

Ductile Brittle Transition Temperature (DBTT) Measurement of Coatings used in Gas Turbines

Summary

Two methods have been identified which yield repeatable results. These are uniaxial tensile tests and four-point bending. The onset of failure is detected by direct observation after a known strain increment, or by monitoring with acoustic emission. There can be a problem with the four-point bending and uniaxial test methods when the substrate material is also brittle, and thus premature failure occurs in the substrate. When appropriate, the coating can be deposited on a ductile material, but where there is significant interaction with the substrate, this practice is not recommended.

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Background

Corrosion resistant coatings are routinely applied to hot components in gas turbine engines. In addition to their corrosion resistance the coatings must also have adequate strain tolerance to withstand the system strains imposed during operation of the engine. Clearly a coating that is cracked is of little use in fulfilling its function as a corrosion resistant layer. The coatings applied to the high pressure gas turbine blade are the most highly strained and typically about 1% creep strain is found. The DBTT is therefore quoted as the temperature below which cracking first occurs at a given strain level; the strain level chosen will be that appropriate to a given application.

Ductile Brittle Transition Temperature Measurement

This measurement note is concerned with the measurement of DBTT for coatings used at high temperatures. The methodology adopted is described and precautions / caveats associated with the methods and some typical results are given. Two methods are described: four point bending in tension and uniaxial tensile testing. Determination of failure can be either by direct observation or by use of acoustic emission.

The work is focussed upon coatings used in gas turbine engines particularly to confer resistance to high temperature corrosion and oxidation, although the methodology developed will find applicability to other coatings of similar thicknesses with DBTTs of up to about 1000°C.

Four-Point Bend Testing

[Figure 1](#) is a schematic diagram of the experimental set-up used showing the use of acoustic emission (AB) to detect the onset of cracking. The arrangement used at NPL employs a 20:40 mm spacing between the upper and lower rollers, respectively, and an oblong sample 100 x 10 x 3 mm. Samples should be coated on one side only and placed coating side down, thus on application of load the coating is strained in tension. The thickness of the sample will be varied according to the strength of the material under test to ensure uniform bending. Strain was measured from the movement of the crosshead on the tensile testing machine. The following relationship is used to calculate the tensile strain imposed on the sample:

$$\varepsilon = \frac{3\delta t}{k(3l - 4k)}$$

where ε is the strain, d is the cross-head displacement, t the thickness of the testpiece, k the distance between the inner and outer rollers and l the distance between the outer rollers.

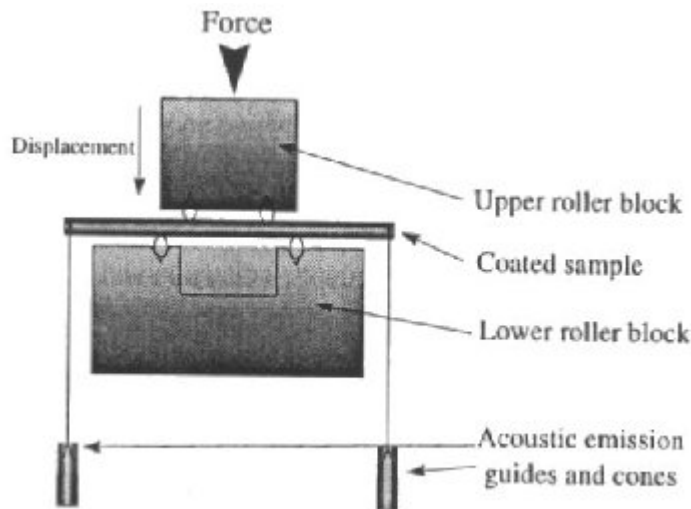


Figure 1: Schematic diagram of the experimental set-up for four-point bending incorporating two AE detectors

Since the test rig operates at high temperature, the components of the four-point bend jig are made of inert ceramic, and alumina is recommended. Whilst this overcomes the problem of deterioration of the bend jig materials by oxidation, it introduces additional "noise" into the system from movement of the ceramic rollers against the upper and lower support blocks. This can, in principle, be reduced by the use of a time-of-flight *AB* system which employs two transducers and appropriate software that allows location of origin of *AB* signals to be performed. Thus all extraneous signals from the jigging and load train can be filtered leaving only coating related signals.

For experiments at high temperature waveguides are normally used since the *AB* transducers are only capable of room temperature operation. A heat resisting material in wire form is used as the waveguide. This is usually welded to the specimen and in the region of wire outside the furnace a cone is attached (brazing is an effective method) to facilitate good contact with the *AB* transducer. Silicon grease is also used at this interface to ensure good coupling of the *AB* signals. The waveguides and cones are shown schematically in [Figure 1](#).

[Figure 2](#) shows the results of *AB* monitoring during tensile straining of a coated sample in which it can be seen that there was a marked increase in *AB* activity at about 1.3% strain. Some *AB* events occurred before this level of strain was imposed, but it is unclear whether this can be associated with cracking of the coating ([Figure 3](#)). In some cases, although no substrate cracking was observed after testing cross-sectioning indicated that internal substrate cracking did indeed take place ([Figure 4](#)).

Hence use of *AB* to monitor coating cracking is somewhat uncertain since if the substrate has low ductility *AB* activity can arise. Thus testing the uncoated material is essential before the *AB* signals can be reliably used to indicate coating failure.

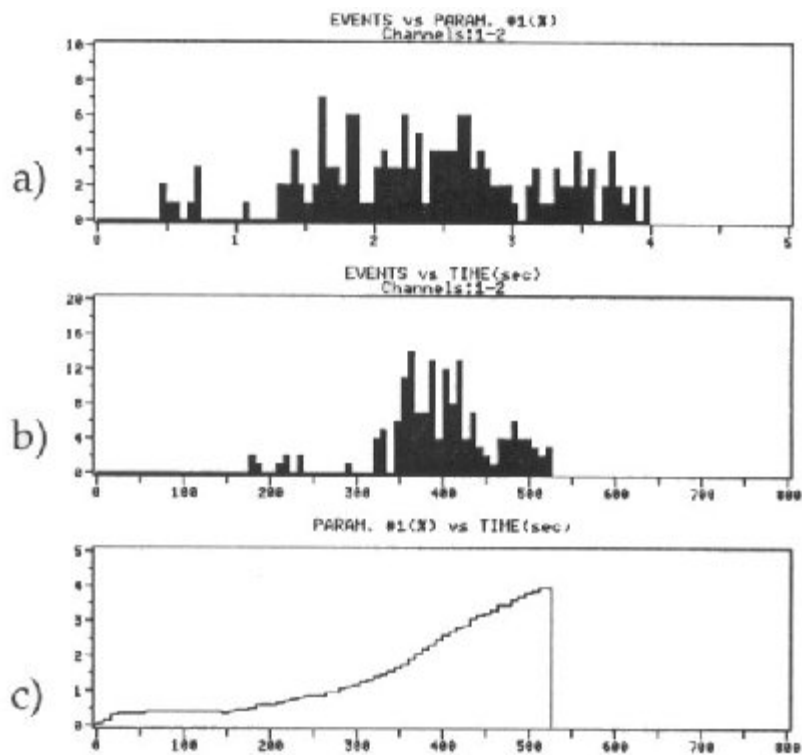


Figure 2: AE signals from a coated sample exposed at 650°C showing onset of failure at about 1.5% strain ("param"), a) AE events as a function of %strain, b) AE events as a function of time and c) %strain as a function of time

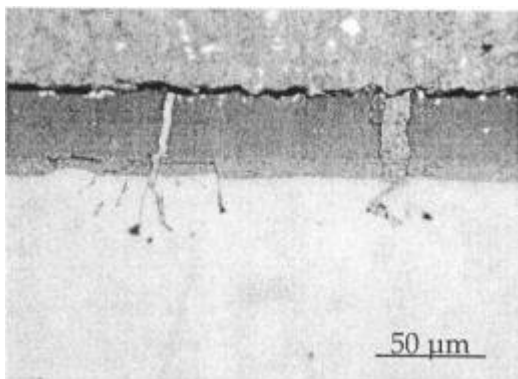


Figure 3: Optical micrograph showing cracks in coating after testing

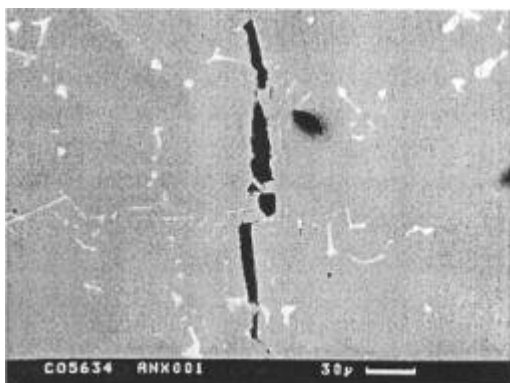


Figure 4: Backscattered electron micrograph of coated sample after DBTT testing, showing cracks in substrate

To ensure unambiguous identification of coating cracking, direct examination of the strained sample is

recommended. This can either be by light or scanning electron microscopy (SEM). The latter is to be preferred so that the initial cracking events can be detected where often only small cracks are present. Cracks are most readily detected when using the backscattered imaging mode of the SEM.

[Figure 5](#) shows a set of optical images for a coated sample strained to 1% at temperatures between room temperature and 800°C. The transition between crack-free sample and observed cracking occurs between 750 and 800°C.

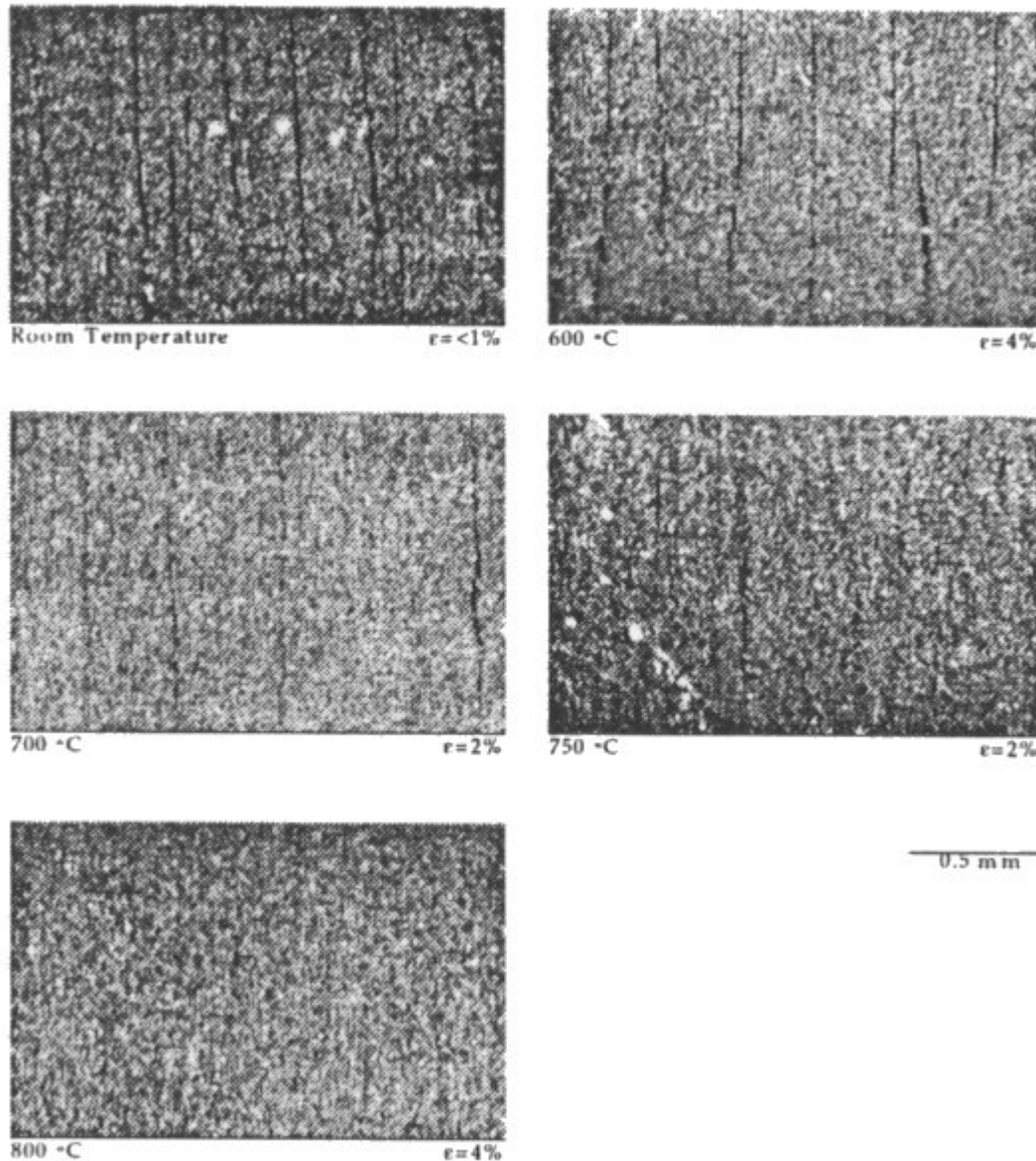


Figure 5: Optical micrographs of a coated sample strained at temperatures between RT and 800°C

Uniaxial Tensile Tests

[Figure 6](#) shows the experimental arrangement used for the uniaxial test configuration. As can be seen similar waveguide and cones are used as proposed for the bend tests. Strain is measured using conventional extensometer systems, and this therefore gives somewhat more certainty in the measurement of strain.

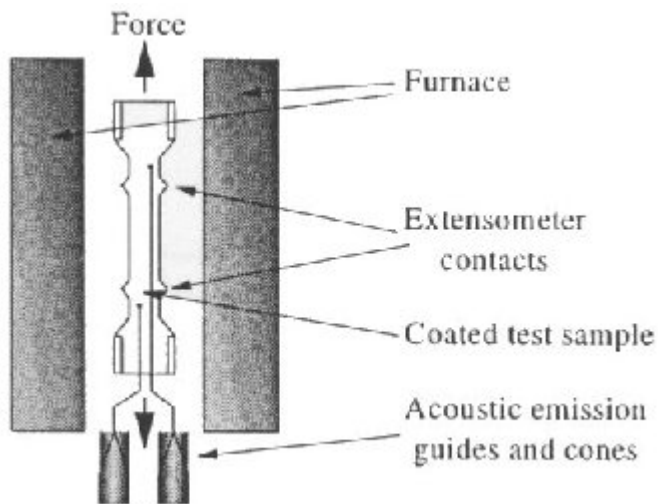


Figure 6: Experimental configuration for uniaxial testing

Acknowledgements

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