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Study on experimental characterization of carbon fiber reinforced polymer panel using digital image correlation: A sensitivity analysis

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ABSTRACT

In this work, the experimental characterization of polymer–matrix and polymer based carbon fiber reinforced composite laminate by employing a whole field non-contact digital image correlation (DIC) technique is presented. The properties are evaluated based on full field data obtained from DIC measurements by performing a series of tests as per ASTM standards. The evaluated properties are compared with the results obtained from conventional testing and analytical models and they are found to closely match. Further, sensitivity of DIC parameters on material properties is investigated and their optimum value is identified. It is found that the subset size has more influence on material properties as compared to step size and their predicted optimum value for the case of both matrix and composite material is found consistent with each other. The aspect ratio of region of interest (ROI) chosen for correlation should be the same as that of camera resolution aspect ratio for better correlation. Also, an open cutout panel made of the same composite laminate is taken into consideration to demonstrate the sensitivity of DIC parameters on predicting complex strain field surrounding the hole. It is observed that the strain field surrounding the hole is much more sensitive to step size rather than subset size. Lower step size produced highly pixilated strain field, showing sensitivity of local strain at the expense of computational time in addition with random scattered noisy pattern whereas higher step size mitigates the noisy pattern at the expense of losing the details present in data and even alters the natural trend of strain field leading to erroneous maximum strain locations. The subset size variation mainly presents a smoothing effect, eliminating noise from strain field while maintaining the details in the data without altering their natural trend. However, the increase in subset size significantly reduces the strain data at hole edge due to discontinuity in correlation. Also, the DIC results are compared with FEA prediction to ascertain the suitable value of DIC parameters towards better accuracy.

1. Introduction

Polymer and polymer based composites are now becoming increasingly popular and enormously used at a higher pace in many industries especially in aerospace. Among various, carbon fiber reinforced polymer (CFRP) has proven to be the most appealing for a broad range of applications in recent years. They offer excellent properties like high specific strength and stiffness, easy formability and improved fatigue life. The properties of composite material mainly depend on the type of reinforcing fiber, matrix material as well as a processing technique. The fact that these materials can be custom tailored to enhance their properties to make them suitable for a specific application, they necessitate a special consideration for determining their mechanical properties accurately [1]. Also, the accuracy of finite element analysis (FEA) prediction strongly depends on the properties of materials evaluated experimentally. The experimental evaluation of material properties essentially relies on accurate measurement of displacement or strain [2]. The accurate measurement of these parameters has always been an important topic of research in experimental mechanics which has led to the evolution of several contact and non-contact measurement techniques. Optical full-field measurement techniques such as reflection photoelasticity, moiré interferometry, holographic and speckle interferometry, grid method and digital image correlation (DIC) are found very promising for the experimental stress/strain analysis of materials and structures [3–7]. All interferometric techniques require stringent system's stability and are very sensitive to vibration [2]. However, a DIC technique is easy to use, involves simple optics, less sensitive to vibration, no heavy surface preparation, reliable and it can be applied on any class of material. Moreover, it is truly a whole field non-contact measurement method. For above reasons it is now

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becoming more and more popular and widely employed for surface displacement and strain measurement in various fields.

DIC was introduced by Sutton et al. [8] in the early 1980s followed by continuous improvement over the years [9,10]. DIC is based on pattern matching between two images of the specimen coated with a random speckle pattern in undeformed and deformed states. The basic principle of DIC is to search for maximum correlation between small square zones within ROI over specimen surface in undeformed and deformed states. The small square zone containing a set of pixels is called as subset and the distance between two subsets is defined as step. The subset size determines the area of image being traced between the successive images for displacement measurement and step size determines the number of pixels over which the subset should be shifted for estimating displacement. A 2D-DIC involves a single camera and provides only in-plane displacement/strain fields whereas a 3D-DIC utilizes two cameras and facilitates out-plane displacement measurement. More details on the DIC technique, displacement and strain field measurement algorithm can be found in Refs. [10–12].

Table 1
Test matrix for material characterization.

Test type	ASTM standard	Lay-up	Geometry	Testing speed (mm/min)	Properties
Tensile	D-3039	$[0^\circ]_3$	Fig. 1(a)	2	E_{11}, ν_{12}, X_T
	D-3039	$[90^\circ]_6$	Fig. 1(b)	1	E_{22}, ν_{12}, Y_T
Shear	D-3518	$[\pm 45^\circ]_6$	Fig. 1(c)	1	G_{12}, S_{12}
Compression	D-3410	$[0^\circ]_6$	Fig. 1(d)	1.125	X_C
	D-3410	$[90^\circ]_6$	Fig. 1(d)[a]	1.125	Y_C
Tensile	D-638	–	Fig. 1(e)	3.75	E, ν

[a] Stacking sequence is $[90^\circ]_6$

Even though the DIC technique has found profound application in various domains accuracy is a primary issue [13]. The error in DIC measurement could arise due to many sources such as illumination variations, quality of acquisition system, camera lens distortion, image noise, etc., or it could be due to the error associated with the implementation of correlation algorithm like subset size, step size, strain window size, sub-pixel optimization algorithm, sub-pixel intensity interpolation scheme, etc. [13–15]. The effect of some of these parameters has been investigated thoroughly by many researchers. They have addressed the issue of unmatched subset shape function [16], intensity interpolation [17], sub-pixel registration algorithm [18], intensity pattern noise [19], subset size [14,15,20–23], step size [14,21,23], strain window size [14,23], speckle pattern [22], in-plane rotation and rigid body translation, out of plane rigid body rotation [23] and errors that arise in the derivation of strain fields from displacement fields [24]. Most of the above mentioned study is for metallic samples.

Now, the researcher has started using the DIC technique for material characterization of composites [7,25–33] which are of heterogonous nature and offers non-uniform strain distribution, so that the material properties estimated based on a whole field strain measurement technique would be more accurate rather than a localized single point wise measurement offered by a conventional technique [25–28]. Even though the researchers have started exploring the mechanical characterization of composite

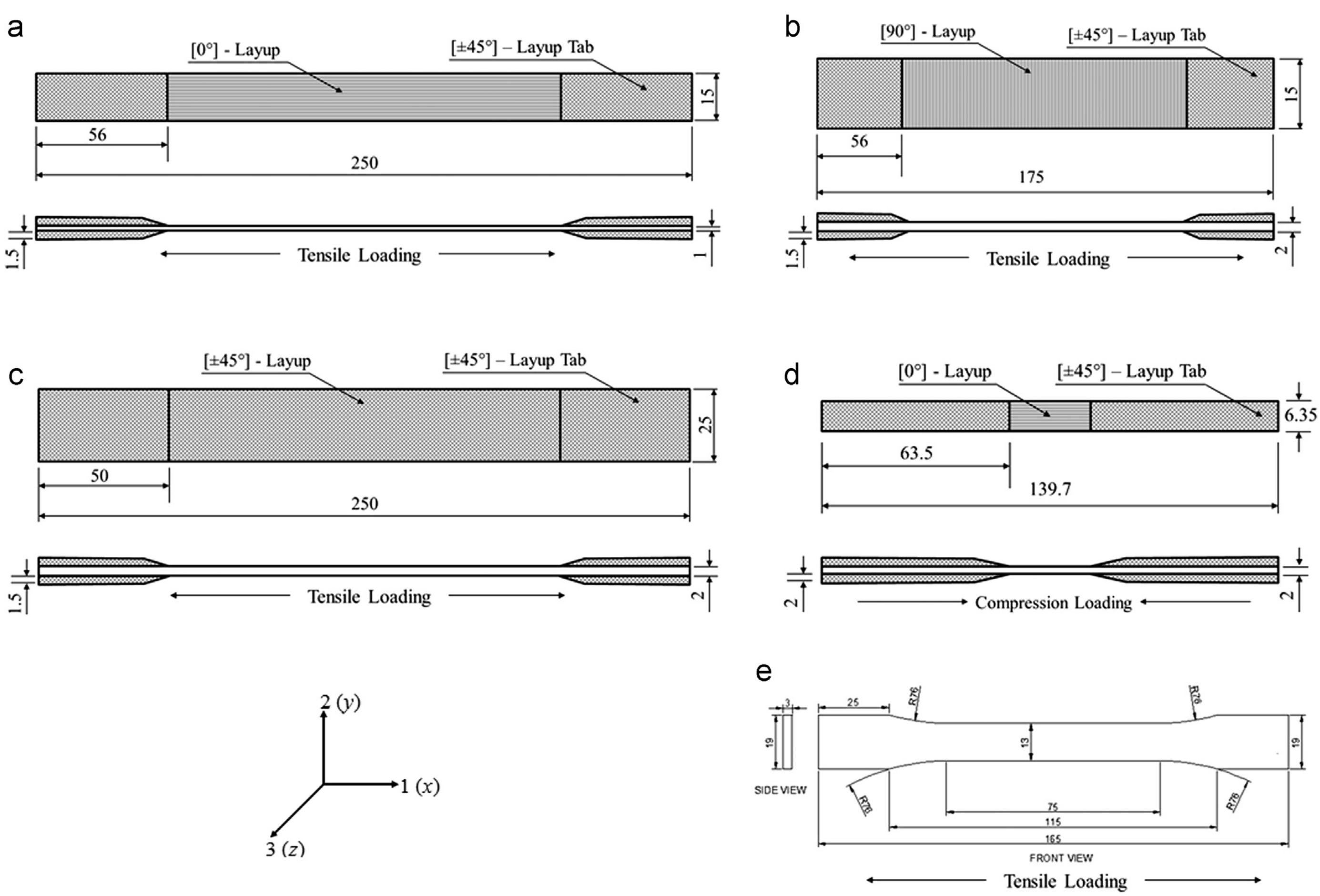

Fig. 1. Specimen geometry as per ASTM standard (a) D3039-tensile test coupon [0°], (b) D3039-tensile test coupon [90°], (c) D3518-shear test coupon [±45°], (d) D3410-compression test coupon [0°], and (e) D638-matrix coupon.