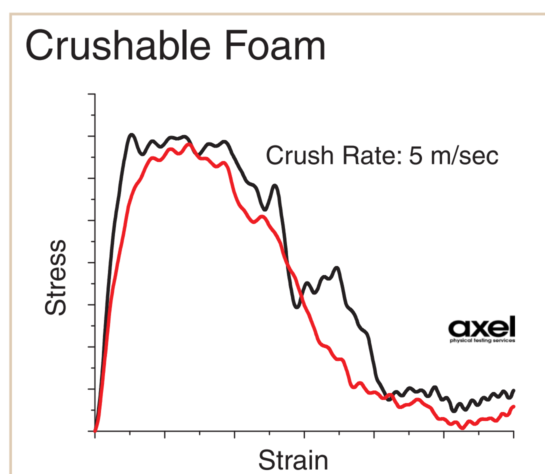

Figure 9, Crushable Foam Compression Test Data

Selection of Strain Rates

Some materials are more sensitive to strain rate than others. However, in most cases it makes sense to observe these changes over orders of magnitude of strain rate. Simply doubling or halving the strain rate may generate very small structural changes that are difficult to observe without testing many specimens. Strain rate measurements over orders of magnitude change in strain rate such as 0.1, 1, 10, 100 and 1000 s-1 will produce more meaningful results.

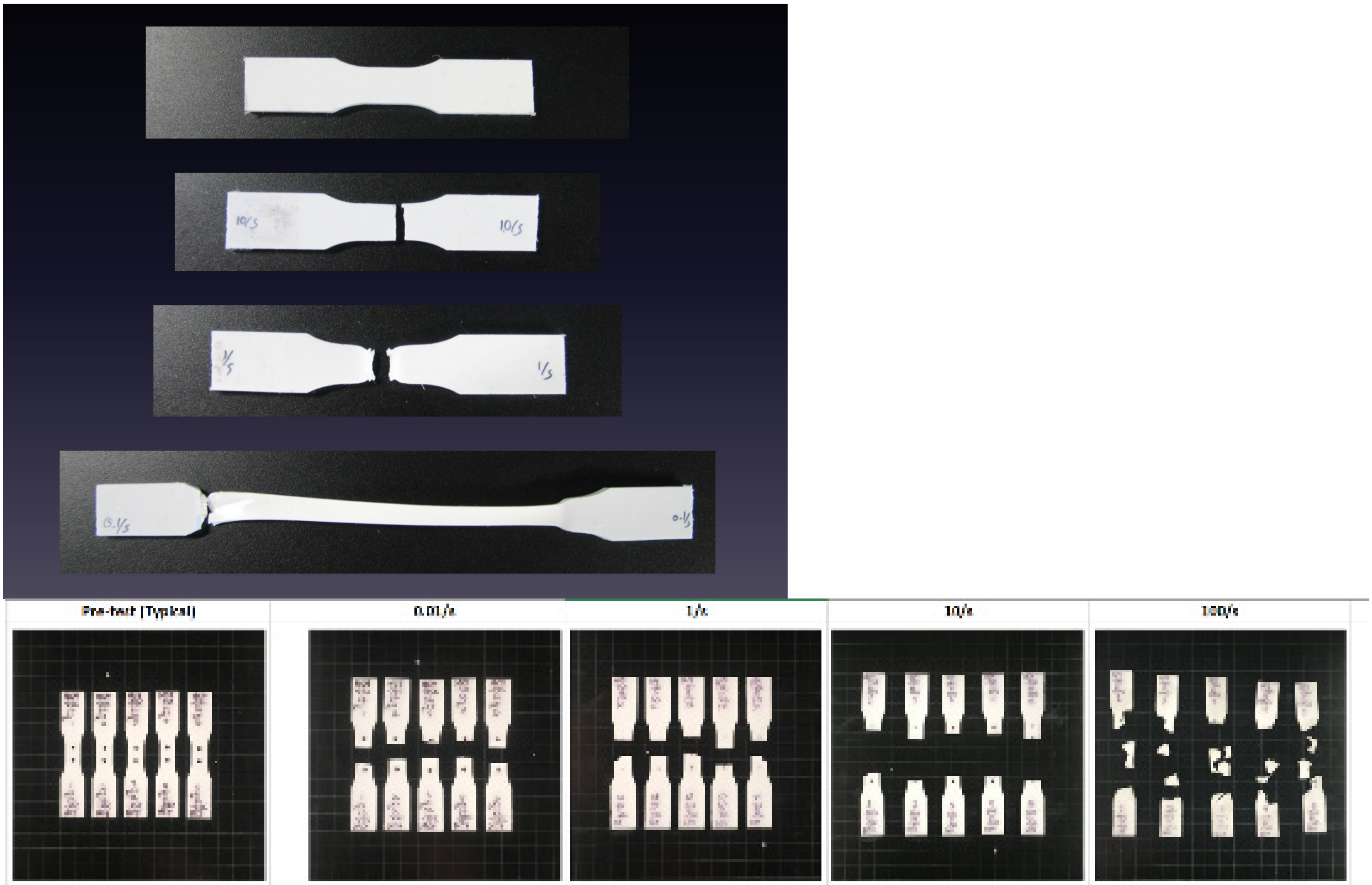

Figure 10, Dramatic Difference between Tensile Specimens Tested at 0.1 s-1, 1.0 s-1, 10 s-1

For more information, visit www.axelproducts.com.

Axel Products provides physical testing services for engineers and analysts. The focus is on the characterization of nonlinear materials such as elastomers and plastics.

Data from the Axel laboratory is often used to develop material models in finite element analysis codes such as ABAQUS, MSC.Marc, ANSYS and LS-Dyna.

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