LA-UR- 00-2084

Approved for public release; distribution is unlimited.

Title: MEASURING SPATIAL VARIATION OF RESIDUAL STRESSES IN A MMC USING CRACK COMPLIANCE

Author(s): Michael B. Prime (ESA-EA)
Partha Rangaswamy (MST-8)
Mark A. M. Bourke (MST-8)

Submitted to: Proceedings of the Seventh International Conference on Composites Engineering
Denver, CO, July 2-8, 2000
Editor: D. Hui
pp. 711-712

Los Alamos
NATIONAL LABORATORY

MEASURING SPATIAL VARIATION OF RESIDUAL STRESSES IN A MMC USING CRACK COMPLIANCE

M. B. Prime (prime@lanl.gov), **P. Rangaswamy**, and **M. A. M. Bourke**
Los Alamos National Laboratory, Los Alamos, NM, 87545 USA

Introduction

We present a novel measurement of the spatial variation of residual stresses in a metal matrix composite (MMC). Failures in MMCs are sensitive to localized residual stresses. For example, the interface bond strength depends on the radial residual stress at the fiber-matrix interface.[1]

Unfortunately, most residual stress measurements in MMCs are spatial averages rather than local values. Neutron diffraction measurements in MMCs typically average over the whole sample, although they do provide separate stresses in the fiber and matrix.[2] Layer removal methods similarly provide a spatial average over a large volume.[3] X-ray diffraction can measure a local stress value but only on the surface.[2]

The measurement of spatially resolved residual stresses is also crucial for validating predictive models. Models with different predictions for local residual stresses can lead to the same averaged values. Therefore, the practice of validating models only against measured average stresses can lead to false confirmations.

Specimen

Kanthal matrix composites containing 200 μm diameter tungsten fibers were fabricated at the NASA Lewis Research Center using the arc-spray method.[4] The composition of the Kanthal by weight % is 73.2 Fe, 21 Cr, 5.8 Al, and 0.04 C. Tapes containing unidirectional fibers were hot pressed at 1065C for 1 hour before being cooled to room temperature. The as-fabricated bars were 25 mm wide, 2.5 mm thick, and 200 mm long. An additional Kanthal bar containing no fibers was fabricated and taken through the same heating cycle.

Measurements

We measured residual stresses in a 10 vol-% specimen using the crack compliance method.[5] A wire (30 μm diameter tungsten) cut a slot 80 μm wide (Fig 1) by wire electric discharge machining (EDM). The slot was cut in 25 μm increments, while strains (ε_X) were measured on the top surface after each increment using a strain gauge. The final slot depth was about 500μm.

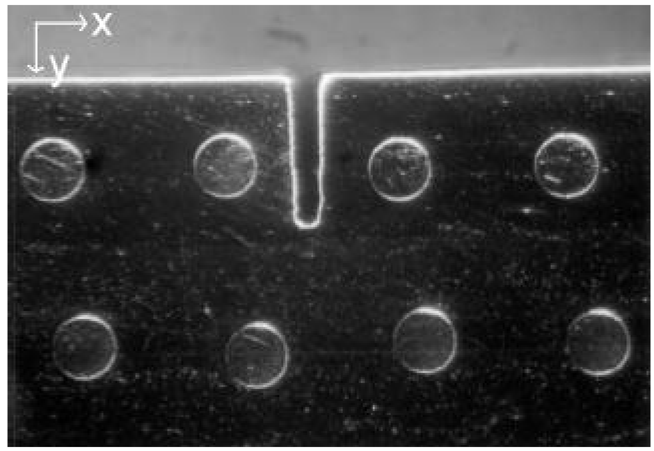

Figure 1. Micrograph showing final depth of slot cut by wire EDM in MMC. Fibers are 200 μm diameter.

The residual stress profile was calculated from the measured strains using a series expansion and a 5th order power series. Fig. 2 shows the result, which is a depth profile of σ_X along the left side of the slot.

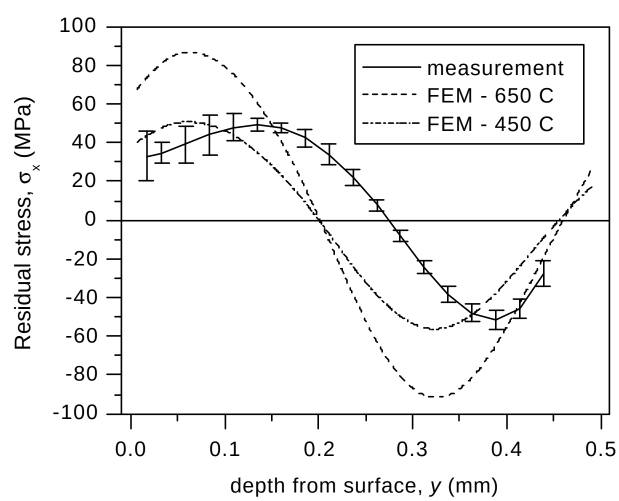

Figure 2. Crack compliance measurements and FEM predictions in MMC.

Figure 3. shows results from measurements in the monolithic (no fibers) Kanthal specimen. The magnitude of the residual stresses is low but not zero.

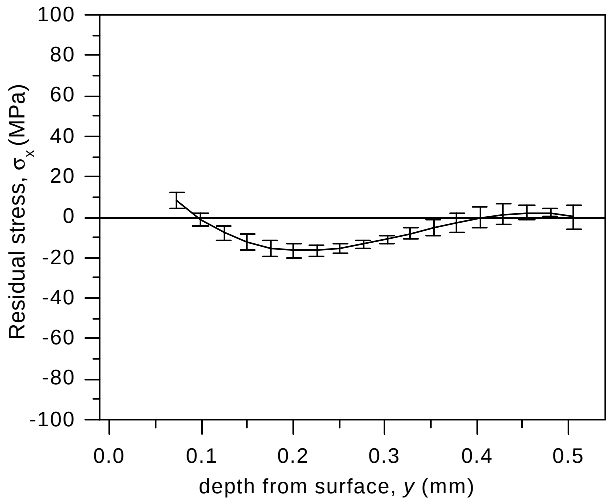

Figure 3. Crack compliance measurements in monolithic Kanthal specimen.

FEM Prediction

The measurement results were compared to predictions from a previously published finite element method (FEM) model.[4] A 2D analysis was performed using generalized plane strain elements. Material behavior was taken as elastic-perfectly plastic with Von Mises yielding and temperature dependent properties. The model used 650 C as the starting point of the analysis—the stress-free temperature. To facilitate direct comparison with the measurements, the finite element mesh reflected the actual specimen geometry, Fig. 4, rather than using the unit cell calculation previously reported.[4]

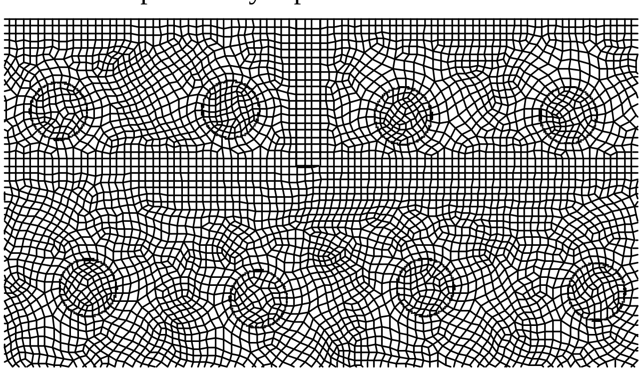

Figure 4. Finite element mesh, zoomed in on region shown in Fig. 1.

The residual stresses were extracted from the FEM model at the same location as the crack compliance measurements. They are plotted in Fig. 2.

Discussion

The general trend of the measurements and predictions are similar; however, the model overpredicts the stress magnitude by about 50%. Neutron diffraction measurements similarly found the average stresses in the matrix of the 10 vol-% specimen to be lower than predicted by the model.[6] Decreasing the stress-free temperature in the model to 450 C resulted in better agreement, although we have no justification for that particular selection, and the locations of the peak stresses are still shifted by about 0.1 mm from their measured locations.

A more realistic model might match the measurements better. The FEM model did not include viscoplastic material behavior or strain hardening, assumed perfect bonding between the fiber and matrix, and assumed uniform cooling. The non-zero residual stress measurements in the monolithic Kanthal specimen, Fig. 3, support the contention that uniform cooling is not a good assumption.

Conclusions

The crack compliance method is shown to be an important tool for spatially resolving residual stresses in MMCs. Such measurements are crucial for failure prediction and for validating FEM models. However, because a slot must be cut between the fibers, crack compliance measurements are limited to relatively low volume fraction composites.

References

[1] Warrier SG et al., "Assessment of the Fiber/Matrix Interface Bond Strength in SiC/Ti-6Al-4V Composites," *Mater. Sci. & Eng. A*, **259**, 220-227, 1999.

[2] Wright PK, "Measurement of Residual-Stresses in Metal-Matrix Composites," *J. Eng. For Gas Turbines & Power*, **116**, 605-610, 1994.

[3] Gungor S, Ruiz C, "Measurement of Thermal Residual Stresses in Continuous Fibre Composites," *Key Eng. Mater.*, **127**, 851-859, 1997.

[4] Saigal A, Leisk GG, "Residual Strains and Stresses in Tungsten/Kanthal Composites," *Mater. Sci. & Eng. A*, **237**, 65-71, 1997.

[5] Prime MB, "Residual Stress Measurement by Successive Extension of a Slot: The Crack Compliance Method," *Appl. Mech. Rev.*, **52**, 75-96, 1999.

[6] Rangaswamy, P et al., "Residual Stresses in Tungsten Fiber Reinforced Kanthal Matrix Composites," *J. Eng. Mat. Tech.*, submitted.