

Proposed Tensile Test Method for Measuring the Young's Modulus of Particulate Reinforced MMCs

At present there are no standards for measuring the Young's modulus of MMCs, and even the methods for the tensile testing of metals are vague in their recommendations regarding modulus measurement. ASTM E111 is the only standard currently available which deals specifically with the measurement of modulus from the tensile test. The European equivalent, EN 10002, which has five separate parts, deals with various aspects of the tensile test including the calibration of the test machine and extensometry, but does not provide any explicit instructions regarding the measurement of Young's modulus itself.

Many of the target applications for MMC seek to exploit the improved properties - particularly the specific strength and stiffness (modulus) - of the composite compared to the unreinforced alloys. Because these parameters can be key factors in material selection, it is vital that accurate measurements of modulus be made to give a true comparison of material performance. Special attention should be taken for MMC because the proportional limit and range of elastic behaviour can be very small, and this places the emphasis on accurate strain measurement.

Previous work on MMCs at NPL has highlighted the importance of using double-sided strain measurement for accurate modulus values at room temperature, and it is reasonable to assume that a similar practice should be used at elevated temperatures. Both ASTM E111 and EN 10002 state that averaging extensometry is preferred but not mandatory, and the only recommendation for elevated temperature tensile testing in EN 10002-Pt5 is that a Class 1 extensometer be used.

A new test procedure has been developed, which is designed to be used separately from the conventional tensile test. It uses a load-unloading test within the elastic limit of the material. Further work is still required to fully validate the method, but by the end of the current project it is planned that the method can be submitted to ISO as an annexe to the ISO/TTA2 document on the tensile testing of MMCs.

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Proposed Revision To MMC Tensile Test Method (ISO/TTA2) - For Elevated Temperature Measurement Of Young's Modulus

For the accurate measurement of Young's modulus it is recommended that a separate test is carried out in addition to that used to measure the full stress-strain curve, following the procedure outlined below. In this procedure the modulus is calculated from the elastic part of the stress-strain curve, obtained during a load-unloading test. The method applies equally to room temperature and elevated temperature modulus measurements. Provided that no gross plastic deformation or microstructural changes occur the same specimen can be tested over a range of temperatures.

1 Recommended Test Procedure

- 1.1 Tests should be carried out within the elastic strain range of the MMC. If possible, the test conditions (max load, strain range etc.) should be based on previous test data, generated on the same material at the same test temperature.
- 1.2 Loading-unloading tests are preferred.

- 1.3 Young's modulus can be measured from either the loading or unloading part of the curve - but it must be stated in the report.
- 1.4 Tests should be carried out at constant strain rate or a constant crosshead speed.
- 1.5 One load-unload test may be carried out prior to making the first measurements to allow for bedding in of the specimen in the grips. Repeat tests should be carried out under the same conditions, to a load equal to or less than that used previously.
- 1.6 The application of a preload is not recommended because of the low proportional limit and limited elastic behaviour typical of MMC.
- 1.7 If measurements are made at elevated temperature the testpiece should be allowed to reach equilibrium for at least 10 minutes prior to the modulus measurement.
- 1.8 3 repeat tests should be carried out for each material and test condition.

2 Strain Measurement

- 2.1 A double-sided, Class 0.2 extensometer is recommended, calibrated according to EN 10002-Pt4
- 2.2 High temperature strain gauges can be used, but a number of practical points must be considered, including the use of high temperature adhesive and solder, coated leadwires and protective coatings for the gauges.
- 2.3 If possible, the calibration of the strain measuring device should be carried out over a similar strain range to that used in the loading-unloading test.
- 2.4 If strain gauges are used, the maximum amplifier gain should be chosen to give the greatest strain resolution and full scale output over the limited displacement range during the load-unload test. An accurate gauge factor must be used and consideration should be made of the variation of gauge factor with temperature.
- 2.5 The extensometer or strain measurement device should be balanced immediately prior to the start of the test.

3 Temperature Measurement

- 3.1 Temperature measurement should be made with a suitably calibrated thermocouple attached to the testpiece gauge length. The temperature equipment should have a resolution of at least 1°C and an accuracy of $\pm 2^\circ\text{C}$.
- 3.2 The maximum deviation between the specified temperature and the measured temperature is $\pm 3^\circ\text{C}$ for tests up to 600°C.
- 3.3 The testpiece should be heated to the specified temperature and maintained at that temperature for at least 10 min before loading. The heating profile should be noted carefully as with some MMCs and heat treatable alloys age hardening may occur which can affect the properties.
- 3.4 During heating the maximum temperature of the testpiece shall not exceed the specified temperature.
- 3.5 If large grips are employed the thermal mass may lead to large temperature differences between the grips and specimen. Conditions should be chosen to minimize temperature gradients along the length of the testpiece.

4 Data Analysis

- 4.1 Reference should be made of the method of modulus analysis - see [Ref 6](#) for full details

Method M1 is a graphical method and the modulus is calculated from the slope of the line drawn over the initial part of the stress/strain curve;

Method M2 is a chordal method, often used with computer software, and the modulus is calculated from the straight line joining two points on the stress/strain curve;

Method M3 uses a quadratic polynomial fit to the stress/strain curve and examination of the tangent and secant moduli to obtain a value for Young's modulus.

4.2 Reported modulus values should be rounded to the nearest 0.5 GPa

5 Report

5.1 The test report shall contain at least the following information:

- reference to this test procedure
- testpiece identification code and material type
- type of testpiece and dimensions
- location and direction of sampling of the testpiece
- specified temperature of the test, and the indicated temperatures
- details of strain measurement device and calibration
- details of thermocouple type and calibration
- test conditions including maximum load and strain range
- method of calculating Young's modulus - M1, M2 or M3 (see [Ref 6](#))
- all results, mean value and standard deviation for each test condition
- representative stress-strain graphs

Summary

- A new tensile test procedure has been proposed which recommends high precision strain measurement and loading within the elastic limit. The method is applicable to metals and other materials, and will be considered for submission as a separate part of ISO/TTA2 - the tensile test procedure for MMCs.
- For tensile tests, double-sided strain gauges or extensometry should be used to take into account bending in the specimen which can seriously affect the modulus value measured. If possible, a Class 0.2 extensometer should be used.
- Demand still exists for a simple, inexpensive, high resolution double-sided extensometer for accurate strain measurement.

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