Image Decomposition of Full Field Strain for Impact Damage Assessment of Composites

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Abstract

This paper discusses techniques for automated classification of damage in carbon fibre composites. Cross-ply composite specimens were manufactured and then impacted to produce delaminations in the specimen with barely visible surface damage. The severity of damage was assessed using ultrasonic C-scans and digital image correlation (DIC). The specimens were then loaded to failure in a four point bend configuration to determine residual strength. The surface strain measured using DIC was processed using image decomposition with Tchebichef polynomials to reduce the dimensionality of the strain maps. The strain data in its dimensionally reduced form can then be used to make comparisons between damaged and undamaged specimens. The numerical similarity between the undamaged and damaged states is shown to correlate with both the impact energy and the residual strength of the damaged specimens.

Introduction

Carbon fibre reinforced polymer (CFRP) composites are increasingly utilised in aircraft structures. Whilst CFRP has a high specific strength it has a significant drawback. CFRP structures are very susceptible to damage from sources such as low velocity impacts and manufacturing defects. To avoid this problem, composite structures are designed assuming that the material contains substantial barely visible damage, which reduces the potential weight savings. Inspection programs are often required to ensure that damage is located before it can grow to an extent where the structure is unsafe. This paper discusses the development of techniques of image decomposition of surface strain to produce more accurate assessments of impact damage in CFRP.

Inspection programs, typically termed non-destructive evaluation (NDE), can utilise several different techniques. The most commonly applied techniques for aerospace composites are ultrasound and thermography. The images captured are typically examined by a trained technician who needs to remain attentive in order to not miss damage. C-scan ultrasound images allow simple metrics such as projected area or width of damage to be calculated. At best, once damage is found the C-scan measurements are compared to an allowable threshold. More often, components with any extent of damage are immediately repaired or replaced; greatly increasing the maintenance costs of the aircraft [1].

To advance NDE and maintenance practices, methods must be developed which not only determine the presence, location and severity of damage but also the residual life of the component with that damage. To move towards this aim Patki and Patterson [2] developed a novel method of assessment based on image decomposition. Glass fibre composites with known levels of impact damage were analysed using digital image correlation (DIC) to produce maps of surface strain. These maps were then decomposed into Fourier-Zernike moments to greatly reduce the dimensionality of the original data. The mathematical moments are then collated into a feature vector. The similarities between the undamaged state and the damaged states were numerically compared using the associated feature vectors. This numerical similarity was found to correlate more closely with impact energy than C-scan measurements could achieve. Image decomposition applied to strain data presents many advantages over traditional methods. The process could be substantially automated and more accurate damage parameters, such as residual strength, determined.

Experimental Method

This study has extended the technique to carbon fibre composites as they are utilised extensively in modern aerospace structures. Unidirectional carbon fibre prepreg has been used to produce eight cross-ply laminate specimens. These specimens have had low velocity impact damage applied using a drop weight impactor. C-scan time of flight images have been captured to determine the shape and depth of the delaminations formed in the specimens. Fig 1 shows the distribution of delaminations produced in one of the specimens. The only damage visible on the impacted surface is a 0.16 mm deep dimple of 4.9 mm diameter. The specimens have then had a speckle pattern applied to the impacted surface and stereoscopic DIC has been used to produce maps of surface strain around the impact location whilst under tension. Subsequently these specimens have been loaded to failure in a four-point bend configuration, with the impacted surface in tension, to determine the residual strength of the specimens.

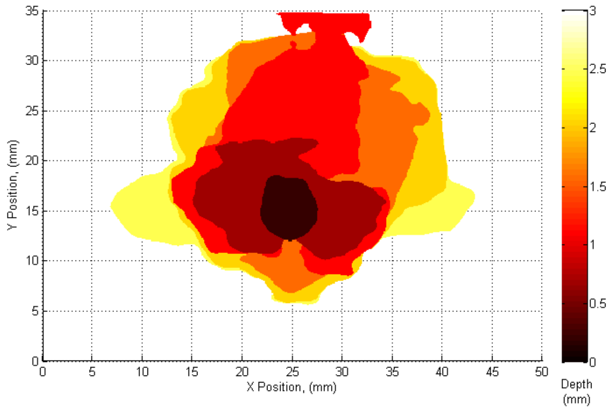

Fig 1. A time-of-flight ultrasound image showing the distribution of delaminations produced by a 12 J impact on a 3 mm thick cross-ply CFRP specimen inspected from the impact face.

Discussion

The use of Tchebichef polynomials for the image decomposition process has been explored. Tchebichef polynomials have a considerable benefit over Zernike polynomials as they can easily be discretised without evaluating an integral and as such the computation time for calculating each entry of the feature vector is substantially reduced [3]. A selection of similarity metrics have been used to compare the feature vectors with the undamaged state such as the Minkowski distances and Pearson correlation. These similarities show how the impacted specimens have changed from the undamaged state. The similarity metrics were then correlated with the impact energy and the measured residual strength of the component, see Fig 2. The correlations between the similarity metrics and the specimen parameters were compared to what can be determined using ultrasound images. Additionally, probabilistic classification is employed to estimate the likelihood that an arbitrary location exhibits a prescribed level of damage given the data provided by the feature vectors.

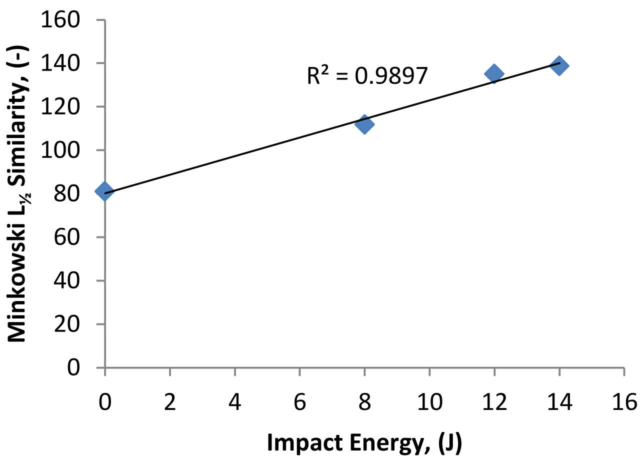

Fig 2. Minkowski $L_{½}$ similarity measure between the feature vectors describing the surface strain for the damaged and undamaged specimens.

Conclusion

This work demonstrates that full field strain data combined with decomposition techniques has the potential to allow predictions of residual strength. With accurate estimations of the residual strength of components, wastage of serviceable parts could be reduced and needless down-time eliminated.

Acknowledgements

WJRC is studying on an EPSRC CASE Award PhD sponsored by Airbus. EAP is a recipient of a Royal Society Wolfson Research Merit Award.

References

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