Adaptation of Open Source 2D DIC Software Ncorr for Solid Mechanics Applications

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Abstract

This study focuses on establishing the utility of open source, MATLAB based 2D Digital Image Correlation (DIC) software Ncorr for solid mechanics applications. Various experiments like ring under diametral compression and beam under four point loading are conducted and corresponding displacement and strain fields are estimated using Ncorr. These results are compared with commercially available 2D DIC software Vic 2D from correlated solutions. The results generated from Ncorr are found to be in good agreement with its commercial counterpart Vic 2D.

Key words

Accuracy, Digital Image Correlation, Displacement, Ncorr, Software, Strain

1. Introduction

There are various contact and non-contact techniques in the field of experimental mechanics for measurement of surface deformation and strain. Direct measurement techniques like strain gauge method and non-contact methods like Moiré interferometry [1], Holography [2], Speckle interferometry [3] and Digital Image Correlation (DIC) are among the most popular ones. Among these methods, the interferometric techniques have stringent requirements like vibration free setup and coherent light source. The relatively simple optics and less stringent requirements gives DIC an edge over other conventional methods. Digital image correlation has been extensively used for displacement and strain field estimation in various applications like material characterization, structural health monitoring, fatigue crack growth, high temperature testing etc. With the advancement in computational capabilities, more robust algorithms have emerged for tracking the material points to estimate whole field displacements and strains. The adaptability of DIC technique helps in exploiting the advancements in image capturing technology enabled in microscopes and high speed cameras to estimate displacement and strain data from the captured images.

There are various commercial software available in the market which uses 2D-DIC as a tool to estimate displacement and strain fields. Correlated Solutions, Dantec Dynamics are quite a few well known software companies producing 2D DIC software which are known for their accuracy and user friendliness. A lot of investments are involved in procuring these commercial software along with additional costs for their version upgrades. The limitations of using commercial software are the inherent costs involved in procuring and the restrictions imposed on users, as they cannot modify the source code as per their requirements. Alternatively, an open source, user friendly software can drastically cut down costs and could be modified as per user requirements. Ncorr [4] is one such open source 2D DIC code based on MATLAB [5] and developed at Georgia Institute of Technology by Antonia Antoniou's group. It is capable of estimating displacement and strain fields from the given input speckle images. To compare its capabilities with the existing commercial code, various experiments are conducted and results have been compared with commercial software Vic 2D, developed and sold by correlated solutions Inc, USA.

The following study compares the displacements and strain fields generated by Ncorr and Vic 2D using experimental input speckle images collected from different experiments like ring under diametral compression and beam under four point loading. The comparison helps in bolstering the credibility of Ncorr as a reliable open source DIC tool thereby making it a critical part of low cost DIC system for solid mechanics research studies.

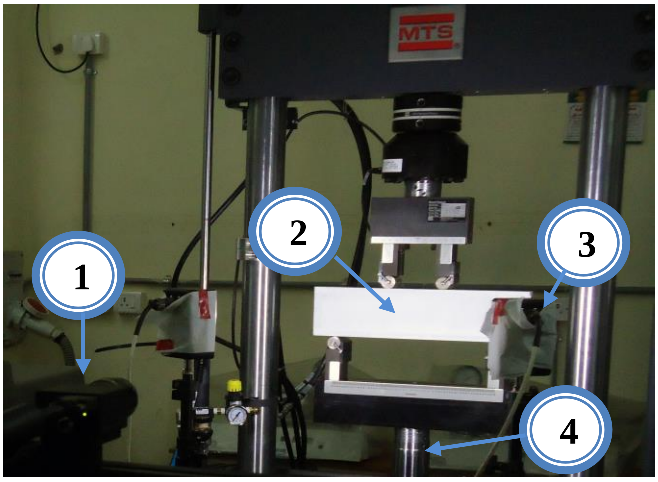
2. Specimen Geometry and Experimental Set up

The ring and beam specimens are cut from an epoxy sheet of 6 mm thickness casted in house by mixing commercially available C–51 epoxy resin and K–6 hardener in the proportion of 10:1 by weight. The mixture is mixed at room temperature for about 30 minutes with due precaution taken to avoid the formation of any air bubbles. The resin-hardener mixture is then poured into the mold and left to cure for 24 hours at room temperature. A circular ring with outer and inner radii 80 mm and 40 mm respectively and a rectangular beam of length 220 mm and breadth 40 mm are milled from the 6mm casted epoxy sheet. The material properties of the epoxy sheet used is as specified in Table 1.

Table 1 Material properties of the specimens used

Material	Yield Strength (MPa)	Young's Modulus (MPa)	Poisson's ratio
Epoxy	35	3300	0.37

The surfaces of the specimens are coated with thin layer of white acrylic paint. Using an airbrush, carbon black paint is sprayed over the white surfaces, creating random black and white artificial speckle pattern. The 2D DIC optical system consists of a CCD camera with a spatial resolution of 2448 x 2048 pixels. Camera is aligned parallel to the specimen surface in order to eliminate errors due to out of plane displacements. A Tamron lens with 180 mm focal length is mounted on the camera and is then connected to a computer controlled image acquisition system. LED flood lights are used to ensure adequate image contrast. A computer controlled MTS Landmark servo hydraulic cyclic testing machine is used to apply the specified load onto the specimens. The experimental setup used for beam under four point bending is shown in Fig 1. Similar to the shown setup, the diametral load on the ring is applied by replacing the four point bending fixture with compression platens in MTS servo hydraulic system.



1. CCD Camera
2. Specimen
3. LED Light Source
4. Actuator

Fig.1 2D DIC Experimental set up for beam under four point bending.

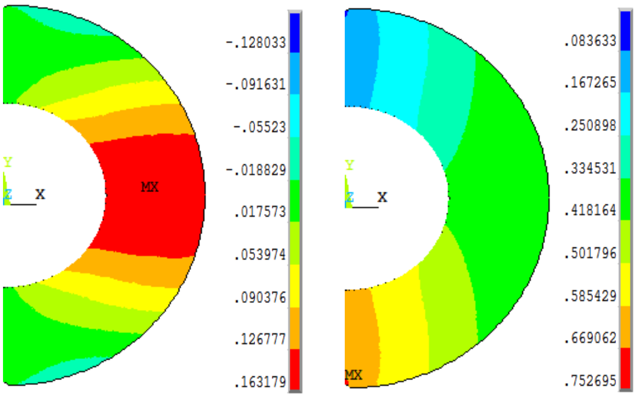
3. Experimental Procedure

The ring is arrested at the top and a diametral compressive load of 1kN is applied at the bottom of the epoxy ring using compression platens attached to the MTS landmark servo hydraulic system. Sequences of images are collected as the loading progresses from 0 to 1kN. The epoxy beam is subjected to a four point bend test with loading point separations of 120 mm in the top surface and 180 mm in the bottom surface as shown in Fig 12 (a). A compressive load of 1kN is applied at the bottom surface of the beam at the two load points P and Q as shown in Fig 12(a). The images collected during the experiments are then processed using Ncorr and Vic 2D to estimate the displacement and strain fields. For computing displacements using DIC, a subset is chosen from the reference image and its corresponding location is tracked in the deformed image [6]. The square subset size and step size used in Vic 2D for the analysis is 21 x 21 and 5 respectively. Ncorr is equipped with circular subset and its radius is set to 11 with a subset spacing of 5. Ncorr uses the Inverse Compositional Gauss-Newton (IC-GN) [7] nonlinear solver which is fast, robust and accurate in displacement measurement compared to classical Newton Raphson or Forward Additive schemes. The displacement gradients or strains can be directly calculated using Newton Raphson (NR), Quasi – NR, Levenberg–Marquart algorithm (LM) [8] or Genetic algorithm. The error in estimated strain fields using NR or genetic method is of higher order and limits its use only for strain values approximately greater than 0.010 [9]. Another approach is to use numerical differentiation to derive strains from displacement field. Eliminating the noise from the displacement data prior to strain calculation can improve accuracy in computed strains. For strain calculation, Ncorr uses a least squares plane fit to a contiguous circular group of displacement values. The radius is set to 3 pixels prior to strain computation.

4. Results and Discussion

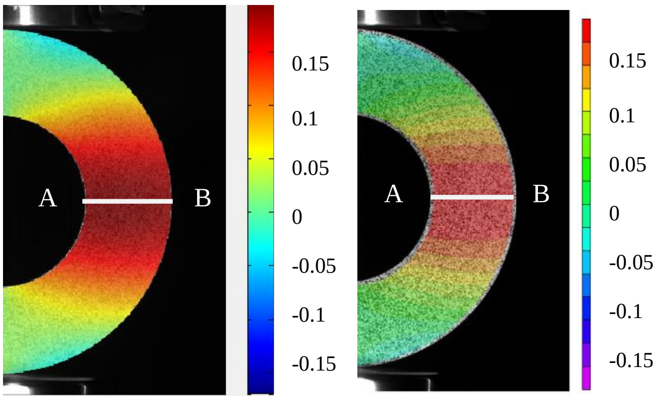
4.1 Epoxy Ring under Diametral Compression

For validation of the experiment, a finite element model of the ring is created using 2D, 6 node triangular plane 183 element and the boundary conditions are applied as per the experimental loading conditions. The ring is arrested at the top and a point load of 1kN is applied at the bottom, simulating the testing conditions. The displacement contours (*u*, *v*) obtained from the finite element model of the ring is shown in Fig 2. During the DIC analysis, the same set of images grabbed during the diametral compression of the ring is given as the input for both Ncorr and Vic 2D for computing displacements and strains. The *u* displacement contours from Ncorr and Vic 2D for the ring problem is shown in Fig 3. Due to symmetry of the specimen and the loading configuration, only half section of the loaded ring is shown in Fig 3. To examine the results more closely, the displacement and strain values are plotted along a line AB as shown in Fig 3. Figures 4 and 6 shows the comparison of *u* and *v* data obtained along line AB obtained from the Ncorr and Vic 2D for the same set of input images. The *u* and *v* displacement contours obtained from Finite Element Analysis (FEA) is compared with DIC prediction. They are in good coherence with each other as shown in Figs 2, 3 and 5



(a) mm (b) mm

Fig.2 Displacement contours for the ring under diametral compression obtained using FEA. (a) *u* contour (b) *v* contour



(a) mm (b) mm

Fig. 3 *u* displacement contours for the ring under diametral compression obtained from DIC technique. (a) From Ncorr (b) From Vic 2D

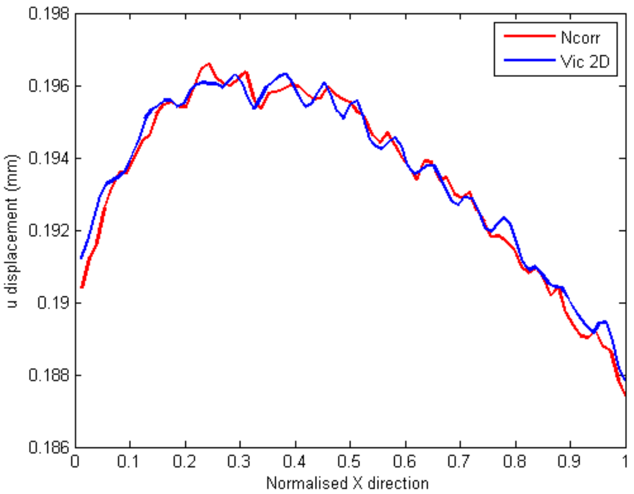


Fig. 4 Comparison of u displacement along the line AB between Ncorr and Vic 2D estimates

There is a slight deviation between Ncorr and Vic 2D in estimating u displacement along line AB. This deviation can arise due to the difference in subset shape being used in the software. The y axis in Ncorr is positive downwards while in Vic 2D the y axis is positive upwards. This results in a sign change in representation of v displacement as shown in Fig.5. The magnitude of the v displacements along the line AB are compared in Fig.6. The field seems to be similar and it contains lot of undulations.

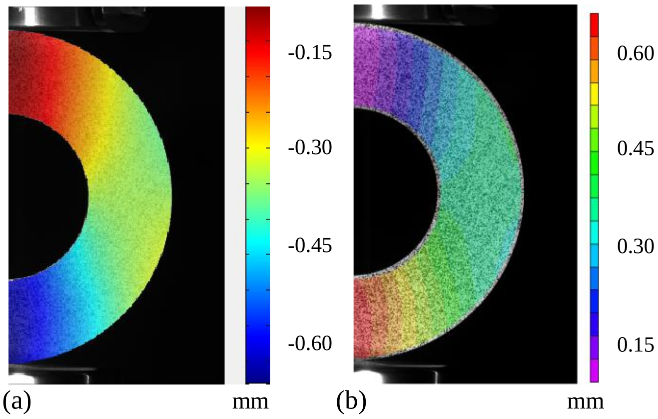


Fig. 5 v displacement contours for the ring under diametral compression obtained from DIC technique. (a) From Ncorr (b) From Vic 2D

The accuracy of the strains computed from numerical differentiation is influenced by the noise contained in the displacement field. Also, for the ring problem, the orders of magnitude of the computed strains are very small. These factors can cause slight deviation in the strains computed by Ncorr and Vic 2D. The sensitivity towards noise is also dependent on the numerical schemes used for strain computation in Ncorr and Vic 2D. The $\mathcal{E}_{xx}$, $\mathcal{E}_{yy}$ and $\mathcal{E}_{xy}$ contours obtained using DIC technique is shown in Figs 7, 9 and 11. Further comparison of the $\mathcal{E}_{xx}$ and $\mathcal{E}_{yy}$ strain values from both softwares along line AB is shown in Figs 8 and 10.

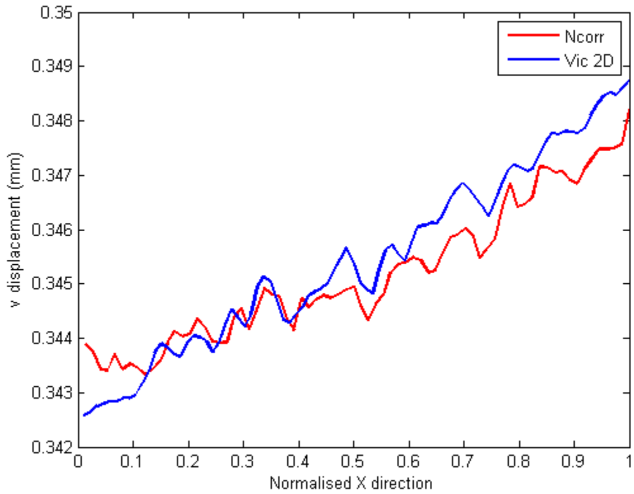


Fig. 6 Comparison of v displacement along the line AB between Ncorr and Vic 2D estimates

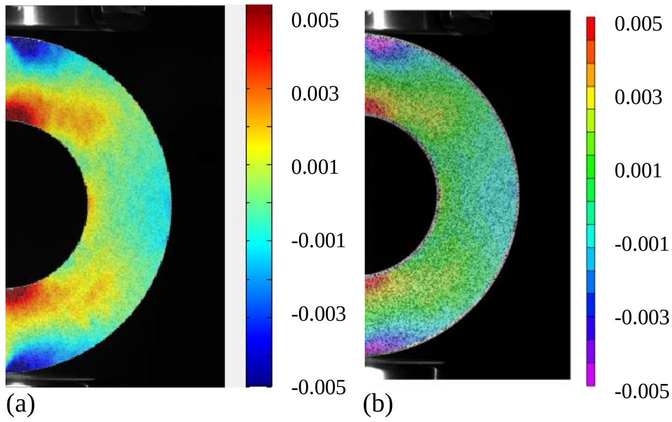


Fig. 7 $\mathcal{E}_{xx}$ contours obtained for an epoxy ring under a diametral load of 1 kN using (a) Ncorr (b) Vic 2D

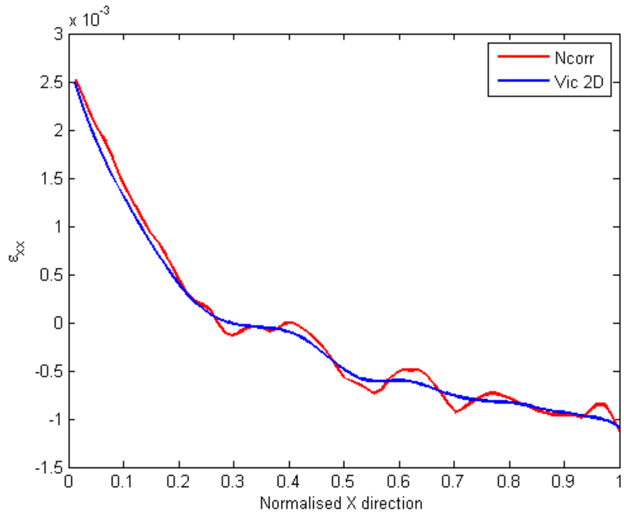


Fig. 8 Comparison of $\mathcal{E}_{xx}$ along the line AB between Ncorr and Vic 2D estimates

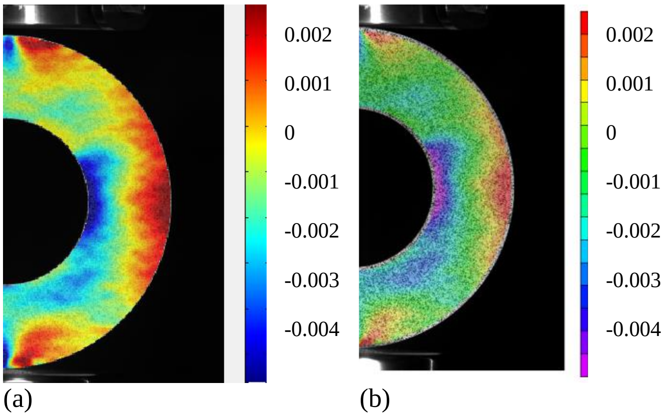


Fig. 9 $\mathcal{E}_{yy}$ contours for an epoxy ring under a diametral load of 1 kN using (a) Ncorr (b) Vic 2D

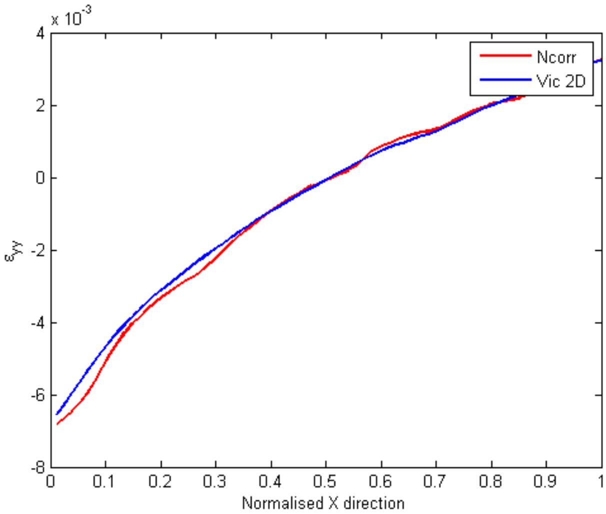


Fig. 10 comparison of $\mathcal{E}_{yy}$ along the line AB between Ncorr and Vic 2D estimates

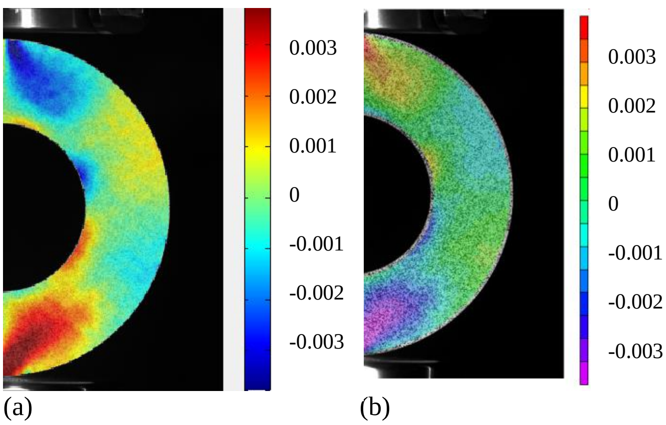


Fig. 11 $\mathcal{E}_{xy}$ contours obtained for an epoxy ring under a diametral load of 1 kN using (a) Ncorr (b) Vic 2D

4.2 Beam under four point loading

The epoxy beam is kept in four point bend configuration under a 1 kN load applied from bottom. The *u* displacement contours of the epoxy beam under the prescribed loading obtained from Ncorr is shown in Fig.12 (a) Fig.12 (b) shows the corresponding *u* displacement contours from Vic 2D. For further comparison, a line CD is drawn as shown in Fig.12 and the corresponding displacement and strain values obtained from the two software are compared.

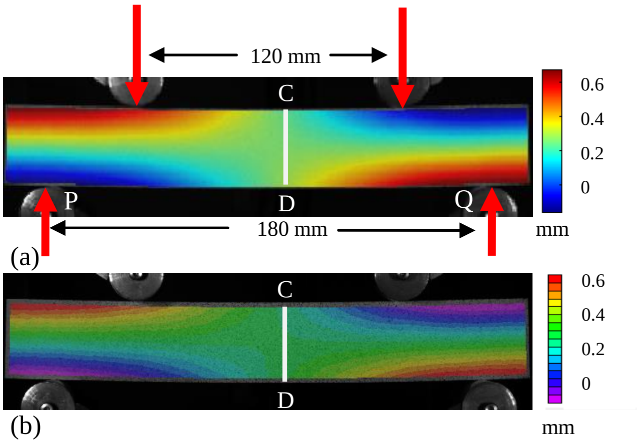


Fig. 12 *u* displacement contour obtained for an epoxy beam under four point bending using (a) Ncorr (b) Vic 2D

The *v* displacement contour for the same problem is shown in Fig.13. Qualitatively both of them compare well. The sign change is caused due to the difference in the *y* axis orientation.

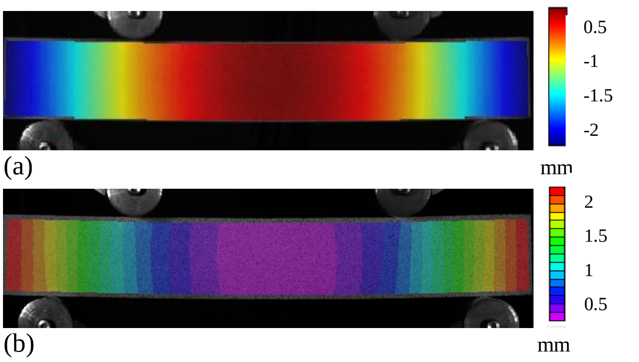


Fig. 13 *v* displacement contour obtained for an epoxy beam under four point bending using (a) Ncorr (b) Vic 2D

Figs 14 and 15 show the comparison of *u* and *v* displacement data obtained from Ncorr and Vic 2D along the line CD. Figs 16 (a) and 16 (b) show the $\mathcal{E}_{xx}$ contour obtained using Ncorr and Vic 2D for the same specimen at the same load. Fig.18 shows the $\mathcal{E}_{yy}$ contour obtained from both softwares . The displacement and strain values along the line CD is found to be in good agreement with each other. Figure 17 shows the quantitative comparsion of $\mathcal{E}_{xx}$ along the line CD obtained from both Ncorr and Vic 2D. They agree very well, thereby confirming the accuracy of Ncorr software. Simililarly $\mathcal{E}_{yy}$ data along the line CD is compared in Fig.19. Both data are in good coherence.

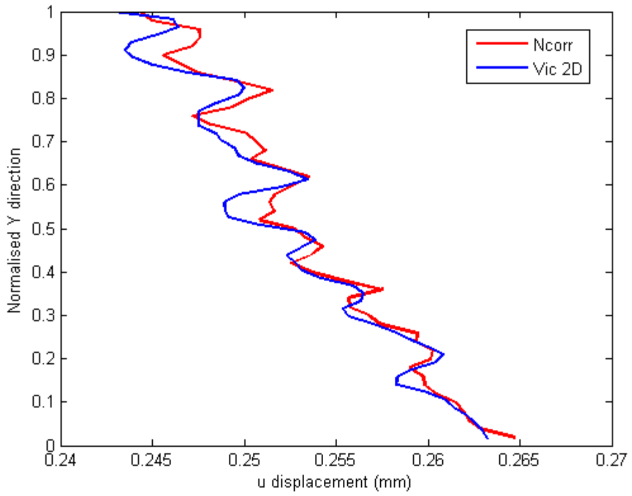


Fig. 14 Comparison of *u* displacement along the line CD between Ncorr and Vic 2D estimates

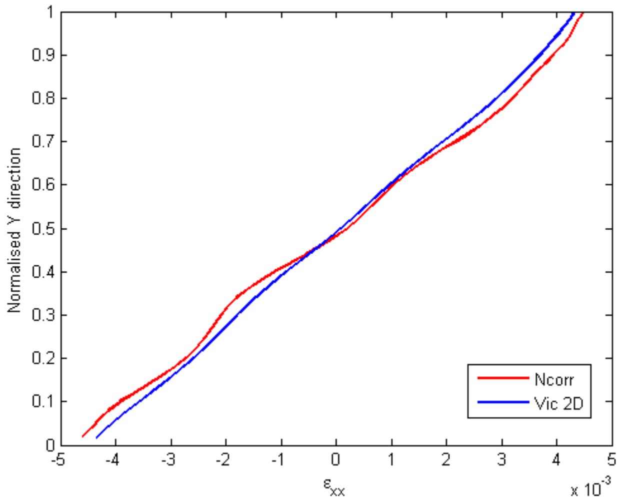


Fig. 17 Comparison of $\mathcal{E}_{xx}$ values obtained by Ncorr and Vic 2D along the line CD

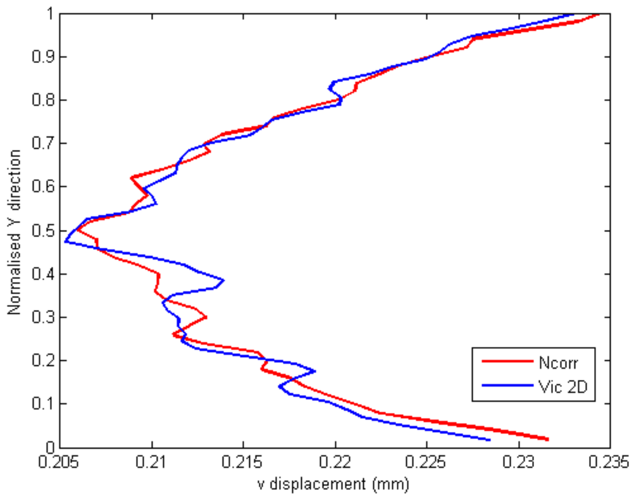


Fig. 15 Comparison of *v* displacement along the line CD between Ncorr and Vic 2D estimates

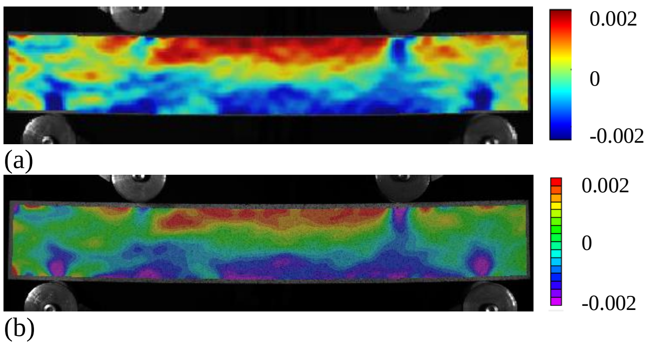


Fig. 18 $\mathcal{E}_{yy}$ contours for an epoxy beam under four point bending, obtained using (a) Ncorr (b) Vic 2D.

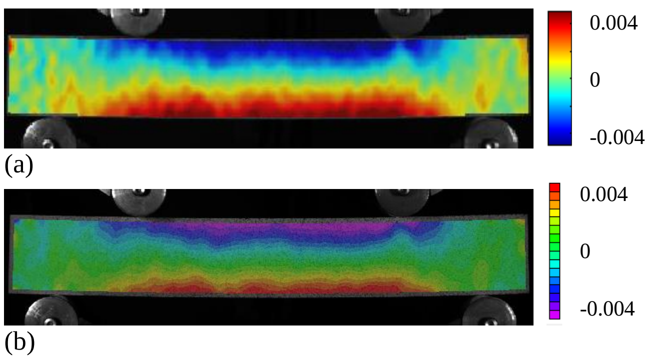


Fig. 16 $\mathcal{E}_{xx}$ contours for an epoxy beam under four point bending, obtained using (a) Ncorr (b) Vic 2D.

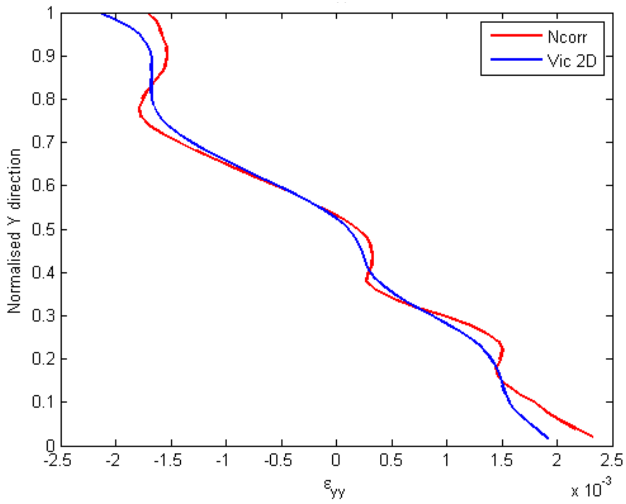


Fig. 19 Comparison of $\mathcal{E}_{yy}$ values obtained by Ncorr and Vic 2D along the line AB

5. Conclusion

Two different problems namely, ring under diametral compression and beam under four point bending has been considered. The displacements obtained from Ncorr and Vic 2D for the same set of input images have been compared for both the problems and are found to be a close match with each other. The strain values being very small in order of magnitude can suffer undulations due to the errors caused from the noise contained in the displacement data during the numerical differentiation. The results obtained are in par with the most widely used Vic 2D software thereby making it a reliable open source alternative for DIC applications. Hence it is highly recommended for solid mechanics applications. Further, it forms an integral part of a low cost, accurate DIC system. Since the source code is freely available, users can modify the software based on their requirements.

6. Nomenclatures

u displacement along x direction [mm]
v displacement along y direction [mm]
ε_{xx} Strain along X direction
ε_{yy} Strain along Y direction
ε_{xy} Shear strain

7. Acknowledgement

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