Composite Characterization Using Digital Image Correlation (DIC) Approach for Stress-Strain Prediction

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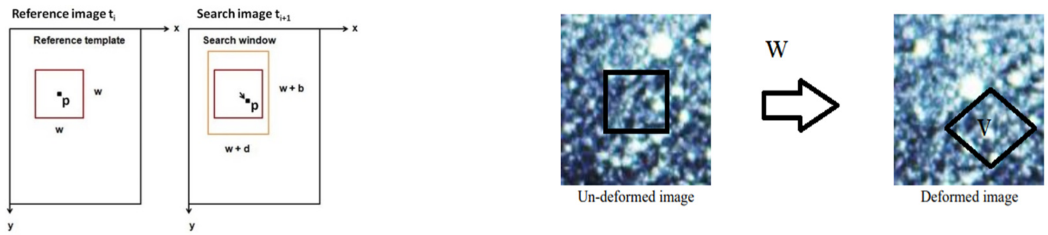
Abstract. Identifying elastic parameters such as Young's modulus and Poisson's ratio is an important step in analysing material properties. They can be obtained by different ways : using extensometer, strain gauge, laser or more complex approach such as Digital Image Correlation (DIC). This last technology is getting more notoriety in recent years. DIC has the advantages of convenience, economic benefits, non-destructive measurement, and is suitable for most materials such composites materials compared with traditional methods. In this work, we apply the DIC coupled with new prediction approach to build the stress-strain curves and Poison modulus at the same time. The samples are Bio-composite polymers built using additive manufacturing. The videos recorded are post-treated using DIC software. Only Young's modulus is compared to the obtained parameters with extensometer acquisition.

Keywords: Young's modulus, Poisson's ratio, Digital Image Correlation, additive manufacturing, ANN, machine learning

DIGITAL IMAGE CORRELATION APPROACH

Digital Image Correlation (DIC) (1,2) is a non-contact optical method for measurement of shape deformation, contour, vibration and strain on many different materials. It can applied to tensile, torsion, bending or any combination for static and dynamic analysis. The main advantage of such method is the scale of application as it can be applied from Micro to Macro scales. Results can be also correlated with the finite element FE analysis, gauge or extensometer acquisitions. As it is a crucial step for material characterization. The figure 1.a and 1.b shows the technique to measure the surface deformation by tracking an image feature. The entire surface is measured and it represents the full field required measurement. The initial image at zero loading of the specimen represents the reference image. Than a second load state image is used to compare and calculate the pattern (dots) mentions.
DIC method compare and perform correlation using two-dimensional cross-correlation analysis to correlate The scale sub matrix (decided by the pixels) between the original reference image and the deformed one. Six variables are used (u, v, $\frac{\partial u}{\partial x}$, $\frac{\partial v}{\partial y}$, $\frac{\partial u}{\partial y}$, $\frac{\partial v}{\partial x}$) to evaluate the deformation functions S between two images calculated as follows :



(a) (b)

FIGURE 1. Schematic diagram of field strain calculation and deformation functions between two images

$$S\left(x, y, u, v, \frac{\partial u}{\partial x}, \frac{\partial u}{\partial y}, \frac{\partial v}{\partial x}, \frac{\partial v}{\partial y}\right) = \int_{\Delta M} [G(x, y) - G'(x', y')]^2 dA \tag{1}$$

$$S\left(x, y, u, v, \frac{\partial u}{\partial x}, \frac{\partial u}{\partial y}, \frac{\partial v}{\partial x}, \frac{\partial v}{\partial y}\right) = 1 - \frac{\int_{\Delta M} [G(x,y) G'(x',y')] dA}{\{\int_{\Delta M} [G(x,y)]^2 dA \int_{\Delta M} [G'(x',y')]^2 dA\}^{1/2}} \tag{2}$$

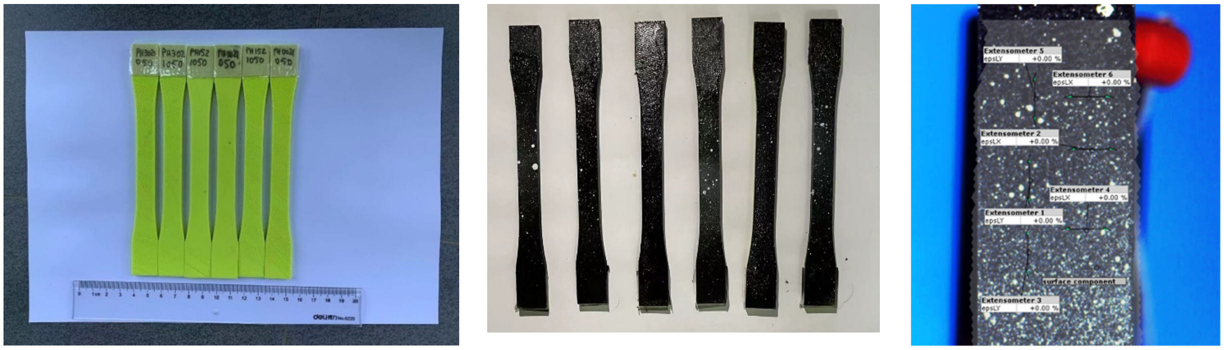
The image is processed into black, white, and grey, in order is to facilitate the DIC to identify the area to be measured. Then, it can track better the deformation of one area. Two high-resolution digital cameras were used in the measurement. The first one (HT-SUA502C-T) with lens HT-FA2518C-25mm was used for the front the sample. The second one (HT-U300C- lens HT-FA2518C-25mm) was used to check the thickness reduction for ductile materials. Both cameras were coupled with KJ63HW Light source to increase the brightness (figure 2.a-c). The system was then mounted on tensile test machine (WDW-100D) using an extensometer (YYU-5/50). The post treatment (Data collection and video analysis) is based on GOM correlate pro software. The approach uses G (x, y) to represent the light intensity and grey level at the selected points (x, y), and calculates the field displacement with the following light intensity function G (x, y). The function takes the above six variables as the factors of the deformation function and obtains the expression of the deformation function by integrating the functions of grey level and light intensity (3)**.**

(a) (b) (c)

FIGURE 2. (a) Experimental equipment installation and data collection ; (b & c) A side view of two cameras coupled with GOM correlate pro software.

EXPERIMENT WITH PREDICTIVE APPRAOCH

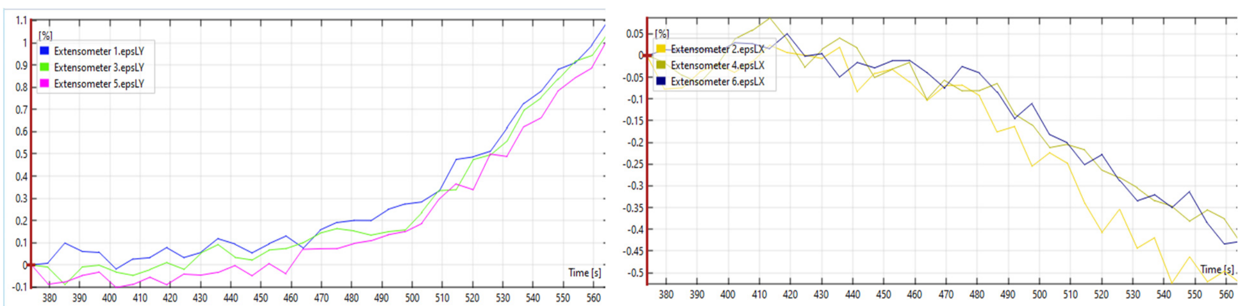
Concerning the specimens (PHA bio-composite polymers and PLA reinforced with carbon fibre), we used an ISO 527 sample (115mm crosshead distance, 5 millimetre thickness) built using Fused deposition modelling (FDM) process. The sample is constructed with 1.5mm filament (figure 3.a). For better image acquisition by GOM (4) we spread the material surface with black background and white dots (figure 3.b). The figure 3.c represents an enlargement of the position used for the virtual strains acquisition. It can be clearly seen that the white translucent film is a plane component, and the virtual extensometer can be placed on this plan (higher quality surface components can obtain more accurate strain monitoring).



(a) (b) (c)

FIGURE 3. (a) Polymer samples reinforced with carbon fibre, (b) sprayed sample ; (c) An enlarged image of the position used for strains acquisition

We have used six extensometers on this plane, three are horizontal and three are vertical, which represent respectively the horizontal and vertical strains of the sample (figure 4.a and 4.b).



(a) (b)

FIGURE 4. Longitudinal (a) and transversal (b) strains acquisition from DIC

It can be seen from these two figures that the fluctuation of a single line chart is very large, but if the mean value of strain is used as the coordinate, the fluctuation can be reduced to a certain extent. Prediction using ANN (5–8) helps to approach the next points and smooth later the curves.

DATA PROCESSING

After the experiment, the data processing is a very critical process. It is necessary for the Poisson's ratio's to delete some unreasonable points due to errors acquisition. Regarding Young's modulus, offset curves are used (figure 5). We can notice that the stress-strain curves for different samples and its duplicate both are smooth, we had a good correlation with the extensometer. It can be seen that the scattered points are perfectly distributed on the fitting curve, and the R value is close to 1, which indicates that the experimental accuracy is high. The error of the Poisson's ratio is no more than 9%, and it is within the normal polymer Poisson's ratio range. For the samples Ph1521050 and Ph3021050, Poisson's ratio is equal respectively to 0.3332 and 0.3238 (figure 6).

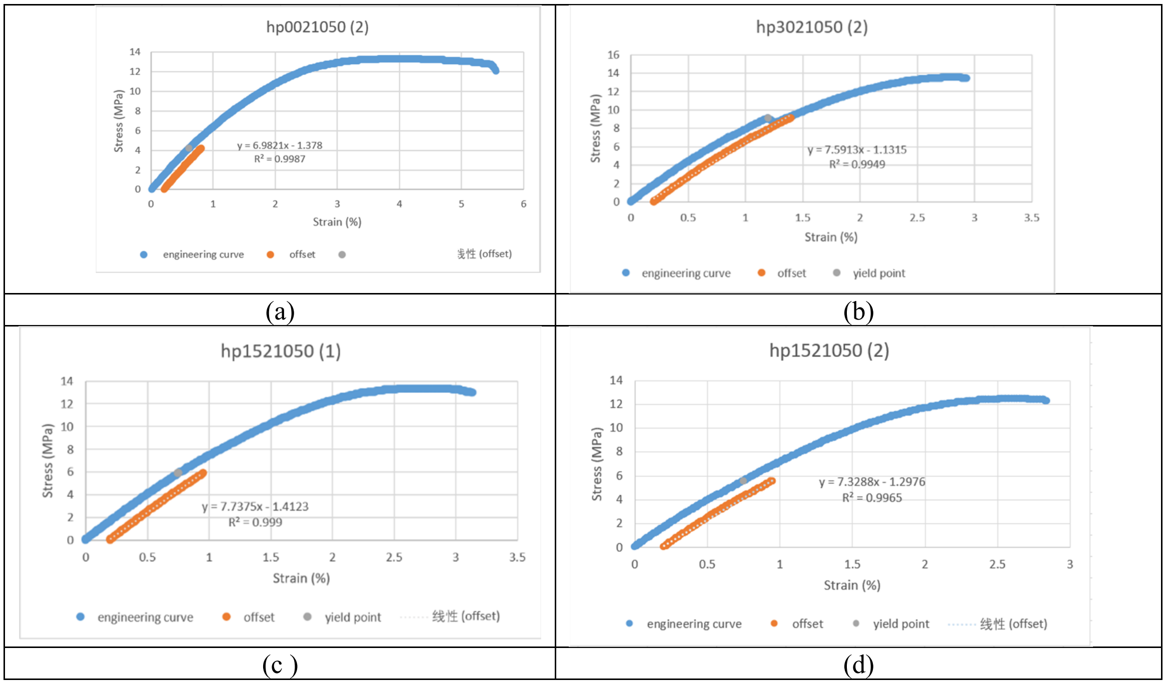


FIGURE 5. Young's modulus engineering curve for 3 sample (a-b) and replicate (c & d).

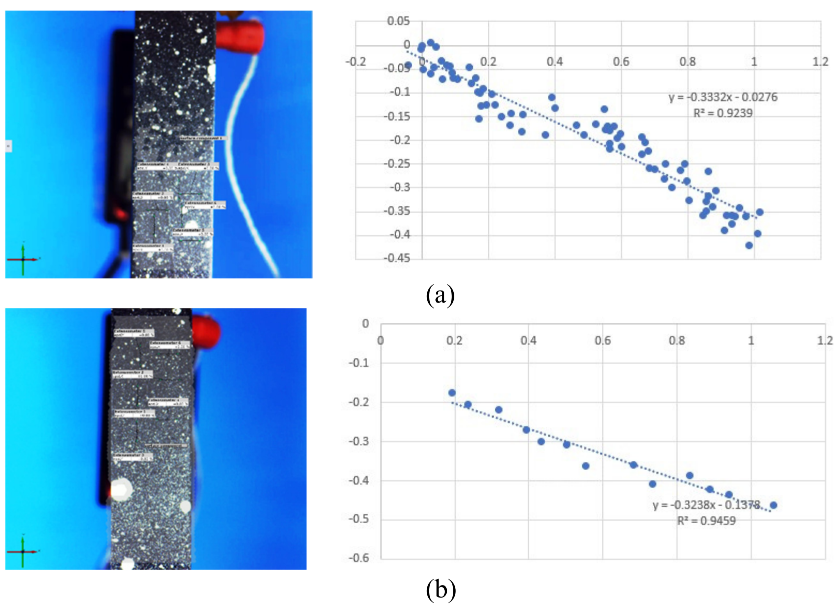


FIGURE 6. Poisson's ratio for Ph1521050 (a) and Ph3021050 (b) samples

The prediction process can be extended in addition to longitudinal and transversal strains acquisition from DIC to direction Poisson's ratio and Young's modulus. AI and machine learning (9)(10–12) can get a good and efficient prediction in Realtime. The challenges will remain the strain ratio and the nature of the sample as the stress strain curves can get large changes from ductile to brittle materials, especially around the plasticity part. Meanwhile, at the linear part, prediction using DIC and machine learning presents a good alternative. Also, the above approach can be easily applied to linear vibration of structure at different scales (9)(13) (14).

CONCLUSION

Poisson's ratio and Young's modulus have been well evaluated using DIC system as non-destructive approach coupled to ML approach. DIC system have the advantage to provide method for remote measurement of displacement, strain, and stress. It can measure the strain for instance at any point in the sample, and the total strain is obtained by traditional methods. In terms of data processing, experiment and calibration mechanism is very important to ensure the accuracy of the experiment. This is due to the fact that evaluation and treatment are mainly based on light intensity function. This approach can later be improved and integrate Micro CT scan and high performance computing to detect the local cracking and damages.

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