CMMT(MN)003

Validation of Models to Predict Thermal Expansion of Fibre Reinforced Metal Matrix Composites

Summary

This note is concerned with the prediction of the thermal expansion properties of fibre reinforced metal matrix composites given the properties of the fibres and matrix for a titanium composite. The matrix modulus and expansion coefficients have been measured experimentally and their temperature dependence determined. Relatively simple models are used to predict the axial and transverse properties of a unidirectional composite having a volume fraction of 0.32. The results are then used to predict the thermal expansion coefficients of a cross-ply laminate of the type [0/90]8. Comparison with experimental data for silicon carbide fibre reinforced titanium alloy shows that model predictions agree well with measured values for both unidirectional and laminated composites.

Neil McCartney

February 1997

General Background

Composite structures in service conditions rarely experience uniform temperature distributions throughout their service lives. Thermal stresses arising from thermal transients can build up and lead to high stresses that can sometimes be damaging to the structure. The thermal expansion behaviour of the composite is an important thermal property that affects the build up of such stresses. For fibre reinforced metal matrix composites the differing thermal expansion coefficients of fibre and matrix leads to the need to estimate values for the thermal expansion of composites that must be characterised experimentally, and theoretically by the use of suitable prediction models.

In contrast to polymer composites, applications of fibre reinforced MMC involve mainly unidirectional composites and cross-ply laminates. A modelling methodology is described that predicts the thermal expansion coefficients of both unidirectional composites and cross-ply laminates from the properties of the fibres and matrix. Predictions are compared to experimental data that validate the models for the case of titanium matrix composites.

Predictive models for the thermal expansion coefficients of fibre reinforced composites cannot be realised in isolation from the elastic constants. The equations on which the models are based are too numerous to include in this note although it is emphasised that they are relatively simple in form, and therefore easy to use. For metal matrix composites the temperature dependence of the matrix properties is very important, and account is taken of this effect when making predictions of composite performance. Readers should consult the publication [1] for full details of the methodology, the fibre and matrix properties, and more detailed results.

Basic Fibre And Matrix Data

All predictions have been made from one set of fibre and matrix properties. The silicon carbide fibre properties are assumed to be temperature independent such that the Young's modulus is 409 GPa, Poisson's ratio is 0.25 and the coefficient of thermal expansion is 5×10^{-6} /°C. The temperature dependent Young's modulus, measured from a titanium foil laminate that has been made in a similar way to the composites, is shown in Fig. 1.

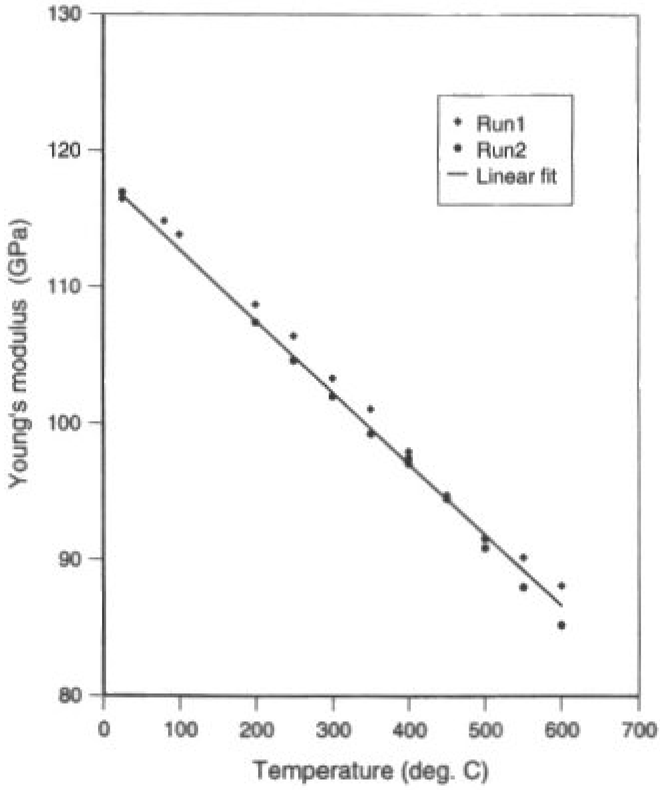

Fig. 1 Dependence of Young's modulus on temperature for laminated Ti-6Al-4V titanium alloy.

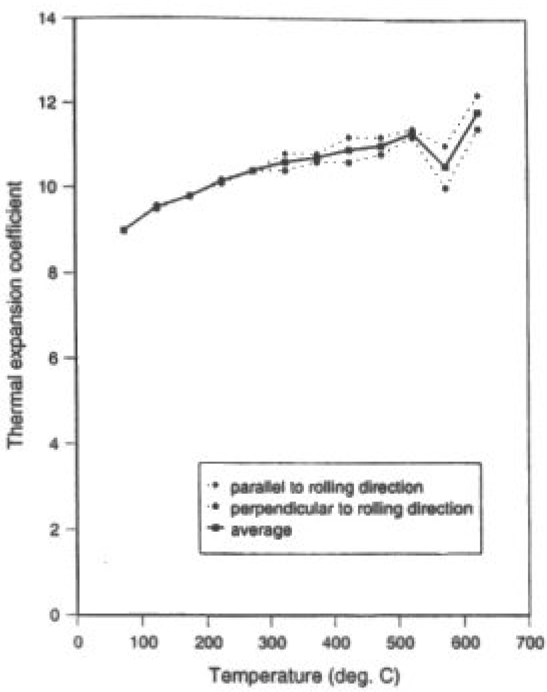

Fig. 2 Experimentally measured values of the thermal expansion coefficient (x 10^6/ °C) for titanium alloy (Ti-6Al-4V) as a function of temperature.

The data exhibited in Fig. 1 are almost linear and easily represented mathematically by a straight line. The corresponding temperature dependent thermal expansion measurements for the titanium foil laminate are shown in Fig. 2. Measurements have been taken parallel and perpendicular to the rolling direction of the laminate. For prediction purposes the average of these values was used.

Results

Figure 3 shows the comparison of model predictions with experimental results for both unidirectional and cross-ply laminates. The unidirectional material having a fibre volume fraction of 0.32 is anisotropic and it is seen that the axial expansion coefficient is less than the transverse expansion coefficient. This behaviour is expected as the axial deformation is limited by the fibres that have a lower expansion coefficient than the matrix. The cross-ply laminate has equal numbers of fibres in the axial and transverse directions with the result that the axial and transverse expansion coefficients for the laminate are expected to have more or less the same value.

The results shown in Fig. 3 indicate that the laminate expansion coefficient lies approximately mid-way between the results obtained for the unidirectional composite. It is particularly important to note that in all cases the model predictions are close to the values measured experimentally, thus validating the models used for prediction purposes in the case of fibre reinforced titanium composites. The models are expected to be valid also for other fibre reinforced metal composites, e.g. silicon carbide and alumina fibres in aluminium alloys.

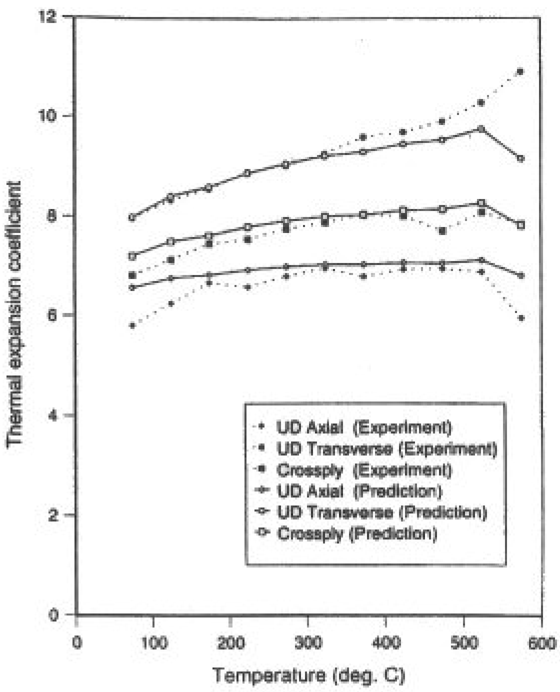

Fig. 3 Comparison of experimental and model predictions for the thermal expansion coefficients (x 10^6/ °C) of Sigma silicon carbide reinforced Ti-6Al-4V titanium composite.

Reference

1. L N McCartney, R Morrell and J D Lord, 'Validation of models for the prediction of the thermal expansion coefficient for fibre reinforced titanium composites', NPL Report CMMT(A)56 December 1996.

Acknowledgement

This work is part of the *Materials Measurement* programme of underpinning research financed by the UK Department of Trade and Industry.

For further information contact:

Dr L N McCartney
Centre for Materials Measurement and Technology
Tel: 020 8943 6686

Fax: 020 8943 2989
Email: Neil.McCartney@npl.co.uk
Experts Link to Expert

National Physical Laboratory
Queens Road
Teddington
Middlesex
United Kingdom
TW11 0LW

Tel: 020 8977 3222
Fax: 020 8943 6458
Email: materials@npl.co.uk

CMMT(MN)003
Validation of Models to Predict Thermal Expansion of Fibre Reinforced Metal Matrix Composites
February 1997