Improving Strain Field Measurements for Textile Composites

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Abstract

In this paper, an algorithm based on linear regression in conjunction with the periodical nature of textile composites for improving the strain fields measured by DIC and ESPI techniques is presented. Specimens of textile composites were prepared with regular stacking of layers using vacuum assisted RTM process and then tested under tensile loading within the elastic region. The improvement of strain fields determined by the proposed algorithm is illustrated and the applicability of which is discussed.

Keywords: Textile composites; Strain fields; Digital image correlation (DIC); Electronic speckle pattern interferometry (ESPI)

1. Introduction

Full-field optical strain measurement techniques such as digital image correlation (DIC) and electronic speckle pattern interferometry (ESPI) have been widely used in the testing of composite materials. The current state of these techniques makes it possible to acquire displacement fields with high quality. These are in turn used to obtain full-field maps of strain components, which are useful for damage monitoring and validation of finite element modelling. However, the inherent use of spatial differentiation in calculating the strain fields amplifies the experimental noise in the displacement results. In particular, for DIC measurements in the elastic region, the noise in the strain results can become of comparable magnitude to the strains, making DIC of limited use for measurement of elastic strain fields where significant spatial variations are of interest. This problem is particular intractable because spatial smoothing (which is often used to reduce noise in DIC and ESPI results) would destroy the spatial resolution which is required for such measurements.

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if the results are to form a useful comparison with numerical predictions of local strains. The problem of noisy data is much less significant beyond the elastic region as the measured strains then become large compared with the noise. A number of techniques have been developed to filter out the noise, among them linear regression [1] and interpolation [2]. However, none of them has made use of the repeating nature of the textile composite. This study presents an algorithm for improving the accuracy of strain field measurements relating to in textile composites under tensile loading within the elastic region. The regularity which is exploited here is present in composites involving a single layer of 2D textile reinforcement; it is also applicable to 3D woven textiles and as in the present case, the situation where a consistent relationship between the positions of successive reinforcement layers has been artificially enforced.

2. Experiments

2.1. Specimen manufacturing

A 2×2 twill weave textile manufactured by Carr Reinforcements (style 38391) was used for the experimental studies. The textile consisted of 12K Grafil 34-700 carbon fibres woven with density of 4.2 picks/ends per cm and the overall areal density of textile was 660 g/m². The textile was used to manufacture 6-layer laminates with regular stacking (no nesting, no layer shift) of layers using vacuum assisted RTM process [3]. Textile preforms with regular layer stacking were assembled on a wooden board, and layers of the textile were fixed in a selected position over each other with use of metal pins. Layers were bound together using NeoXil binder, which prevented them from undergoing relative shifts in position during manufacturing. Both regularly and randomly stacked preforms were placed in a metal tool with 4mm cavity and infused with Prime 20LV epoxy resin mixed with Prime 20 Slow Hardener. As a result five composite panels (three with random stacking and two with regular stacking) with overall fibre volume fraction 55% were manufactured.

2.2. Experiments

Specimens from each panel were tested in tension in warp direction according to EN ISO 527:2012 standard using Instron 5985 machine with 250kN load cell with test speed of 2mm/min at room temperature 20°C. The specimens were tabbed with aluminium tabs using epoxy glue to prevent early damage in jaws. DIC and ESPI measurements were carried out with DANTEC Q400 and DANTEC Q300 systems, respectively. Additionally, acoustic emission system was used to monitor the onset of damage in order to define limits of elastic behaviour.

3. Improvement of strain field

The original images were exported as HDF5 files using the ISTRA 4D software and processed with an in-house MATLAB program, the algorithm of which goes as follows. Firstly, clearly noisy values and outliers were filtered out. This task was performed by removing from the analysis values with unrealistically high amplitudes and values defined as NaN (Not a Number). Then a linear regression of strain vs. load was applied to every pixel through all the load steps within the linear region (the limits of which can be detected with AE analysis). The resulting matrix of gradients was segmented into series of unit cells of defined size, with care being taken to match the unit cell boundaries to those observed in the experiment. Then a mean strain field over all unit cells was calculated. Finally, the resulting matrix of averaged gradients was scaled proportionally to obtain the strain fields at given load. The results of this algorithm applied to DIC measurements are presented in Fig.1 for a specimen with controlled stacking. Strain fields obtained with both DIC and ESPI techniques can be processed with the same algorithm; only those for DIC are presented here. Similar results were obtained for ESPI maps though the initial levels of noise were considerably less than for DIC as the method is more directly applicable to lower strain levels.
The apparently poor quality of strain data captured using DIC in the elastic region is apparent from Fig. 1(a), with the regular pattern of unit cells being barely visible if at all. However, elimination of outliers/NaNs and application of the linear regression to the strain maps at different loads produces a map of strain gradient which clearly shows the regularity in Fig. 1(b). Specifically, the textile pattern can be clearly recognised i.e. regions where yarns are transverse to loading direction exhibit higher strain than regions where yarns are parallel to loading direction. However, a great deal of noise is still present, and in particular outliers are clearly visible. A further improvement can be seen in Fig. 1(c) where strain field is averaged over all unit cells. Map of standard deviation for each pixel in the unit cell is also calculated as shown in Fig. 2, which shows that a small minority of pixels still exhibit large standard deviations, and these pixels generally show outlying values of averaged strains.
While the linear regression aspects of this algorithm are applicable to any linear elastic specimen, the unit cell averaging is only strictly applicable where the specimen as a whole (rather than just an individual layer) exhibits periodicity. It is therefore debatable whether the unit cell averaging approach could validly be applied to a multi-layer specimen without controlled stacking, i.e. where the nesting is not constrained at lay-up stage, as the nesting pattern will vary over the area of the specimen and will consequently affect the ply-to-ply bridging effects and hence the local strain field.

4. Conclusion

The presented algorithm of improvement of DIC and ESPI images was demonstrated to be useful for analysis of strain fields in textile composites. Linear regression in conjunction with information about periodic structure of reinforcement allowed determination of more reliable and detailed strain fields in the elastic region. The proposed algorithm has the potential to be a useful tool for validation of finite element models of textile composites which are usually based on unit cell representation of a composite.

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References