Advancing the Contour Method for the Measurement of Residual Stress in Polymer Composites

Praveen K R[1,*], Foroogh Hosseinzadeh[1], P John Bouchard[1], Fabien Lefebvre[2], Damien Guillon[2]

[1]*School of Engineering and Innovation, The Open University, Milton Keynes, UK*
[2]*Centre Technique des Industries Mécaniques, Senlis, France*
**Corresponding author: praveen.karebasar@open.ac.uk*

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The manufacturing route for polymer composites inevitably introduces residual stress. This internal stress generated during the curing regime results in distortion and problems of "fit-up" post-manufacture. Consequently, the composite structures might need to be pre-loaded to get the desired assembly tolerances, creating additional internal stresses and reducing the overall performance of the product. Residual stresses in polymer composites also promote fatigue and other degradation mechanisms which can compromise the life and structural integrity of components in service. In order to optimise the design and structural integrity of polymer composites, knowledge of bulk residual stresses is required. Analytical and numerical methods have been developed to predict residual stresses in polymer composites but these procedures are computationally expensive and require cure and temperature dependent physio-chemo-rheological properties when the entire curing cycle is modelled [1]. Experimental measurements offer an alternative solution for developing a quantitative understanding of the sign, magnitude and distribution of residual stresses. In addition, experimental characterisation is essential for validation of predictive methods. But there is no consensus regarding what experimental method to use for measuring bulk (through-thickness) residual stress in polymer composites.

The Contour Method is a well-established technique for measuring bulk residual stresses in metallic components [2]. It involves sectioning the component into two halves across the plane of interest, measuring the out of plane deformation of the created cut surfaces and applying the measured deformation map to a finite element model of the cut component to back calculate the original residual stresses at the cut section. The first research challenge in applying the Contour Method to non-metallic materials, such as Carbon Fibre Reinforced Polymer (CFRP) composites, is developing a suitable method for cutting the material. Here we present results of cutting trials on a thermoset composite cross ply laminate using two different cutting techniques: abrasive waterjet machining and diamond wire cutting. The cut surfaces from both cutting techniques are thoroughly assessed using optical microscopy, scanning electron microscopy and high resolution surface topological scanning to validate the contour method assumptions. This includes characterization of the microstructure, material defects and cutting artefacts affecting the deformation topology of the cut surfaces. In applying the Contour Method high resolution out of plane deformation data (0.025mm pitch) from mating cut faces were aligned, averaged and obvious noise and outliers removed, prior to data smoothing using different approaches [3]. In particular, the effect of the smoothing length-scale, smoothing method and finite element mesh size on the back-calculated residual stress field has been investigated and objective measures of fit [4] developed suited to the length-scale of ply to ply residual stress variations. Residual stresses through the thickness of a reference two ply laminate (0^o, 90^o) measured by the Contour Method using diamond wire cutting are presented and compared with numerically predicted thermal contraction residual stresses. The work is at an early stage but demonstrates how the contour method has the potential for determining the distribution of residual stresses through the thickness of CFRP cross ply laminates.

References

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