Measuring the Long Term Creep Properties of Plastic Materials for Finite Element Analysis

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Introduction

The objective of the testing described here is to examine the long-term straining in a plastic material subjected to a constant stress. These experiments are often performed at elevated temperatures and the data is sometimes used to predict material behavior beyond the time frame of the actual experiment. Plastics are generally considered to creep more than metals at similar temperatures making it critical to understanding this vulnerability in metal replacement applications.

Figure 1, Multiple creep frames in the "creep farm".

Although the idea is simple enough, put a stress on a specimen and watch it strain, getting meaningful data can be challenging.

These “long term” experiments typically run for days, weeks or months at a time. They are intended to characterize the irreversible mechanical and chemical changes in the material. There are other “short term” creep experiments, which typically run less than 1 hour, that are intended to characterize the reversible viscoelastic behavior of materials. The short-term reversible viscoelastic behavior is frequently defined with various mathematical representations of springs and dashpots. These same representations are typically not appropriate for the prediction of long term behavior. The introduction of irreversible mechanisms into finite element codes is a new and evolving field.

The Experiments

While these experiments are easily described by the duration of the experiment, there are significant practical considerations in the design of the experiments. While it is reasonable and cost effective to use a universal tensile tester such as an Instron to perform short term creep experiments, it is prohibitively expensive to engage these instruments for long periods to perform long term experiments. As such, long term creep experimental test stands tend to be lower cost systems constructed using dead weights to apply the desired creep stresses. The practical result of this is that it becomes difficult to obtain useful short-term data with long-term test stands because the method of applying the loading is less precise and because the force during loading typically isn’t measured.

Applying a Stress to the Test Specimen

Long-term creep experiments are typically performed in tension. A "dogbone" style tensile specimen is used. At Axel Products, these experiments are performed using individual fixtures mounted in individual test frames. Individual test frames are considered necessary to eliminate interaction between experiments.

To apply a stress to the test specimen, weights are loaded onto a pan and the weight is transmitted through a lever arm into a loading fixture set to create a tension condition. The weight is transmitted smoothly through a motorized loading mechanism. However, the specimen is largely unconstrained such that no rotational or bending forces are introduced. The situation allows for a reasonable measurement of the initial strain after the loading is completed.

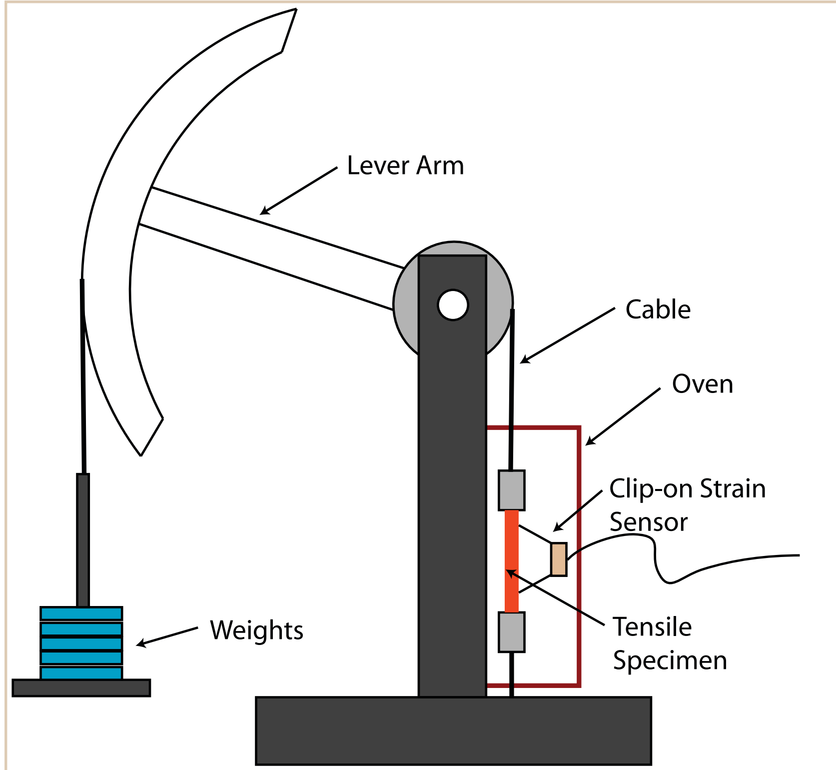

Figure 2, Schematic of the creep frame loading mechanism.

Creating the Thermal Environment

Each test frame has a dedicated environmental chamber for control of temperature. Individual chambers are used so that specimens may be changed out without interrupting other test specimens.

Measuring Strain

Measuring strain during creep experiments is challenging for several reasons.

The strain must be measured in the gage section of the test specimen where the state of strain is known and the stress is understood. This typically requires a clip-on style extensometer that will need to endure the specimen temperatures.

The measurement of interest is the creep of the test specimen after a stress is applied. However, the extensometer is attached to the specimen prior to loading which means that the extensometer will need to have sufficient range to capture both a large initial loading strain followed by a potentially small creeping strain. The creeping strain continues to be of interest over several decades of time meaning that smaller and smaller strain changes are of interest.

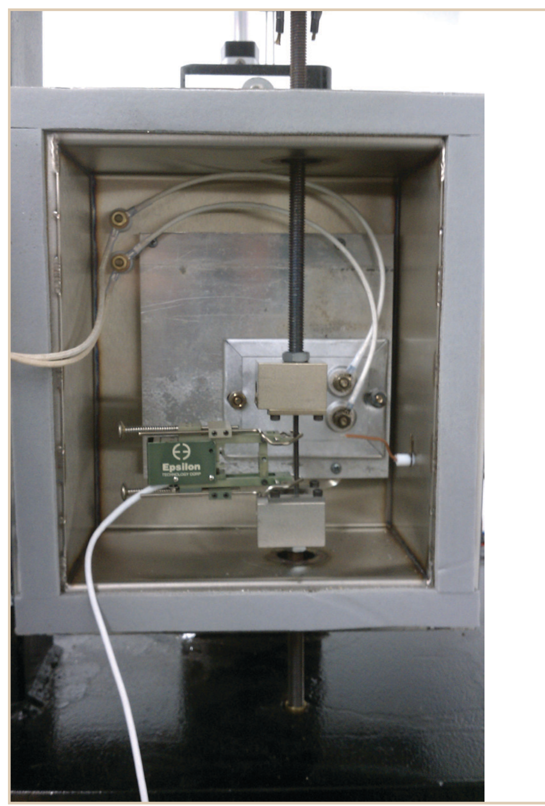

Figure 3, Plastic tensile specimen with extensometer (green) mounted inside the temperature chamber of a creep frame.

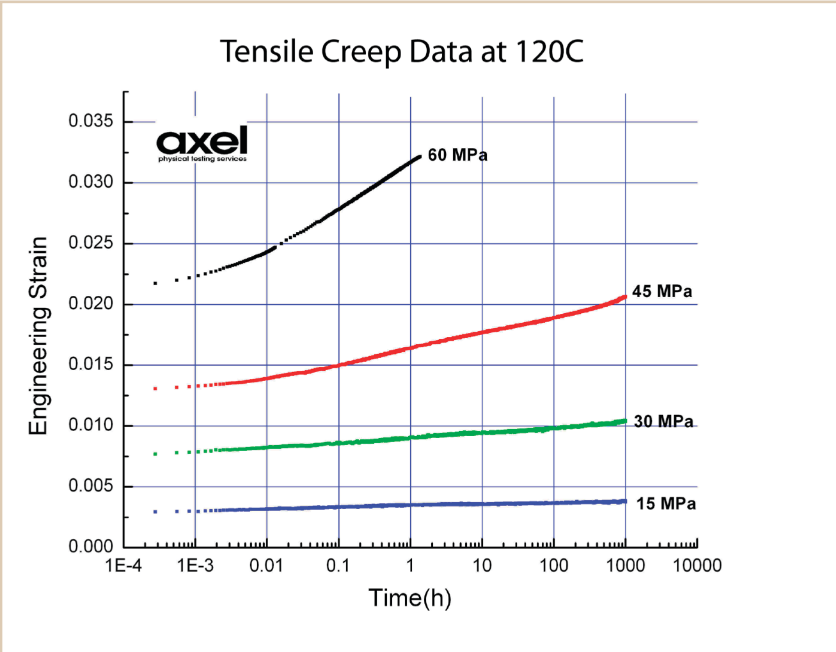

Figure 4, Example of creep data collected at 120°C at four separate stress levels..

This measurement demand requires that the extensometer measure precisely over a broad range of strain.

Plastics are being employed at increasingly elevated temperatures. At Axel, our creep stands support testing up to 200°C. At temperatures above 100°C, the ability of the extensometers to resist creep or outright failure becomes a concern. The construction of the strain gage extensometers employs epoxy strain gage bonds which may also creep. Capacitive based extensometers are also in use at Axel but these devices can be heavy devices which generate unacceptable side forces on soft test specimens.

The electronics instrumentation that are used with the strain measuring extensometers must also be free of noise and drift over these same long time periods. This requires things like high end power supplies, specialized shielded wiring and a constant thermal environment for the electronics to live in.

A central data collection system is used to continuously monitor strain from the clip-on strain sensors.

Designing the Experiment

Creep experiments are typically designed such that strain data is collected at three or four different temperatures and at 3 or 4 different stress levels. The stress levels employed are based on the application stress anticipated or on the material's ultimate tensile strength. The temperatures selected are typically based on the application temperatures and are bounded by the materials melt temperature.

Figure 3, Example of tensile specimens cut at 45 degrees from the flow direction.

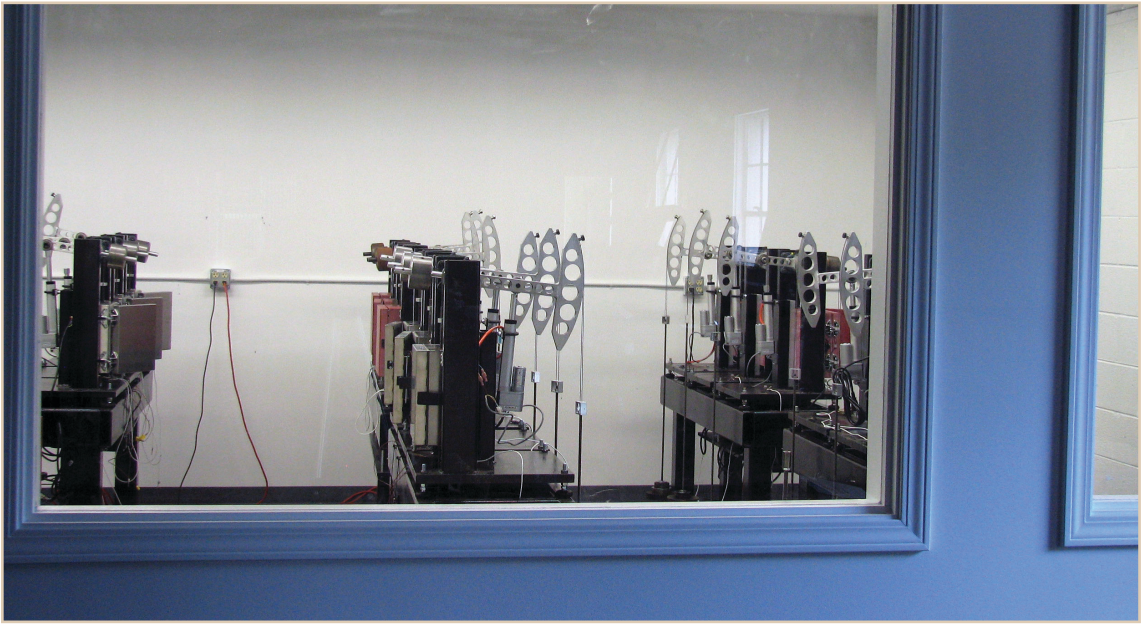
Figure 6, The creep farm is enclosed in an environmentally controlled room..

General

There are readily available standards that provide guidance on the use of long term creep data and long-term relaxation data for the prediction of mechanical properties beyond the duration of the experiment. These include:

- ISO standard 899-1 Plastics - Determination of Creep Behavior - Tensile Creep

- ASTM D 2990 Standard Test Methods for Tensile, Compressive, and Flexural Creep and Creep-rupture of Plastics

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