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Digital Image Correlation (DIC) Technique in Measuring Strain Using Opensource Platform *Ncorr*

A. F. Ab Ghani^{*,1,a}, M. B. Ali^{1,b}, S. DharMalingam^{1,c} and J. Mahmud^{2,d}

¹Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka (UTeM), Hang Tuah Jaya, 76100, Durian Tunggal, Melaka, Malaysia

²Faculty of Mechanical Engineering, Universiti Teknologi MARA, Selangor, 40450 Shah Alam, Selangor, Malaysia

^aahmadfuad@utem.edu.my, ^bbasri@utem.edu.my, ^csivakumard@utem.edu.my, ^djm@salam.uitm.edu.my

Abstract – This paper presents a systematic explanation on procedure and method of digital image correlation (DIC) technique in utilizing open source platform *Ncorr*. The use of digital image correlation in measuring strain is shown from its initial stage of speckle preparation on surface of gauge area, acquisition of images through video imaging, splitting the images, and postprocessing the image correlation to obtain displacement and strain field on surface under study. Some technical issues relating the quality of results to be obtained are discussed. Validation of output obtained from strain measurement using *Ncorr* has been performed via tensile test on GFRP with comparison of modulus of elasticity obtained from experimental. Limitation of using in house equipment such as DSLR camera with considerably low frame per second capability and resolution has given the prospect of high reliability of low cost strain measurement using high speed camera and integrated load cell data acquisition for recommendation and future research activity. **Copyright © 2016 Penerbit Akademia Baru - All rights reserved.**

Keywords: Digital Image Correlation, DIC Technique, *Ncorr*, Strain Measurement, Opensource DIC

1.0 INTRODUCTION

Digital Image Correlation is a non-contact, optical method which captures of digital images of a surface of an object then performs the image analysis to obtain full-field deformation and measurements[1]. This technique starts with a reference image (before loading) followed by a series of pictures taken during the deformation. Deformed images show a different dot pattern relative to the initial non deformed reference image. These patterns difference can be calculated by performing correlation of the pixels of the reference image and any deformed image and a full-field displacement measurement can be computed. It is the use of a digital camera that separated DIC from other experimental techniques that are employed to measure strain deformation [2,3]. Many scholars discussed and studied NDT techniques on composite materials which encompasses methods such as ultrasonic, AE technique, thermography etc. The research incorporates most of the advanced techniques in NDT to detect defects, deterioration and voids but DIC is not in the study [4,5]. DIC has the ability to record images of deformed surfaces, allowing for accurate analysis of the material being stressed under load. The strain distribution can then be obtained by applying the derivatives in the displacement

field. This can be achieved by creating different methods like dots, grids, lines etc, on the specimen surface. The qualities of the results are mainly dependant on two factors: resolution of the camera, and quality of the speckle pattern on the specimen [1,3]. The strain distribution can then be obtained by applying the derivatives in the displacement field. To apply this method, the object under study needs to be prepared with random dot pattern speckle pattern to its surface. The concept of correlation is used to calculate the strains from the deformation of specimen. By observing the speckle pattern of the image before and after the loading, comparisons can be made. The image is split up into a grid made from small subsets. It is the position of these co-ordinates before and after deformation that allows correlation to take place and to calculate strains from the imaging process[2]. There are many softwares of DIC in the market such but opensource Ncorr which built on Matlab platform provide promising tool for researcher around the world to utilize the technique of measuring displacement and strain at affordable cost as compared to high end equipment and postprocessing software. Ncorr software can be used in any material that could hold fine speckle pattern on its surface under study and composite material is new area under exploration with the use of Ncorr[6].

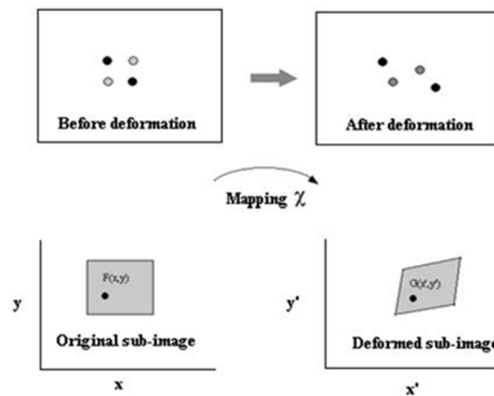


Figure 1: Digital image correlation deformation working principle[1]



Figure 2: Image with speckle on the surface of object acquired by camera

Assuming 2D DIC, before a load has been applied it can be assumed that the coordinates that will be tracked can be denoted as (x_p, y_p) . After loading, the new positions can be denoted as (x_p', y_p') . Figure 1 depicts the reference subset before deformation occurs, and the target subset after loading. Figure 2 shows example of acquired image with speckle pattern under study with the use of digital camera. It can be seen that (x_p, y_p) is the subset centre from which other

points such as (x_q, y_q) can be referenced to. The deformed image shows the position of these co-ordinates after loading, and using subset matching, can be correlated back to the original reference image. The following equations governing relation behind correlation algorithms to compute deformed positions with relation to initial coordinates[2]:

$$x_q' = x_q + u_p = \frac{\partial u_p}{\partial x} \Delta x_q + \frac{\partial u_p}{\partial y} \Delta y_q \quad (1)$$

$$y_q' = y_q + v_p = \frac{\partial v_p}{\partial y} \Delta y_q + \frac{\partial v_p}{\partial x} \Delta x_q \quad (2)$$

where u_p and v_p are the x and y components of the displacement vector point p. Accordingly, x_q and y_q are the co-ordinates of q prior to loading [2].

2.0 DIGITAL IMAGE CORRELATION SET UP

Experimental setup used in present study is shown in the Figure 3. The experiment setup consists of a Universal testing Machine (UTM), an adequate light source, Camera (Nikon D90) with a resolution of $4,288 \times 2,848$ pixels (12.3 effective megapixels), with lenses of 35 mm focal length. The camera are mounted on a tripod having inbuilt spirit level to ensure horizontal level.

2.1 Specimen Preparation

When performing DIC, it is essential for the use of high resolution camera to track a unique speckle pattern on the surface of the surface under study as shown in Figure 4. When preparing the specimen, a background must be sprayed onto the surface before the speckles are applied which is either black or white [7]. To obtain accurate results with the digital image correlation it is important to get an adequate speckle pattern. An adequate speckle pattern must have a considerable quantity of black speckles with different shapes and sizes. In order to get small and refine speckle pattern, air compressor and air brush kit will be used. The pattern will then be imaged under lighting level which maximized grey level distribution in the dynamic range [8].

2.2 Image Acquisition

Digital images will be recorded at different levels of load and the strains developed in the bonded region will be obtained using DIC. Strain accuracy and spatial resolution can be improved by increasing the resolution of the images or by using high magnification lenses to zoom in the area of specimen to be analysed [9]. Several scholars suggested subset size of 64×64 pixels with image resolution of 250 pixels/mm with LED ring flash light. Due to limited budget and funding, experimental set up for this project is using Camera (Nikon D90) with a resolution of $4,288 \times 2,848$ pixels (12.3 effective megapixels) and two (2) stand lights focussed towards the specimen under testing.

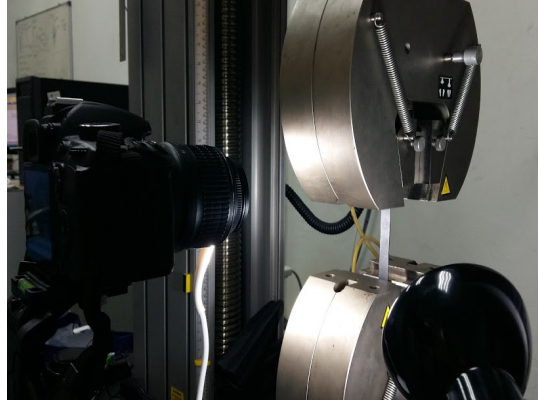


Figure 3: Setting up of DIC on tensile test coupon/specimen

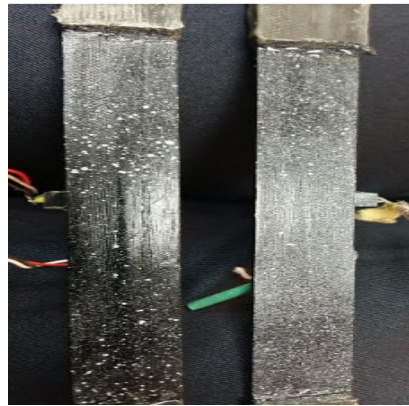


Figure 4: Speckle pattern obtained from black/white paint using air spray

As the DIC set up is built in house and not an integrated system bought from supplier such as commercial system such as La Vision : *Davis* or Aramis : *GOM*, it is essential for the user to record the batch time and series of images together with the matching load from the load cell from testing machine. In order to relate which image correspond to which load in order to plot stress strain curve, a system of recording the image and labelling it must be established. This is the procedure in brief of step by step acquisition of images and recording activities for DIC system developed in house:

- i. *Play and start the camera and the stopwatch at the same time.*
- ii. *After several seconds/minutes, start the tensile test. (for noise computation)*
- iii. *Take the reading of time of the loads (500kN, 1000kN, 5000kN until Nth reading) by using time laps.*
- iv. *Record the reading of time in tabulated form as in the Table 1*

Table 1: Load(reading from load cell UTM machine) and corresponding time

LOAD, N	TIME, s
500	15
1000	21
1500	25
2000	30

i.

Table 2: Load and matching image at corresponding time

LOAD, N	TIME, s	SEQUENCE/BATCH OF IMAGE
500	15	
1000	21	
1500	25	
2000	30	

As the camera video recorded on surface of specimen taken throughout the test, it is essential to know how the series of images acquired from video could be extracted. Here is the concise step by step recommended to the user:

- i. Convert video to image in **tiff** format by using Video To Picture Image Converter software and save into the new file folder.
- ii. The total value of image that has been converted is divided by the duration of the video in second, *s* to get the value of Frame Per Second (FPS).

$$\frac{\text{TOTAL IMAGE}}{\text{VIDEO DURATION, } s} = \text{FPS}$$

- iii. The value of Frame Per Second (FPS) is multiplied to the reading of time at every loads to get the number of image at corresponding load.

$$\text{FPS} \times \text{TIME, } s = \text{Number Of Image}$$

Based on the sequence/batch image at its corresponding load, take the actual image at their load on the image tiff file folder. As shown in Table 2, corresponding load at specified timeframe is match with its matching image at similar time.

3.0 IMAGE CORRELATION USING NCORR

After the setting up of camera together with other tools, acquisition of images and extraction from video format, it is then time for important stage which is how to determine and studying the strain field obtained from correlation technique on images. The developer of Ncorr in their manual documentation suggested version of at least R2009a+ and toolboxes required are Image Processing Toolbox and Statistics Toolbox. Besides that, compiler also required for postprocessing and correlation activity [10].

3.1 Running Ncorr program from MATLAB

The *Ncorr* program from MATLAB R2012 is run after the installation completed. None of the files has been moved or altered. The "handles_ncorr = ncorr" is typed in the MATLAB terminal as shown in Figure 5. When the files are compiled properly, a Ncorr program menu appeared as in Figure 6 [10].

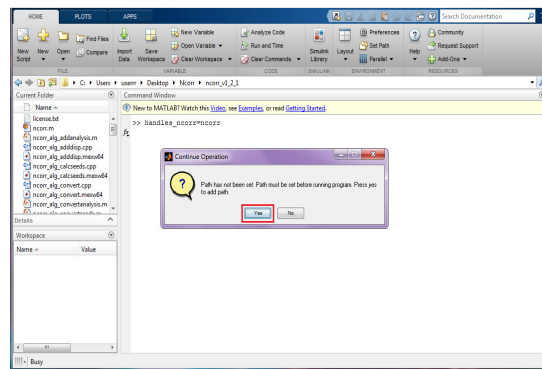


Figure 5: Program Ncorr called via Matlab

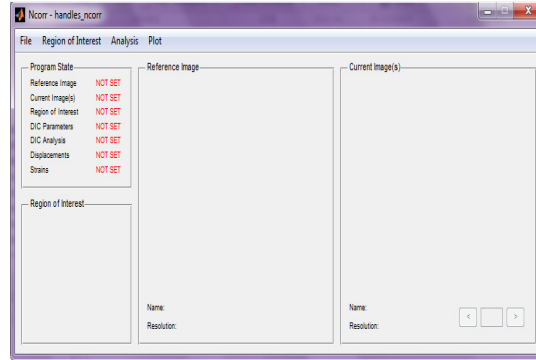


Figure 6: Main Menu of *Ncorr* Platform

3.2 Strain Computation Method using *Ncorr*

This section explains the procedure of setting up images to be correlated and processed for producing displacement/strain field.

3.2.1 Setting Images

The image as the reference image was loaded at zero loads after all the experiment is set up. The current image(s) were loaded based on the entire force loading used for the experiment. (Example: Image 1 for 500kN, image 2 for 1000kN until the force is measured). Setting the Reference Image is as shown in Figure 7. The reference image means the initial/first image taken of the sample before any deformation occurs. Current images interface is where all the subsequent images to be correlated are compiled and ready to be processed via correlation algorithm discussed before. To accomplish this, the current image must have the same format as shown below[10]:

“name” is the name of the image set and “#” is a number associated with the image. The image must be in tif format (an example would be “cfrp0_5.tif”).

Simply drag and select current image to process. After the current image are uploaded, there are button on the bottom right of the *Ncorr* which become enable and allow you to scroll through the image as shown Figure 8.

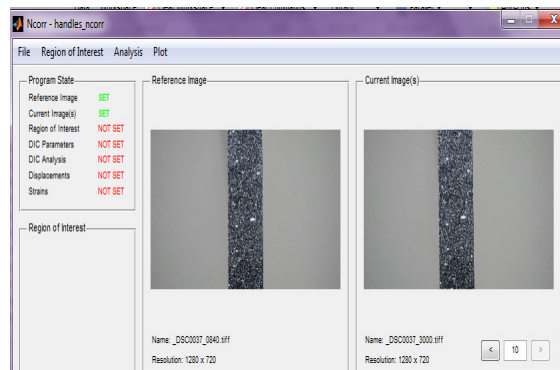


Figure 7: Loading of Reference Image

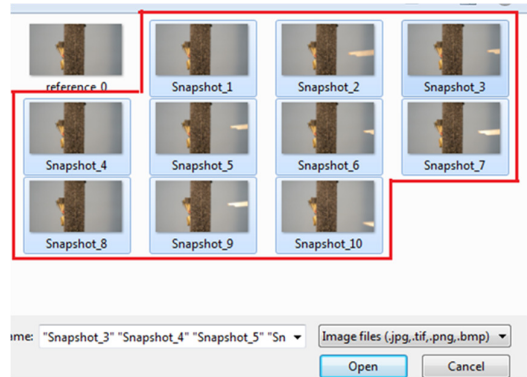


Figure 8: Loading of Current Image(s)

3.2.2 Setting of DIC Parameters

Region of Interest is drawn based on the area of gauge and strain field to be determined. Normally it depends on the application, loading condition, expected failure mode, expected deformation etc. In some cases such as tensile test or off axis shear test on coupon, middle part is chosen as gauge section as shown in Figure 9[10].

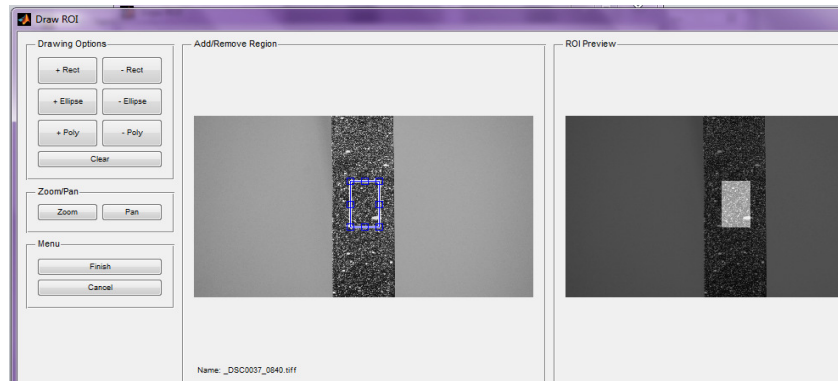


Figure 9: Selecting the gauge region for specimen under study

Several parameters appear to the left box on the screen. A green point was placed in the “Subset Location”. For the subset option, the size of the subsets is dependent on spacing between the dots. Basically, the spacing between the dots is proportionally reduces the computational load. Multithreading options is for the speed up the computation process. The larger the number of thread, the more precise the result will become.

Next steps are selecting a contiguous region to process. In this example, only one region was processed but it is possible to have more than one region when forming the ROI as in Figure 10. The seed placement process provides the initial guesses for the DIC analysis. After the seed placement completed, a preview appears as in Figure 11. The seed is then checked to preventing the process incorrect. As for the calibration and scaling part of the process, we have to specify corresponding pixels with unit measurement that we wish. It is used to convert the displacements from pixels to real units [10]. The real value of width of the specimen directly insert at the “# of Units” which is for example 20mm width of the coupon is chosen as in Figure 12.

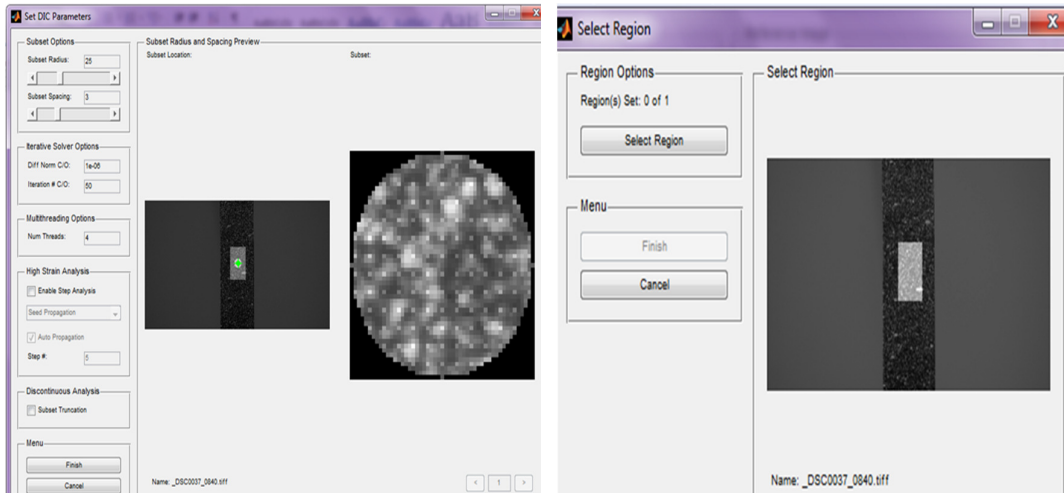


Figure 10: Subset option and region of interest

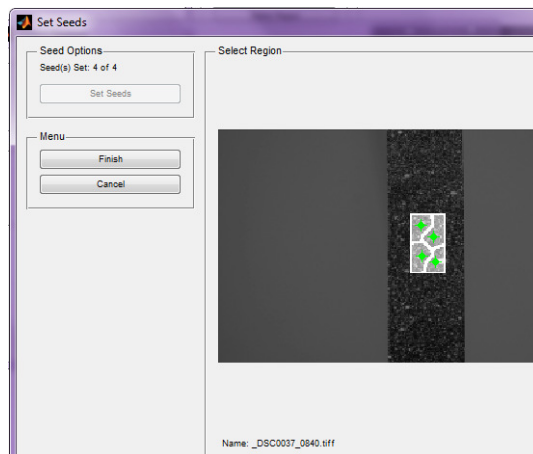


Figure 11: Setting seed on region

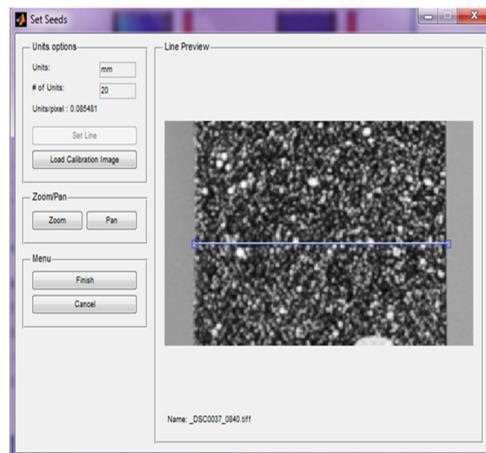


Figure 12: Calibration and Scaling

3.2.3 Calculating Strains

Strain option consists of parameter of strain radius as shown in Figure 13. This radius of a circle selects a group of points to fit a plane into computation. The selection of the ideal strain radius is similar to the selection of the ideal subset radius, in that the smallest radius desired which does not result in noisy strain data. As suggested in the manual documentation of *Ncorr*, the optimal radius is 13[10].

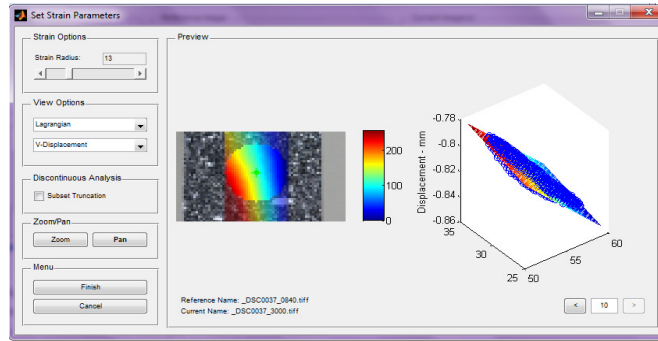


Figure 13: Strain radius setting

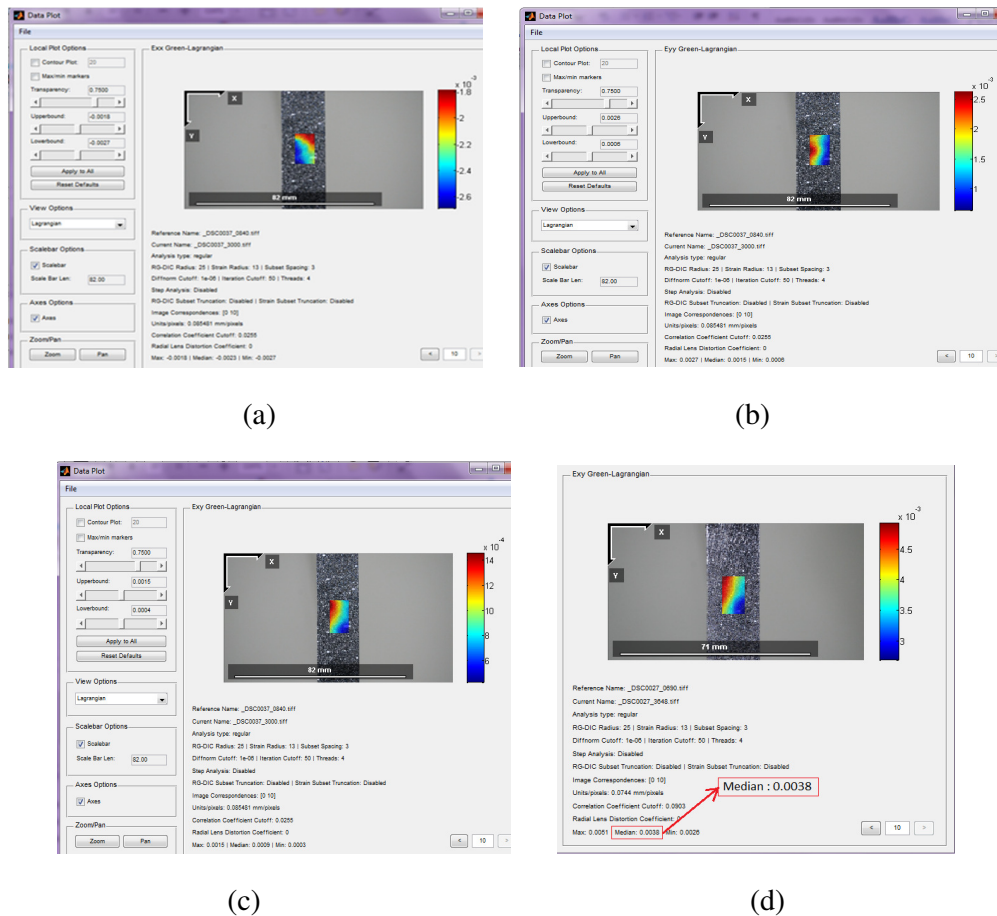


Figure 14: (a) Strain ϵ_{xx} contour, (b) Strain ϵ_{yy} contour, (c) Strain ϵ_{xy} contour and (d) Strain ϵ_{xy} contour and median value

Lastly, it is assumed either the displacement has been formatted or the strain has been calculated. This is the last step of the analysis. The values of the strain computation available for in plane space are ϵ_{xx} , ϵ_{xy} and ϵ_{yy} as in Figure X (a), (b), (c). The value of the strain corresponding to the load applied can be determined from the contour of strain for example as in Figure 14 (a), (b), (c) and (d) at 5000 N the value of median strain ϵ_{xy} is 0.0038.

4.0 VALIDATION OF STRAIN MEASUREMENT USING DIC

For measurement of the strain, the Strain Gauge and Digital Image Correlation (DIC) are used. These two methods have the same aim but different in set up, equipment and cost [11]. Strain gauge is a conventional method to measure the strain on an object. It needs a strain gauges which operates on the basis of resistance change, usually measured using a Wheatstone bridge that related to the strain. It is a resistive elastic unit whose change in resistance is a function of applied strain [12]. Apart from that, it needs wire/cable which connecting the strain gauge reading to data logger. This is obviously expensive than setting up of DIC technique. Comparison of modulus of elasticity (E_l) for GFRP 0 degree, with 60 percent volume fraction (ν_f) is done for both methods (DIC and Strain Gauge as well as with manufacturer data sheet. As shown in Figure 15, the comparison of Young Modulus, E_l (GPa) for both methods strain gauge and DIC is 40.114 and 42.31 respectively which is within 5% deviation.

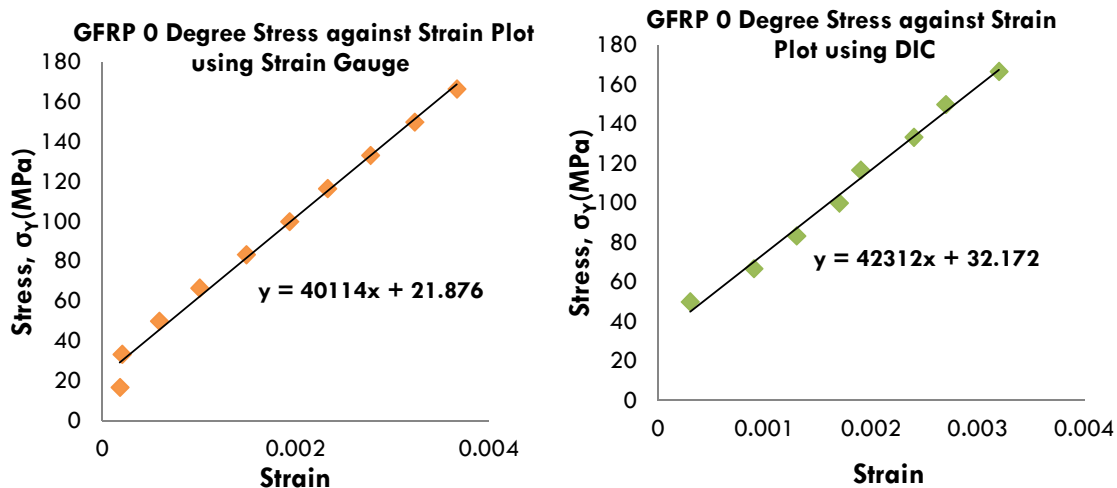


Figure 15: Stress against Strain Plot for GFRP 0 Degree Unidirectional Tensile Test

5.0 CONCLUSION

This paper presents systematic presentation of technical procedure, theoretical issues and methodology of using opensource platform *Ncorr* which is based on Matlab for low cost strain measurement. This method exceptionally gives high accuracy result in comparison with conventional method such as strain gauge that requires high cost and equipment/tool setting. Step by step procedure has been explained as accordance to the suggested instruction by *Ncorr* developer in acquisition of images, extraction of images, tabulated the input of load and corresponding image until the processing and post processing part of strain computation. DIC is reliable yet easy to handle for studying deformation of object of any type of materials,

nondestructive evaluation technique and noncontact optical measurement of displacement/strain field. The accuracy and practicality could be improved by having integrated system of load from load cell measurement and image matching simultaneously, having high resolution and magnification lense, high speed camera upto 900fps and adequate amount of light.

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