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Tech Notes

Dynamic Temperature Applications

Using and Understanding Thermal Strain Compensation Methods

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Overview

All Epsilon extensometers are designed and qualified for testing in ***quasi-static*** temperature conditions. Extended temperature range options are available, but it is expected that the temperature will be nominally static over the duration of the test.

Forced dynamic temperature applications with large temperature swings such as TMF and measurement of CTE are quite complex; they require significant additional considerations *and a high level of user expertise.* Some *basic* guidance is provided below for the interested user.

Compensation for drift caused by small uncontrolled variations in ambient temperature can sometimes be made using using the temperature-base compensation method described later in this document.

Basic Challenges

Small changes in extensometer *sensitivity* occur with shifts in temperature. Gain correction factors for this 1st order effect may be drawn from a *Span–vs—Temperature Calibration* curve. For static temperature testing at non-ambient temperatures, this correction is typically sufficient.

Far more challenging, changes in *zero point reading* (ε_{TSE}) occur with shifts in temperature. These effects can be quite complex, and for many systems, a linear zero-vs-temperature correction is not sufficient.

- A measurement system may exhibit zero-vs-temperature relationships at several time scales and coefficients.
- Zero point shifts with temperature are often rate dependent. A change of 10 °C over 1 minute may have a very different response than a change of 10 °C over 1 hour.
- Factors beyond the extensometer such as specimen bending, load frame alignment etc. affect zero point shift – *it is not necessarily a measurement error.*

The unsought indicated elongation due to thermal effects is referred to here as *Thermal Strain Error (TSE),* whether it is a true measurement error or only an undesirable test result. The treatment is the same*:*

$$\Delta l_{indicated} = \Delta l_{actual} + \Delta l_{TSE}$$

It is left to the user to determine based on the application whether to treat elongation due to CTE thermal expansion of the specimen as a component of the Δl_{actual} or the Δl_{TSE} term as below:

$$\Delta l_{TSE}(T,t) = \Delta l_{CTE}(T) + \Delta l_{bending\_strains}(T,t) + \Delta l_{measurement\_error}(T,t) + \cdots$$

Thermal Strain Compensation

It is possible to provide some compensation for TSE, using thermal strain compensation techniques. ASTM E2368, *Standard Practice for Strain-Controlled Thermomechanical Fatigue Testing* provides some guidance on possible methods. The reader is directed to section 7.6. Epsilon recommends a similar concept as outlined below. Note that E2368 7.6.1 nominally compensates for CTE only, whereas Δl_{TSE} as used here explicitly includes *real* but unsought contributions from CTE expansion, specimen bending strains and load frame alignment errors, as well as measurement *errors* from the extensometer.

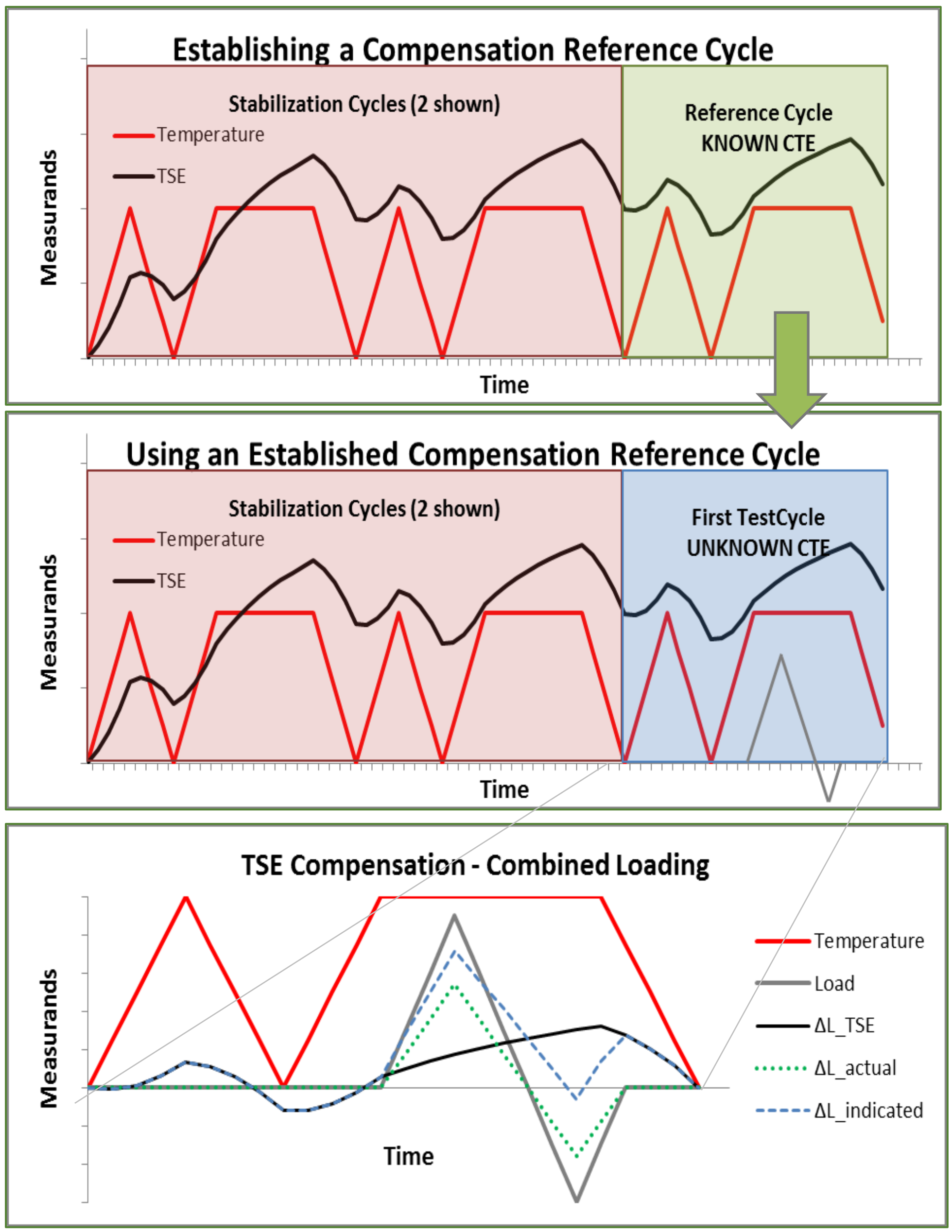
Compensation using a reference material

In order to compensate for TSE, Δl_{TSE} is measured over a compensation reference cycle and subtracted from subsequent test cycles to actively correct for TSE. It is necessary to utilize a regular repeating thermal cycle in order to obtain a stable thermal hysteresis loop. The thermal cycle may be arbitrarily complex *but must match the thermal history T(t) of the test cycle*.

Once a stable loop is established, *typically after 3-4 cycles*, the reference cycle data may be collected. The reference cycle must be established using a test of known actual elongation – typically using a no-load test and a material of known CTE such as borosilicate.

This method may be used when CTE is treated as a component of Δl_{actual} and will be measured.

One the compensation data has been obtained, it may be applied to subsequent tests with combined thermal and mechanical loading.

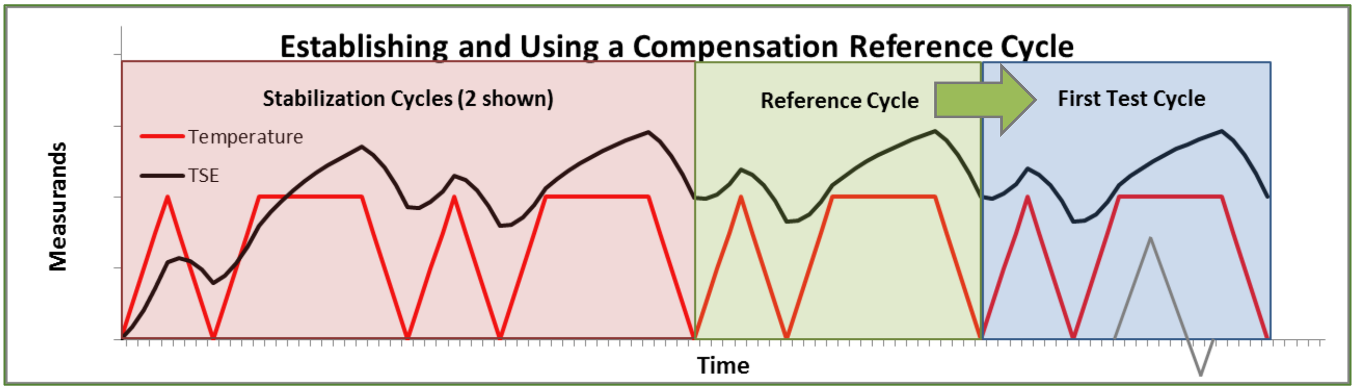


It should be noted that Δl_{TSE} includes components which may vary from test to test. If specimen bending strains, load frame alignment errors etc are significant but not repeatable between tests, it will be difficult to compensate for these real but unsought strains. Variation between tests in the thermal environment of the system such as changes in manual positioning of furnace packing material etc which affect TSE will affect the method.

In such cases it may be necessary to improve the physical setup to reduce the effects of contributions to TSE which vary between tests. An alternative method may also be used, which can better accommodate variations between tests (next).

Compensation without a reference material

An alternative method is to establish a unique compensation reference cycle *with each test*. In this method each physical test specimen is used as its own compensation reference. Treating CTE as a component of the Δl_{TSE} term, it is not necessary to know the CTE of the material under test. This method accommodates variations between tests which can complicate compensation by reference, but obviously cannot be used when measurement of CTE itself is necessary:



Summary Notes on Time-based Thermal Strain Compensation:

- A number of factors contribute to TSE, *not all of which are true measurement errors*.
- Direct compensation is a recommended technique in dynamic thermal applications.
- The reference cycle *<u>must match the time-temperature history</u>* of the test cycle.
- Sufficient stabilization cycles are essential to develop a stable hysteresis loop.
- Variation between tests should be considered and self-compensation may be applicable.

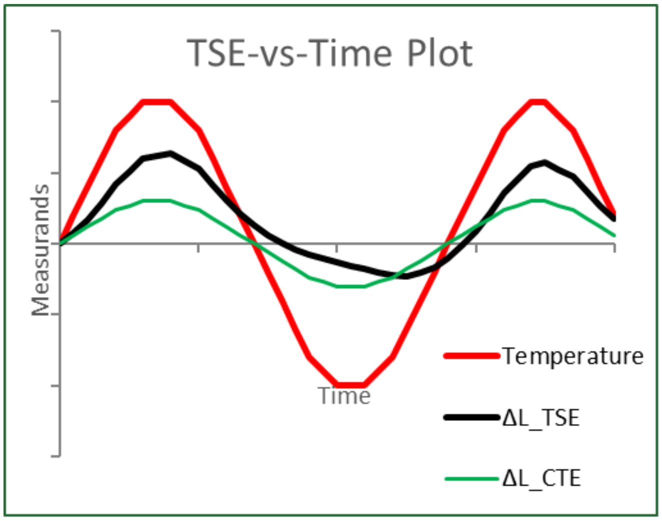
Time-based compensation is recommended rather than temperature-based compensation (next page).

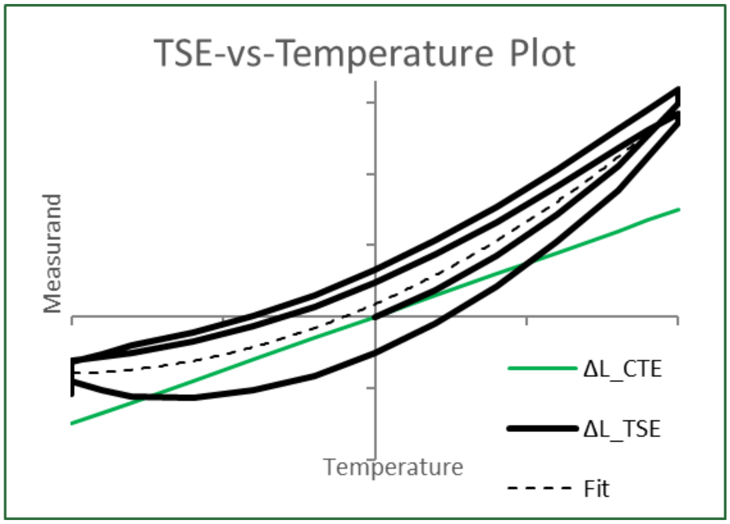
Temperature-based compensation

Time-based compensation is recommended whenever possible due to the rate dependency and thermal hysteresis typical of TSE. However, this method requires a regular and controlled thermal cycle and is not generally possible if temperature is an uncontrolled parameter.

Temperature-based compensation – using temperature rather than time as the independent variable – is generally less accurate because it cannot accommodate hysteresis, but may be used to obtain a degree of compensation in applications with irregular cycles such as diurnal thermal cycles for which a stable thermal cycle cannot be obtained. It is most effective when thermal rates are slow and thermal excursions are small.

As with time-based compensation, a reference specimen of low or known CTE such as borosilicate may be used to establish the relationship between time and TSE. In the example below we see the linear contribution to indicated elongation from the CTE of the specimen, as well as the nonlinear and hysteretic contribution from the TSE to be corrected.





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