On the Use of Digital Image Correlation to Analyze the Mechanical Properties of Brittle Matrix Composites

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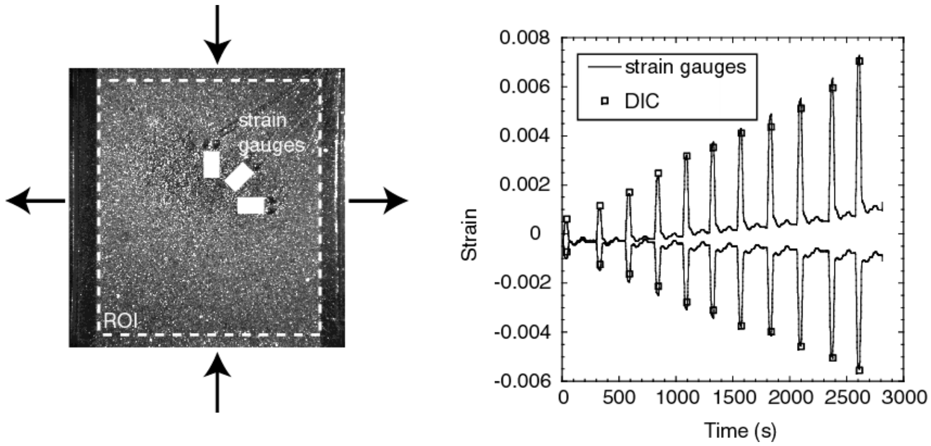
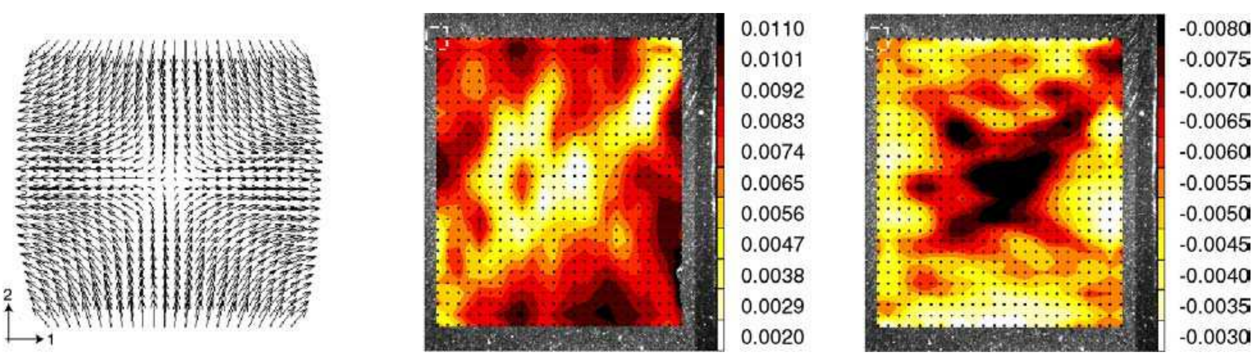


-a- -b-

Figure 10. (a) Shear experiment, (b) comparison between gauge response and measurements by a digital image correlation technique (l = 64 pixels and δ = 32 pixels).

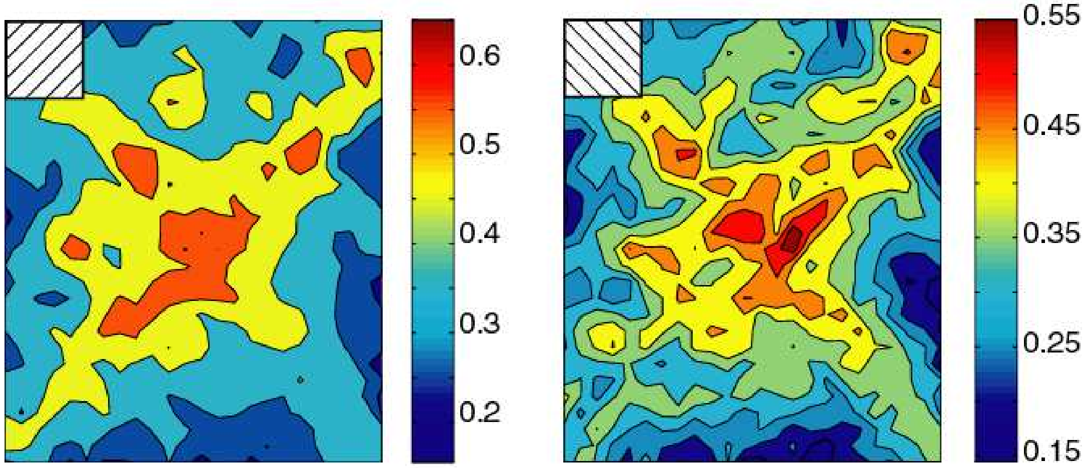
Figure 11a shows the displacement field on the surface of the specimen just before the failure of the specimen. One can note the good symmetry of the displacement field about the two loading directions. The strain maps (Figs. 11b-c) show heterogeneities, which is a first indication that the material is not homogeneous on the scale of the measurements (of the order of 2-3 mm). It is worth remembering that the uncertainties related to the correlation technique are negligible for strain levels greater than 10^{-3}. Therefore, it can be stated that the strain field fluctuations are mainly due to material imperfections.



-a- -b- -c-

Figure 11. (a) Displacement field prior to failure (a). An amplification factor of 34 is used for the in-plane displacement vectors. Corresponding strain maps ε_{11} and ε_{22}.

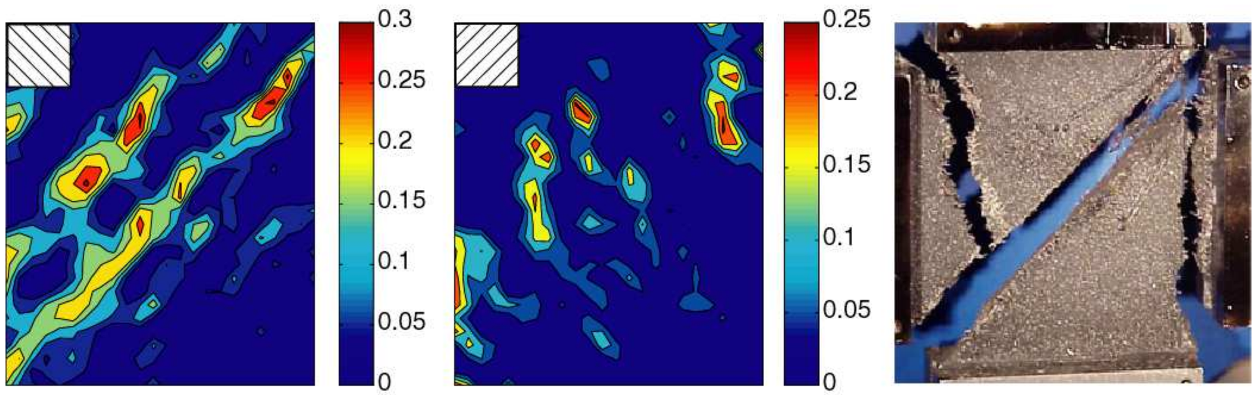
To analyze the experimental results, one uses all the experimental points within the ROI (i.e., all the centers of the ZOIs, Fig. 11a). The strain field is directly deduced from the measured displacement field by a numerical derivation (e.g., Figs. 11b-c). As mentioned earlier, the damage fields can be used to predict the onset of failure related to the degradations in both plies. The damage field inside each layer within the ROI is obtained by a computation using a damage post-processor.[30] Figure 12 shows shear damage fields (d_{12}) in the +45° and −45° plies. As anticipated by the *a priori* computations (Fig. 9), shear damage increases more in the central part of the specimen than near the edges. The damage field is heterogeneous and indicates a high degradation of the matrix, even more important (i.e., 0.6) than that observed in a tensile test at ±45° (i.e., 0.5[30]). However, this damage field does not correspond to the actual failure pattern (Fig. 13c). Matrix damage is probably not the prevalent mechanism leading to the final failure of the specimen.



-a- -b-

Figure 12. Matrix damage contours d_{12} in both ply directions predicted by a damage post-processor using strains deduced from full-field displacement measurements.

To predict failure, the relevant variable to consider is damage of the fibers (d_1), i.e., fiber breakage is likely to be the mechanism responsible for the final failure. Figures 13a-b show the damage field for the two ply orientations. The analysis of the damage contours in both ply directions can reproduce the overall failure pattern. This failure pattern is induced by the anisotropy of the material, and fiber breakage caused by the heterogeneity of the material on the scale of the measurements.



-a- -b- -c-

Figure 13. Fiber damage contours d_1 in both ply directions (a-b) predicted by a damage post-processor using strains deduced from a full-field displacement measurement and the final failure pattern (c).

These results show that a damage meso-model is able to capture the overall failure pattern (i.e., damage maps in both ply directions) and to conclude that fibers in both directions are damaged at the inception of a macrocrack. It also important to note that these conclusions can be drawn only thanks to a full-field strain measurement (on the macro scale) used as input to a post-processor to evaluate the damage variables on the ply level (i.e., on the meso scale). Therefore, this test could be analyzed and a damage scenario could be proposed by combining full-field kinematic measurements and a damage model identified earlier.

SUMMARY

Digital image correlation is a well-suited technique for mechanical investigations dealing with brittle materials such as ceramics and ceramic-matrix composites. In particular, no special preparation of the surface is needed except for some applications that require a coating by a random black and white pattern. From experimental comparisons with conventional gauges, the strain uncertainty of the technique is shown to be equal to 2×10^{-4} when few measurement points are considered with an 8-bit CCD camera and can decrease to levels of the order of 10^{-5} or even 10^{-6} in favorable conditions with a 12-bit CCD camera for a larger gauge zone.

Two applications have been considered in the present paper. In a first study, local analyses were performed to determine elastic constants of a silicon-based joint. The DIC method allowed for accurate estimates of longitudinal displacements and strain fields even in extreme conditions, namely, low displacement and strain levels, high digital image magnification. The BraSiC elastic properties could be estimated and are comparable with those evaluated by a nanoindentation technique.

The second analysis deals with interactions between experimental data obtained on a C/C composite and mechanical investigations (here a shear experiment on a plate). The entire displacement field is considered to derive the strain field. A damage post-processor is applied to the experimental results to evaluate different damage fields describing matrix and fiber degradations. It is shown that fiber breakage causes the failure even when the overall load pattern is shear at $\pm$ 45°.

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