

DEVELOPMENT OF DIGITAL IMAGE CORRELATION (DIC) ON CARBON STRUCTURE



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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2022

DECLARATION

I declare that this Choose an item. entitled "Development of Digital Image Correlation (DIC) on Carbon Structure" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.



APPROVAL

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the Bachelor of Mechanical Engineering Technology (Maintenance Technology) with Honours.

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DEDICATION

To my beloved family and friends who have been my source of strength and inspiration and gave me support in terms of moral, spiritual, and emotional.

To my supervisor Ts. Dr. Ahmad Fuad Bin Ab Ghani for guiding and supporting me in completing the thesis.



ABSTRACT

The digital image correlation approach for strain assessment is a non-contact approach. The goal of this study was to measure the strain of the carbon fiber layer by non-contact method. The goal was to see how well a strain measuring method worked by analysing photos taken with a DSLR camera. The photos of carbon fiber layer processed with the Mathlab R2021a programme. The change in length in the y coordinate of the photographs was used to determine strain. The experimental and literature values were found to be in good agreement. The modulus of elasticity of the stell of the carbon fiber layer was estimated from the strain curves, and the findings were compared by the value given by universal testing machine (UTM) by doing tensile test. The findings show the results of the carbon of the carbon fiber layer's strain measurements by using Ncorr Matlab.



ABSTRAK

Pendekatan korelasi imej digital untuk penilaian terikan ialah pendekatan bukan hubungan. Matlamat kajian ini adalah untuk mengukur terikan lapisan gentian karbon dengan kaedah bukan sentuhan. Matlamatnya adalah untuk melihat sejauh mana kaedah pengukuran terikan berfungsi dengan menganalisis foto yang diambil dengan kamera DSLR. Foto lapisan gentian karbon yang diproses dengan program Mathlab R2021a. Perubahan panjang dalam koordinat y gambar digunakan untuk menentukan terikan. Nilai eksperimen dan literatur didapati dalam persetujuan yang baik. Modulus keanjalan stell lapisan gentian karbon dianggarkan daripada lengkung terikan, dan dapatan dibandingkan dengan nilai yang diberikan oleh "universal testing machine" (UTM) dengan melakukan ujian tegangan. Dapatan menunjukkan hasil pengukuran terikan karbon lapisan gentian karbon dengan menggunakan Ncorr Matlab.



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LIST OF SYMBOLS AND ABBREVIATIONS

DIC	-	Digital Image Correlation
BC	-	Before Christ
FEA	-	Finite element analysis
OSHA	-	Occupational Safety and Health Administration
ASTM		American Society for Testing and Materials
UTM		Universal Testing Machine



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CHAPTER 1

INTRODUCTION

1.1 Background

Strain analysis (also known as stress analysis) is a branch of engineering that use a variety of techniques to determine the strains in materials and structures that are exposed to forces. Strain define as physical term describes internal forces that nearby other material that exert on each other. Whereas strain is a measure of the material's deformation. The convergence of strain analysis, fatigue analysis, and accelerated durability testing gives an indicator of device structural reliability. Finite element analysis (FEA) on a high-performance computer system is commonly used for stress analysis. In general, DIC works by comparing the structure of speckle patterns on deformed and formed samples. For this, black patch of colour is sprayed on specimens in a specified pattern. The digital camera system tracks these colours as they deform. Furthermore, the fundamental advantage of this approach is that it is geometry-independent and can be used to a variety of forms to provide information on deformation behaviour of components in real-world applications (Z.Q. Yue, S. Chen, 2003)

Digital image correlation (DIC) ability to capture full field stress makes it ideal for the analysis of stress concentration in non-uniform cross section. Digital image correlation (DIC) is based on determining a correlation coefficient from pixel intensity array subsets on numerous matching pictures and deriving the deformation mapping function that connects them. The displacements of regions in a picture are monitored across a succession of photos in this way, and the strain is determined consequently. In this new era of vast technology new developments in computer technology and high-resolution digital cameras for static as well as dynamic applications, this measurement method as broadened and digital image correlation (DIC) techniques have proven to be a flexible and useful tool for deformation analysis (Fabienne Lagattu, 2004). The techniques are a fast, robust, highly scalable, and accurate method for determining both the surface profile of a two-dimensional object and the displacements on the surface of the object. This technique has been used successfully for large deformation measurements. In view of its simplicity, the technique has been extended to study the deformation at multiple length scale.

Carbon material have been widely used in aerospace specifically in carbon structure in the form of carbon fiber layer. This is because carbon is flexible, and chemically stable, meanwhile it has standard for resistance capacity. Carbon fiber layer significantly used in inner section of fuselage, main body, wing and tail (Fiber, 2019). In addition, usage of carbon as structure reinforcement can reduce cost and project duration because of high strength of the carbon in the reinforcement will ovoid need of additional anchoring works.

1.2 Problem Statement

For calculating the strain of the specimen, is challenging by using manual calculation. Here Digital Image Correlation (DIC) helps to calculate the strain of the specimen. For strain, the digital image correlation approach is commonly utilized. Measurement in a variety of scientific and engineering fields Compared to other optical approaches, this approach has several benefits. According to certain study, DIC provides the following advantages: -

- To calculate the strain value, no complex fringe pattern analysis or light wave reconstruction is required.
- Handling is not complicated.
- On the specimen, there is no localized stress concentration.
- Resolution is better comparing other optical measurements.

As a result, confirmation that digital image correlation (DIC) can be utilized for a larger variety of materials, with a particular focus on carbon, is required. This is because carbon is widely used in daily basis from household to industry. Precise measurement of strain is much required. In this study, the photos captured during the strain test in this study were captured using a consumer version of high-definition video with the purpose of selecting carbon as the primary material.

1.3 Research Objective

Based on the background and problem statement listed, the objectives of this research

study are as follows:

- a) To determine strain reaction on carbon specimen by using a Digital Image
 Correlation (DIC) and universal testing machine (UTM) based on ASTM d3039.
- b) To obtain reading by non-contact experiment process Ncorr and tensile test.

1.4 Scope of Research

The scope of this research are as follows:

- This project mainly focuses on strain reaction of the specimen using the digital image correlation (DIC) method.
- The carbon fiber layer specimen of the experiment is used to obtained the strain.
- The main parameters that will be of attention during the study is the strain values.
- The values will be determined by using Digital Image Correlation (DIC) method from Matlab merge of Ncorr.



CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Chapter 2 of this project has been split into sections that assist readers with a deeper grasp of the study of the Digital Image Correlation (DIC). Chapter 2 is made up of summaries of papers written by various authors on pertinent topics. This will help to make the knowledge gained from this research more useful.

2.2 Digital Image Correlation Method

The DIC technique has been used since the early 1980s and comes in a variety of versions. The 2-dimensional DIC technique is the topic of this work, and it includes using a single camera, tripod, external light and Ncorr software to measure displacement and strain in a plane. This method has the advantage of using only one camera, lowering equipment costs, and allowing for the incorporation of additional measurements. However, it has one big drawback: all displacements and strain must occur inside a single stationary measuring plane, otherwise severe errors in findings would follow (Pan Bing, 2011)



Figure 2.1 Digital image correlation to set up strain measurement (Yoneyama, Satoru, 2009)

Researchers have utilized the DIC approach to detect axial strain for artificially and experimentally created pictures in the past, with various degrees of success. Smith et al., 1998 reported a strain reading standard deviation of 100. Despite the employment of a concentric lens to reduce out-of-plane distortion, the camera resolution of 640x480 pixels had a detrimental impact on measurement accuracy. When measuring strain, displacement errors caused by the DIC method are typically fractions of a pixel, and the influence of this mistake can be mitigated by employing a longer gauge length to yield a smaller strain error. As a result, higher resolution cameras (such as those employed in this study) improve measurement accuracy by allowing for longer gauge lengths.(Z.Q. Yue, S. Chen, 2003) achieved mean strain errors of 210, however they employed a lower resolution camera (1317 x 1035 pixels) and a less precise sub-pixel interpolation approach, comparable to (Z.Q. Yue, S. Chen, 2003) also utilized a lens with a rather short focal length of 55 mm. The focal length of the lens has a big role in strain measurement accuracy. Smaller mistakes are associated with longer focal lengths.

Measurement of displacements and strains has long been a key issue in material characteristics such as material strengths and fracture characteristics, as well as in experimental stress analysis. Optical methods including moiré interferometry, holography, and speckle interferometry have been demonstrated to be effective in analysing macroscopic characteristics and are used in a variety of applications. Fringe pattern processing is time consuming and labour intensive. This technical challenge has piqued the interest of numerous academics, and automated processes have been devised to automate the data processing from fringe patterns.

The DIC approach was developed by Sutton et al.,(Tsuji N, 2002) and Bruck et al.,(Z. A. Z. M. D. A. Shibkov AA, 2011) over the previous two decades. It was used to calculate stresses and displacements. Microscopic strain measurements in electronic packaging (R. Schwab and V. Ruff, 2012), strain fields in polyurethane foam plastic materials and assessment of their mechanical characteristics (Z, 2007) are only a few of the applications. This approach has even been used to assess the condition of conservation of mural frescoes in situ (L. E. Han BQ, 2005). The advantages of this computer vision technology include a simple architecture and direct sensing. As previously stated, the DIC approach employs two pictures acquired by a solid-state video camera to represent the states of the object prior to and after deformation. To discover the minor changes between the two digitized pictures, an algorithm based on mutual correlation coefficient or other statistical functions was used to correlate them.



Figure 2.2 Differences Between 2D and 3D Digital Image Correlation



Figure 2.3 Process of Digital Image Correlation

2.3 Speckle Pattern

One of the sources of information in DIC measurement that can detect problems is the speckle pattern. When measuring the in-plane displacement of the specimen, the size of the subset has a significant impact on the speckle pattern. The size of the subset is a recurring parameter that must be considered during the correlation process. In the DIC process, the speckle pattern is an essential aspect that the system employs to monitor the specimen's displacement and deformation. The speckle pattern's efficiency must be numerically distorted. The speckle pattern is applied to the specimen, and DIC measures the resulting spackle pattern displacement and compares it to the load applied to the specimen. (D. Lecompte, 2007)

In DIC, it's crucial to figure out how big the pattern is. Some subsets may be tracked solely on the black field or not totally on a white field due to the vast pattern. The camera resolution may not be enough to accurately inform the specimen if the pattern is too small(David., 2006) However, to create a good DIC result, the pattern must have the right size, as seen in figure 2.4.





(a) (b) Figure 2.4 (a) and (b) sample of good speckle pattern

In addition, DIC employs two common speckle patterns are painted speckle patterns and natural surface patterns (Poudel, 2014)1. The specimen painted design was created by randomly spraying paint on the surface. The speckle pattern's background can be black or white, with the spot being white and the background colour being contrasted. The natural surface pattern is the specimen's original surface without any external patterns applied. Figure 2.5a depicts typical speckle patterns for painted speckle patterns, while figure 2.5b depicts a natural speckle pattern.



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Figure 2.5 (a) the typical speckle pattern, (b) natural speckle pattern

2.4 Spackle Pattern Preparation

A satisfactory strain measurement is dependent on the good structure of the speckle pattern when employing DIC analysis. The speckle pattern must be high contrast, constant dot sizes, and equal amounts of black and white must be present on the sample surface to produce an acceptable result for DIC analysis of strain measurement (Giacomo Lionello, 2014). When the force is applied to the specimen in DIC, the speckle pattern is utilized to trace the ensuing motion. A subset of the track and the speckle pattern's motion. Furthermore, the speckle pattern must be created using an algorithm with a high contrast on the specimen's surface. The quality of the designs has a direct impact on the DIC measurement resolution and accuracy. To lower the level of noise in the photos, the pattern quality must have a good contrast to the backdrop on the specimen. In reality, the minimum size of the speckles must be 3-5 pixels in order to avoid oversampling the features in each speckle pattern, which would result in a grey image if not recognized properly.

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2.5 Strain

Strain is associated with deformation in terms of relative particle displacement in the body, excluding rigid-body motions. Depending on whether the strain field is defined with regard to the initial or final configuration of the body, and whether the metric tensor or its dual is considered, several equivalent choices for the formulation of the strain field may be made. A deformation field occurs in a continuous body as a result of a stress field caused by applied forces or changes in the body's temperature field. Constitutive equations, such as Hooke's law for linear elastic materials, express the relationship between stress and strain. Elastic deformation is defined as a deformation that disappears after the stress field is eliminated. The continuum totally resumes its initial configuration in this situation. Irreversible deformations, on the other hand, persist. Even when all tensions have been removed, they still exist. Plastic deformation is one sort of irreversible deformation that occurs in material bodies after stresses reach a particular threshold value known as the elastic limit or yield stress and is caused by slip or dislocation mechanisms at the atomic level. Viscous deformation, which is the irreversible part of viscoelastic deformation, is another type of irreversible deformation (Z. P. Bažant, 2010).



Figure 2.6 Procedure of Strain Testing

2.6 Universal Testing Machine

The tensile and compressive strength of materials are tested using a universal testing machine (UTM), also known as a universal tester, materials testing machine, or materials test frame. A tensometer is an older name for a tensile testing machine. The name's "universal" element refers to its ability to perform a wide range of typical tensile and compression tests on materials, components, and structures.

A test method, which is generally published by a standards organization, describes how to set up and use the equipment. This covers sample preparation, fixturing, gauge length (the length being studied or observed), analysis, and so on. The specimen is put between the grips of the machine, and if necessary, an extensometer can automatically record the change in gauge length during the test. The machine can record the displacement between its cross heads on which the specimen is held if an extensometer is not used (Joseph R. Davis, 2004).

This method, on the other hand, captures not only the change in specimen length, but also any other stretching / elastic components of the testing machine and its driving systems, as well as any slipping of the specimen in the grips. When the machine is turned on, it starts applying an increasing load to the specimen. The load and extension or compression of the specimen are recorded by the control system and its related software during the testing.



Figure 2.7 Universal Testing Machine (INSTRON)

2.7 Carbon Fiber Layer

Carbon fibres or carbon fibres (alternatively CF, graphite fibre or graphite fibre) are carbon-based fibres with a diameter of 5 to 10 micrometres (0.00020– 0.00039 in). High stiffness, good tensile strength, low weight to strength ratio, high chemical resistance, high temperature tolerance, and minimal thermal expansion are only a few of the benefits of carbon fibres. Carbon fibre is widely used in aircraft, civil engineering, military, and motorsports, as well as other competitive sports, due to its unique qualities. However, when compared to similar fibres such as glass fibre, basalt fibres, or plastic fibres, they are quite pricey (Pooja Bhatt and Alka Goe, 2017).

To make a carbon fibre, carbon atoms are bonded together in crystals that are more or less aligned parallel to the fiber's long axis, resulting in a fibre with a high strength-tovolume ratio (in other words, it is strong for its size). Thousands of carbon fibres are bundled together to create a tow that may be used alone or woven into a fabric. To make a carbon fibre, carbon atoms are bonded together in crystals that are more or less aligned parallel to the fiber's long axis, resulting in a fibre with a high strength-to-volume ratio (in other words, it is strong for its size). Thousands of carbon fibres are bundled together to create a tow that may be used alone or woven into a fabric.

2.7.1 Structure and Properties

Carbon fibre is typically delivered on a reel in the form of a continuous tow. The tow is made up of hundreds of tiny carbon filaments that are kept together and protected by an organic covering, such as polyethylene oxide (PEO) or polyvinyl alcohol (PVA). For use, the tow may be easily unwound from the reel. Each carbon filament in the tow consists almost entirely of carbon and is a continuous cylinder with a diameter of 5–10 micrometres. T300, HTA, and AS4 were among the first generation, with sizes of 16–22 micrometres. Later fibres (such as IM6 or IM600) have a diameter of about 5 micrometres.

Carbon fibre has an atomic structure similar to graphite, consisting of sheets of carbon atoms arranged in a regular hexagonal pattern (graphene sheets), with the distinction being how these sheets interlock (W.J. Cantwell, 1991). Graphite is a crystalline material in which the sheets are arranged in a regular pattern parallel to one another. The intermolecular forces between the sheets are Van der Waals forces, which give graphite its soft and brittle properties.

Carbon fibre can be turbostratic or graphitic or have a hybrid structure with both graphitic and turbostratic portions, depending on the precursor used to create it. The sheets of carbon atoms in turbostratic carbon fibre are carelessly folded or crumpled together. After heat treatment at temperatures over 2200 °C, carbon fibres formed from polyacrylonitrile (PAN) are turbostratic, but carbon fibres derived from mesophase pitch are graphitic. Heat-

treated mesophase-pitch-derived carbon fibres have a high Young's modulus, but turbostratic carbon fibres have a high ultimate tensile strength.

2.7.2 Application

The aircraft and aerospace industries, as well as wind energy and the automobile industry, have the highest need for carbon fibre. Carbon fibre can be more expensive than other materials, which has been a barrier to adoption. When comparing steel with carbon fibre materials for automotive applications, carbon fibre is likely to be 10-12 times more expensive. However, over the last decade, this cost premium has decreased from estimates of 35 times more expensive than steel in the early 2000s (IYRS, 2021).

2.7.3 Composite Materials

Carbon fibre is most commonly used to strengthen composite materials, particularly the carbon fibre or graphite reinforced polymers class of materials. Carbon fibres can also be encased in non-polymer materials as a matrix. Carbon has had limited success in metal matrix composite applications due to the development of metal carbides and corrosion concerns. Reinforced carbon-carbon (RCC) is a high-temperature structural material made of carbon fiber-reinforced graphite. The fibre is also used in high-temperature gas filtration, as a high-surface-area electrode with excellent corrosion resistance, and as an anti-static component. Because a dense, compact coating of carbon fibres efficiently reflects heat, moulding a thin layer of carbon fibres considerably increases fire resistance of polymers or thermoset composites. Because of galvanic corrosion difficulties, carbon fibre composites are displacing aluminium from aerospace applications in favour of other metals. Because of galvanic corrosion difficulties, carbon fibre composites are displacing aluminium from aerospace applications in favour of other metals (Pooja Bhatt and Alka Goe, 2017).

Carbon fibre can be used to generate electrically conductive asphalt concrete by mixing it with asphalt. The use of this composite material in transportation infrastructure, particularly airport pavement, reduces some winter maintenance issues that result in flight cancellations or delays due to ice and snow. Passing current through a 3D network of carbon fibres in a composite material dissipates thermal energy, raising the asphalt's surface temperature enough to melt ice and snow above it.

2.8 Tensile Strength

A tensile test is commonly used to determine ultimate tensile strength, and the engineering stress versus strain is recorded. The ultimate tensile strength, which has units of stress, is the highest point on the stress-strain curve. The compressive strength is the comparable point in the situation of compression rather than tension. Tensile strengths are rarely relevant in the design of ductile elements, but they are crucial in the design of brittle ones. Carbon, alloys, composite materials, ceramics, polymers, and wood are among the materials that have been tabulated (Degarmo, 2003).

Because a material's ultimate tensile strength is an intensive attribute, its value is independent of the size of the test specimen. Other aspects, including as specimen preparation, the presence or absence of surface imperfections, and the temperature of the test environment and material, may be affected depending on the material. Brittle failure occurs when a material breaks very sharply without deforming plastically. Others, such as most metals, which are more ductile, go through some plastic deformation and possibly necking before breaking.

Tensile strength is a stress that is quantified in terms of force per unit area. It can be reported as a force or as a force per unit width for some non-homogeneous materials (or completed components). The pascal (Pa) is a unit in the International System of Units (SI) (or a multiple thereof, frequently megapascals (MPa), with the SI prefix mega); or, equivalently, newtons per square metre (N/m2). The pound per square inch (lb/in2 or psi) is a standard unit in the United States. Kilopounds per square inch (ksi, or kpsi) is a unit of measurement for tensile strength in the United States. It is equivalent to 1000 psi.



2.8.1 Ductile Materials

Many materials exhibit linear elastic behaviors, as defined by a linear stress-strain relationship. However, the elastic behaviors of materials frequently extend into a non-linear region, as represented by point 2 (the "yield point"), up to which deformations are completely recoverable upon removal of the load; that is, a specimen loaded elastically in tension will elongate, but will return to its original shape and size when unloaded. Deformations in ductile materials, such as steel, are plastic beyond this elastic area. When a plastically distorted specimen is unloaded, it does not restore to its previous size and shape. Plastic deformation is unsatisfactory in many applications and is utilized as a design constraint.

After reaching the yield point, ductile metals go through a strain hardening process in which the stress increases with increasing strain, and they start to neck as the cross-sectional area of the specimen shrinks due to plastic flow. When necking becomes significant in a suitably ductile material, the engineering stress-strain curve reverses. Because the engineering stress is estimated based on the initial cross-sectional area prior to necking, this is the case. On the engineering stress-strain curve, the reversal point is the greatest stress, and the engineering stress coordinate of this point is the ultimate tensile strength, which is provided by point 1 (Kalpakjian, 1984). Because design procedures necessitate the use of yield stress, ultimate tensile strength is not considered in the design of ductile static components. However, due of the convenience of testing, it is utilized for quality control. It's also utilised to make educated guesses about the material types of unknown samples. Because brittle materials have no yield point, ultimate tensile strength is a frequent engineering metric for designing members.



CHAPTER 3

METHODOLOGY

3.1 Research Flow Chart

The project's process flow chart is shown in Figure 3.1. The project began with a discussion and clarification of the supervisor's title. The second part of this research is to identify the research background, problem statement, objective, and scope. Weekly meetings with the supervisor have also been set up, and the sessions are being held as planned. Finding books and journals that are connected to the title as a research reference started the literature review. The way ahead on how to perform the research and experiments related to the project was determined based on the literature study. The next step was capturing a part of carbon fiber layer structure and implement in NCORR MATLAB software. After the trials were completed and the video was recorded, the strain data was measured by analysing the snapshots of the movie using MATLAB's Image Processing Toolbox function. The study ended with documentation.


Further research and studies are being undertaken on the issue in order to not only acquire crucial project facts, but also to determine the project's state through other people's research and studies, as well as any recent breakthroughs.



Figure 3.2: Final Year Project Flow Chart

3.3 Model Development

The design concept generation should occur first, in the form of a draught, followed by idea evaluation to determine the best concept design to continue with. Simulation based on actual product and variables, generation of comprehensive design including dimensions and material qualities, and prototype manufacture would all be part of the idea development process. Documentation will be completed to capture all information and actions from the planned project's first stages. The report's objective would be to act as a formal and thorough collection of proof on the planned project's development.

3.4 Testing Preparation

The equipment that will be used in the experiment will be specified in the testing preparation. To set up the experiment, needed a digital camera, a carbon layer, and a sufficient light source, among other things. Aside from that, it should have a tripod to ensure that the digital camera is level with the specimen being examined, as shown in Figure 3.6.



Figure 3.3 Digital Image Correlation Test Setup

3.4.1 Camera (NIKON D750)

Camera Nikon d750 have been used for the experiment. The major reason was the specification of the Nikon d750 which believed will ensure high accuracy of the results during the entire experiment. This is because it has 24mp full-frame CMOS sensor with AA filter, it's also specified flip up/down 3.2"1.229k-dot RGBW LCD screen and this will ensure reduction on external errors during capturing the results. For the frame per second for continuous shooting was 6.5 to capture more detail. For the object focusing its have 91,000pixel RGB metering sensor with object detection and spot-metering linked To auto focus point. For the picture quality was 1080/60p video recording. And its powered aperture for control during video to reduce expose background. Tripod stand have been used to hold the camera in parallel position to the specimen in universal testing machine to avoid errors during capturing the results of the experiment. Light stand has been used because the importance of lighting in the creation of a successful image cannot be overstated. Not only does lighting affect brightness and darkness, but it also affects tone, mood, and atmosphere. As a result, in order to achieve the best texture, colour vibrancy, and luminosity on your subjects, you must effectively regulate and manipulate light. You can make stylized professional-looking images by evenly spreading shadows and highlights.

3.4.2 Speckle Pattern



Figure 3.4 Different Sample Of Speckle Pattern(Speckle Pattern Quality Assessment for Digital Image Correlation, 2013)

Before beginning the testing, a background of the specimen must be sprayed black and white onto the specimen's surface. High contrast and enough to draw a clear distinction between the speckle pattern and the background (Jihyuk Park, Sungsik Yoon, Tae-Hyun Kwon, 2017). The speckle pattern's quality is the most significant factor for the specimen; assize effect resulting in the speckle pattern. The speckles, on the other hand, must be neither too little nor too huge. In practice, the size of the speckle pattern can be changed in a variety of ways, but the optimal design provides the most flexibility Figure 3.2 displays several examples of patterns that fail one or more of the excellent pattern requirements. In DIC analysis, this pattern cannot be used since the pattern motion is difficult to follow the subset (P. Reu, 2015). (P. Reu, 2015).

3.4.3 Specimen

The carbon fiber layer is the specimen that will be used in this project. The use of DIC in this experiment was to see if it was a useful way for obtaining the strain that occurs at the carbon fiber layer when a force is applied. The behaviour of the strain displacement when testing is applied to the specimen will be investigated in this study. The carbon chosen is carbon fiber layer, which is usually applied in the aircraft industry. To compare the value of the specimen's mechanical qualities. It is also necessary to investigate the mechanical characteristics. The size is determined using ASTM d3039, which is used for tensile testing and has the dimensions shown in Figure 3.7.



Figure 3.5 a)The dimension of the specimen standard of ASTM d3039, (b) the specimen used in the experiment

3.5 Mechanical Testing

Mechanical testing is an important part of determining the mechanical properties of a specimen. The reaction and deformation of the material as a result of the applied load can be used to determine mechanical characteristics. When the data is compared, the results of the testing will be used to check the accuracy of the DIC. Aside from that, the specimen's failure mode can be detected.

3.5.1 Tensile Test

The Universal Testing Machine Tensile (INSTRON) is the testing technique that will be employed for this experiment. The purpose of the test is to evaluate the strength of the material being tested by pulling it to failure in a relatively short period of time at a consistent rate. In this experiment, a 2mm/min speed is being used to determine the optimal image data acquisition for the Ncorr platform analysis to determine the best image data acquisition. Tensile testing can be used to determine the mechanical properties of a material, such as the modulus of elasticity and yield strength, as well as measures of elongation and reduction of surface area. A standard test technique for tensile testing of carbon fiber layer material, ASTM D3039, is followed from the beginning to the end of the procedure.



Figure 3.6 Universal testing Machine (INSTRON) for tensile testing

3.6 Image Data Acquisition

When the specimen was being tested, the camera recorded video. The specimen can be obtained by employing the 2D-DIC by using the recorded video, and the video can demonstrate the force assigned to the specimen at various levels. This has been converted into a digital image batch as well as the distribution of strain across the specimen. As a result, in order to grow the strain's accuracy, it's also important to enhance the picture's resolution or, alternatively, to zoom across the region of the specimen to be evaluated with a high magnification camera. The device used in the experiment has a resolution of 24.3 megapixels.



Figure 3.7 Set up for video recording

3.6.1 Converting Video to Image

After the video has been recorded under uniaxial loading, it must be converted into a variety of photos. The image must be saved in Jpeg format. As a result, the video is converted by exporting it to the Final Cut Pro Software's Video to Picture Converter software. The image is then saved as a whole photos into a new folder. After that, all of the transformed images must be divided into Frames Per (FPS) Second to acquire the photo's number.

$$\frac{Total\ image}{Video\ Duration\ (s)} = FPS$$

Once the Frame Per Second (FPS) number has been generated, it is important to determine the image amount at the associated load. The time of the image is divided by the video length in seconds for a specific load, and the resulting value is then multiplied by the converted complete image.



3.7 Image Correlation using Ncorr

The phase of image correlation, which usually begins after the acquisition of image data, is the most significant step in DIC. After all of the photos have been processed during the picture acquisition stage, calculate and analyse the strain field that has been obtained out of the all the picture. The Ncorr application, which works with the MATLAB software, was used to create the image correlation system. The Ncorr publisher has previously suggested the MATLAB edition R2015 and higher for superior correlation findings, which will result in an exceptional achievement in the image strain sector. Ncorr, on the other hand, frequently requires the Toolbox for Image Processing and the Statistical Toolbox, as well as Microsoft Visual C++ for correlation and post-processing activities. The number of threads should be three or more in order to achieve the Ncorr correlation process with the greatest accuracy (J. Blaber1 & B. Adair 1 & A. Antoniou1, 2015)

3.7.1 Running Ncorr Program using the MATLAB Software

WALAYSI.

To begin the DIC process, open the program in request after installing MATLAB R2021a. First, import the Ncorr file into MATLAB so that it may be used to run the program. Then, in the command box of the MATLAB terminal, type "handles_ncorr=ncorr" to launch the Ncorr, as shown in Figure 3.11.



Figure 3.8 Launch the Ncorr program by using MATLAB

After that, the new window will appear in the MATLAB software on behalf of Ncorr. Then, on the OpenMP, select the number of threads that have been advised, which is four(4) or more. Then, if the file partially is correct, a new window for setting the path will appear, as displayed in Figure 3.12. Set the path to allow the photo to be uploaded to a different folder. The Ncorr option was provided in the MATLAB interface when the overall setting was set, as illustrated in Figure 3.13.



Figure 3.10 Ncorr main menu bar

3.7.2 Selection of Reference Image and Current Image

First and foremost, select the reference image and upload it to Ncorr. The initial image that is captured when there is no deformation on the sample is referred to as the reference image. The image is then received from the folder of the photo that was previously altered. To get a superb DIC final result, it's critical to use the proper reference image because it has an impact on the outcome. If the reference image chosen is incorrect, it will result in a strain measurement error because the value obtained may be negative. It demonstrates how to upload a reference image. Right after the reference image is successfully sent, an indicator for the reference image will appear on the left.



Figure 3.11 Uploaded reference image

Thereafter, select the current image based on the load being applied to the product during the test. The current image is a photograph of the specimen on which the force is being applied. The photo is then compared between the reference image and the current image, which is utilized to correlate the deformation that occurs on the speckle pattern, using the algorithm. The format of the present photograph should be in the following name format(J. Blaber1 & B. Adair 1 & A. Antoniou1, 2015) when uploaded. The "name" refers to the specimen's name, and the "#" refers to the number associated with the photograph, for example () The image cannot be uploaded if the name is not saved as mentioned above.





3.7.3 Setting the Region of Interest

The ROI must be determined since it will provide a clear region to study. If the ROI is not accurately identified, it should influence the resulting contour and eventually lead to the stress concentration being affected. The gauge and strain field measurement area will be focused on it when creating the ROI. Typically, the ROI dimensions are determined by a number of factors, including the loading situation, application, expected deformation, and so on. There are two methods for calculating the ROI. The first method is to load it from a photo that has already been saved throughout the folder by clicking *Region of Interest*, then *Set Reference ROI*, and finally *Load ROI*. The second method is to manually draw it into MATLAB by going to the Interest Region, clicking on the *Set Reference ROI*, and then going to the *Draw ROI*, as shown in Figure 3.16. The second option was chosen for this project since it is simpler and takes less time than the first. The person can glide into and pan the view to ensure that the ROI drawing becomes correct and precise.



Figure 3.13 Setting the Region of Interest (ROI)



Figure 3.14 Drawing the ROI into the specimen

3.7.4 Setting Up the DIC Parameters

The DIC variable is one of the important parameters to be determined in 2D-DIC using the Ncorr software. The effect if the parameter is not set appropriately is the ultimate result of the DIC study. The DIC parameter can affect the precision of the strain value as well as the strain contour in the sample. Choosing the correct DIC parameter is therefore critical in order to achieve the best possible result. Several parameters will show on the left of the Ncorr menu when you pick the DIC parameter. To select the DIC parameter, go to Analysis and then to Set DIC Parameter. The "Subset Location" will be a green point that has been highlighted in the image. The subset selection on the left menu is made up of the subset spacing as well as the subset radius.

It is critical to define the size of the subset size in order to get a good DIC result. To determine the best value for sub-set spacing and radius, the size of the speckle pattern is employed. The proportions of speckle patterns should not be too big or too little, and they should be distinct and high contrast. Excessively small subsets, according to (Y. Wang, P. Lava, P. Van Houtte, 2015), may not contain enough data to pre-process the speckle pattern, despite the fact that excessive subsets may make matching shape and deformation harder. According to the parametric study's preceding chapter, the ideal number of sub-set ratios is between 6 and 8. In this experiment, the sub-set radius was 45 and the sub-set spacing was 3 using a ratio of 7, as shown in Figure 3.18.



Figure 3.15 Setting up the Subset Radius, Subset Spacing and Number of Threads

Following that, you must select a contiguous region to be processed. To run the process, go to Analysis and then DIC Analysis on the Ncorr. The next step is to select an area (contiguous region), look for the Select Region key, and position the pin point for processing anywhere in the region, as displayed in Figure 3.19. Then, as shown in Figure 3.20, continue with the seed placement process.



Figure 3.16 Selecting the Region on the specimen

The seed positioning technique is important since it generates the DIC analysis assumptions. As a result, the number of seeds is necessary for a better DIC outcome. The greater the thread number, the more accurate the result will be. In order to create a larger quantity of seeds, the number of threads must be increased. A preview should appear in the window once the seeding procedure is complete, as shown in Figure 3.20. This preview allows you to double-check seed placement to avoid taking the wrong action.





(b)

Figure 3.17 (a) Setting up the seed on the region, (b) Seed preview

Some other method for conducting the scaling and calibrating process will be on the specimen assist. The overall system is set up to convert displacement from unit pixels to millimeters (mm), which is an actual measurement unit. The above task is important for producing strain in a real unit that can be compared to another measuring method. As a result, this phase is primarily for evaluating the DIC process's final result. To begin this stage, proceed to Analysis, then to displacement formatting, and finally to get Unit Conversion to upload an image with a known measurement, as illustrated in Figure 3.21. Then, using the Load Calibration Image button, may submit the reference image for calibration purposes. The next step should be to show the correlation from one end of the specimen to the other. Select the Set line button and enter the value in mm as shown in Figure 3.22. After the calibration process is completed, could go on to the data analysis step.

🚺 Format Displacements		-		×
Units Options Get Unit Conversion Units/Pixel: 1	Preview U-displacement V-displacement			
Units: pixels Formatting Options Max/min markers Corr-Coef Cutoff: 0.1392			-8	
Apply To All Lens Distortion Options Lens Coef: 0	-0.5		-10	
Cet Lens Coef			-14	
Menu Finish Cancel	Reference Name: pw-0mil-p2-n14_000.jpg Current Name: pw-0mil-p2-n14_031.jpg	×	31	>

Figure 3.18 Setting up the displacement format



3.8 Calculating the displacement and strain measurement

To begin the test, go to Analysis and then to the Ncorr main menu and select Calculate Strain from that. There is only one variable that may be changed in this section, and that is the strain radius. A strain radius is a circle radius that selects a point group for use in a calculation (J. Blaber1 & B. Adair 1 & A. Antoniou1, 2015). The process of determining the ideal dimensions of a strain radius is identical to that of determining the size of a subset radius. The minimal size of strain radius is required to avoid noisy data in strain data, but it is up to determine the size that is significant to their data. The strain radius that has been chosen throughout this project is 25. When compared to the previous parametric study, the choice of size 25 is based on the subsequent form of the contour, which has a clean shape. Last but not least, the strain result is plotted. To access the plotting, the user must first select Plot from the Ncorr menu, then View Displacement or View Strain. The View displacement and View Strain buttons will reveal the displacement and strain measurements, respectively.



Figure 3.21 U-displacement plot, (b) V-displacement plot



(a)

(b)



(c)

Figure 3.22 a) Strain contour for EXX plot, (b) strain contour for EXY plot, (c) strain contour for EYY plot

CHAPTER 4

INTRODUCTION

4.1 Introduction

In this experiment total of 8 specimen of carbon fiber layer in the dimension of length 250mm, wide 25mm, thickness of 0.1mm have been used to obtain the strain. The instrument used such as Nikon d750 camera and the universal testing machine was ensured to be calibrated before the experiment was conducted to avoid error on obtained results. The apparatus of the experiment was inspected before and after every test on each specimen to obtained more accurate results. The carbon fiber layer specimen was handled with proper procedure before and after the experiment to avoid error on results.



Figure 4.1 Universal Testing Machine (Material Science Laboratory)

Based on the method described in the previous chapter, the results of this experiment were achieved. Graphs, tables, and a projection of the DIC analysis contour were all used to convey the experimental data. The main purpose of this chapter is to clarify the results of the study, by evaluate and explain strain using the Digital Image Correlation (DIC) approach. Tensile Test was conducted by using the Universal Testing Machine (UTM) along with the optimal speed for the camera to capture the perfect visualization of strain images.

4.2 **Mechanical and Physical Properties**

87	Units	_	SPG 196-P	SPG 370-8H
Fibre Type	-7.		IM7 6K	IM7 6K
Fibre density	g/cm ³ (lb/in ³)		1.77 (0.064)	1.77 (0.064)
Weave			Plain	8HS
Mass	g/m² (oz/yd²)		196 (5.78)	374 (11.03)
Weight Ratio, Warp ; Fill			50 :50	49 :51
Nominal cured ply thickness	rene (in als)		0,100 (0,0070)	0.000 (0.0150)
@ 37% resin content	mm (incn)		0.199 (0.0078)	0.380 (0.0150)
Nominal Fibre Volume	%		55.57	55.57
Nominal Laminate Density	g/cm ³ (lb/in ³)		1.56 (0.056)	1.56 (0.056)
2 Not	- a a a			- 410
Mechanical Properties			S. U	(July)

Mechanical Pro	perties
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Test	Units	Temp°C (°F)	Condition	SPG 196-PW	SPG 370-SH
U	VIVERSITI	T -5 5 (-67)	DryAYS	979 (142)	965 (140)
0°Tensile Strength	MPa (ksi)	25 (77)	Dry	1090 (158)	1014 (147)
		91 (195)	Dry	-	-
		-55 (-67)	Dry	862 (125)	903 (131)
90°Tensile Strength	MPa (ksi)	25 (77)	Dry	945 (137)	959 (139)
		93 (200)	Dry	979 (142)*	879 (130)*
		-55 (-67)	Dry	85 (12.3)	86 (12.5)
0°Tensile Modulus	GPa (msi)	25 (77)	Dry	85 (12.3)	86 (12.4)
		91 (195)	Dry	-	-
00°Topoilo		-55 (-67)	Dry	80 (11.6)	81 (11.7)
Modulus	GPa (msi)	25 (77)	Dry	80 (11.6)	81 (11.7)
Wodulus		93 (200)	Dry	79 (11.5)*	79 (11.5)*
		-55 (-67)	Dry	-	-
0° ILSS (Shortbeam shear)	ar) MPa (ksi)	25 (77)	Dry	88 (12.7)	90 (13)
		91 (195)	Dry	69 (10)*	74 (10.8)*
		25 (77)	Wet	80 (11.6)	83(12.1)
		71 (160)	Wet	61 (8.8)**	63 (9.1)**
		91 (195)	Wet	-	-

Figure 4.2 Prepreg Properties - HexPly® 8552 Woven Carbon Prepregs (IM7 Fibre) (Product Data Sheet, 2020)

The figure 4.2 above shows the mechanical properties of carbon fiber layer. Its shows the nominal laminate density of 1.56 g/cm³, for the experiment SPG 370-SH carbon prepreg fiber as been used. Therefore, the 0°Tensile Strength at the temperature 25 °C was 1014 MPa and for the 90°Tensile Strength at the temperature 25 °C was 959 MPa. In addition, 0°Tensile Modulus at the temperature 25 °C was 86 GPa and for the 90°Tensile Modulus at the temperature 25 °C was 81 GPa.

4.3 Defection of the carbon fiber layer upon completion of the experiment



The figure 4.3 above shows all 8-carbon fiber layer which have been used in the experiment. The figure clearly shows that all 8 specimens undergo maximum strain. This is because of the crack of all the 8 specimens. Cracking occurs when a layer's critical stress exceeds its capacity to withstand it. This critical stress is dependent on particle radius, volume percentage, shear modulus, and coordination number, as well as layer thickness and solvent interface tension, according to (Singh & Tirumkudulu, n.d.)

The following subtopic has been defined as a series of contour pictures generated by the Ncorr software at EYY. The contour indicates that the strain distribution is nonhomogeneous. The result was then examined in evaluate the testing effectiveness based on the strain acquired from the DIC analysis. The study discovered that larger subset sizes produce more accurate results than lower subset sizes. The references algorithm creates a simulated image of a speckle pattern. Following the technique, the contour images were created based on the reference image, and after deformation, the strain measurement was determined using DIC. The contour different subsets which is 4 and 3 threads and 4 and 4 subsets spacing in DIC EYY strain.



4.3.1 Difference Between 3 And 4 Threads And 3 And 4 Subsets Spacing in Dic EYY Strain



Table 4.1 Difference between threads and subset spacing by Ncorr





The contour series reveals a different shape for each load being applied, indicating that strain displacement has happened. The red colour indicates where the largest displacement happens during this testing, with the failure occurring first in the red area. When the tensile test is applied, the blue one represents the lowest strain displacement. As can be observed, the subset spacing and thread of 3 and 4 correspondingly have only a little difference in pattern and value. The larger the subset, the more accurate the measurement becomes, as the subset displacement functions match the actual underlying deformation, and the accuracy of the measurement increases much more gradually as the subset scale grows larger. However, due of the machine time requirements for the analyses solution, using larger subset sizes will result in lower DIC analysis output. In order to avoid exceeding the subset size, the maximum limit of the subset size must be present.

Alternatively, in some cases, the larger subset is not suited for improving the accuracy of the DIC process. When the speckle size is small, a small subset size is required in some instances. The size of the pattern determines the sub-set. To obtain the ideal subset size, there must be enough capacity to incorporate enough distinct and traceable speckle patter characteristics for a successful and suitable displacement outcome. Small selections under specific situations can provide a satisfactory displacement result but identifying the

speckle pattern's change requires a greater camera resolution. Aside from that, a big subset size can reduce the ability of the speckle pattern's fine tiny dots, but somehow the method also can work.

4.3.2 Root Mean Square Error

In this analysis, the root mean squared error (RMSE) is used to determine the consistency between two sub-sets. The RMSE is a formula for calculating the difference between expected and measured values. In this situation, strain measurement data obtained from the DIC are estimated and compared to displacement values obtained from the Universal Testing Machine.

Number of samples	LOAD (N)	DIC	يبو אדש يتي	9 Error value
Sample 1 ERSITI	16214.415	0.0103	SIA0.0122	(A 0.0019
Sample 2	14572.322	0.0116	0.0145	0.0029
Sample 3	14375.472	0.0095	0.013	0.0035
Sample 4	16438.031	0.0085	0.0124	0.0039
Sample 5	14180.784	0.0098	0.0174	0.0076
Sample 6	14275.604	0.0097	0.0124	0.0027
Sample 7	14316.052	0.0098	0.0112	0.0014
Sample 8	14383.338	0.0096	0.0112	0.0016

Table 4.2 Maximum strain value measurement by comparing between the DIC and UTM

To get the value RMSE is by equation below:

$$RMSE = \sqrt{\frac{1}{N} \Sigma (x - \bar{x})^2}$$
(4.1)

The value of the mistake \bar{x} is the average error value to which x refers, and N is the number of results predicted. The least RMSE number is the best outcome, according to the results. The estimated RMSE is shown in table 4.6.

DIC 0.0098836 UTM 0.0372726	MALAYS	Method	RMSE
UTM 0.0372726	·	DIC	0.0098836
		UTM	0.0372726

Table 4.3 Comparison Between the Prediction Errors DIC and UTM

There is a difference between the DIC and UTM standard deviations, as indicated in Table 4.6. The DIC standard deviation is 0.0098836 and the UTM standard deviation is 0.0372726, which differs from 0.027389. It simply shows a tiny difference in value, which could be due to an error in data collection utilizing the DIC. As can be seen from this result, the UTM has a lower value than the DIC, indicating that it has a better output than the DIC. It's possible that it's because the speckle pattern used isn't good enough. As is well known, the lower the RMSE value, the better.

4.4 The Strain and Displacement Measurement Result From NCORR



4.4.1 Data of V-Displacement

The translations of the sub-center images in the Y directions are represented by v. Delta y denotes the distances between the sub-center images and point y. As a result, the correlation coefficient rij is determined by the displacement components v and gradients.

Based on the Y-displacement graph obtain above, its shows that the value remains on a constant pattern for all 8-carbon fiber layer specimen of the test. The lowest initial Ydisplacement reading was recorded on specimen 4 which is -5.7632 and the highest final Ydisplacement reading was recorded on specimen 6 which is -13.9616. Overall, it was found that the Y-displacement value of all 8-carbon fiber layer specimen varies between -5.000 and -13.000.

4.4.2 Data of EXY Green- Lagrangian



Figure 4.5 EXY Green-Lagrangian graph of Ncorr

Based on the EXY shear strain graph obtain above, its shows that the value remains on a constant pattern for all 8-carbon fiber layer specimen of the test. The lowest initial EXY shear strain reading was recorded on specimen 6 which is -0.0006 and the highest final EXY shear strain reading was recorded on specimen 7 which is 0.0012. Overall, it was found that the Y-displacement value of all 8-carbon fiber layer specimen varies between -0.0006 and 0.0012.

4.4.3 Data of EYY Green-Lagrangian



Figure 4.6 EYY Green-Lagrangian graph of Ncorr

According to EYY GREEN-LAGRANGIAN graph its shows that the strain value of the samples. Among all the samples, sample 2 has achieved the highest strain value at 240 seconds with the value of 0.0116. It also started with higher value compared to other specimen with the value of 0.0090. The sample 2 has achieved highest value because of the positioning of the specimen and the camera was best. The lowest strain value has achieved among the 8 specimen was sample 4 with the value of 0.0085. This is because the specimen could not place properly during the testing. The camera unable to record the strain value of specimen 4.

4.5 Comparison strain measurement using tensile test machine and DIC

In this investigation, two cases of various strain rates were chosen to be compared to the strain value of the specimen. Table 4,3 shows the comparison of strain measurements generated using the DIC method and UTM experiment at a speed of 2 mm/min. In this experiment, the strain from the machine has a very similar value to the strain using DIC, as seen in the table. As the strain increases, the load is increased. The final value of the recorded load during the experiment tabulated. To examine the difference between the two methods, the outcome was analysed in relation to strain using machine and strain using DIC software, as shown in figure 4.3.

Based on the table generated from the test, the strain value on the carbon fiber layer specimen. According to the results in table 4.3, the strain measurement using universal testing machine and DIC software have a little difference in range. Using machine and DIC software, the strain values for all 8 specimens were 0.0019, 0.0029, 0.0035, 0.0039, 0.0079, 0.0027, 0.0014, and 0.0016, respectively. According to the results of the test, as the load increases, the strain must also increase. As a result, using strain measurement data, the protective variable can be modified to eliminate any movement during the testing.

اونيوم سيتي تيكنيكل مليسيا ملاك

Number of samples	LOAD (N)	DIC	UTM	Differences
Sample 1	16214.42	0.0103	0.0122	0.0019
Sample 2	14572.32	0.0116	0.0145	0.0029
Sample 3	14375.47	0.0095	0.013	0.0035
Sample 4	16438.03	0.0085	0.0124	0.0039
Sample 5	14180.78	0.0098	0.0174	0.0076
Sample 6	14275.6	0.0097	0.0124	0.0027
Sample 7	14316.05	0.0098	0.0112	0.0014
Sample 8	14383.34	0.0096	0.0112	0.0016

Table 4.4 Comparison strain value of UTM and DIC



Figure 4.7 Comparison strain measurement value of UTM and DIC

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UNIVERSITI TEKNIKAL MALAYSIA MELAKA Figure 4.3 shows a graph of comparison strain using universal testing machine and

DIC using a 2mm/min test speed. This observation could be related to the camera that captures the mobility of the sample during the testing procedure, however due to poor camera resolution, the movement of the speckle pattern was not captured. When comparing DIC values to machine data, there isn't much of a difference. A side effect that increases image noise, which can disrupt the experiment process, is another because that provides information about this circumstance. If this is correct, it causes an error in the DIC result when compared to a machine result.

CHAPTER 5

CONCLUSION

5.1 Conclusion

The results given in this research demonstrate the potential of Digital Image Correlation to determine strain in the carbon fiber layer. The DIC approach is effectively applied for strain distribution of speckle pattern at the surface of the carbon fiber layer during tensile testing. For digital image correlation strain computation, a DSLR camera is used as acquisition hardware and Ncorr (opensource platform) as a post-processing medium. The strain value acquired by DIC is confirmed by comparing it to a universal testing machine. Comparisons of DIC and UTM calculations at constant speeds showed that some specimens are similar, others are significantly different. This is due to the limitations of the primary technique, which is the camera resolution, as well as the analytic software. The constraint could be the reason of the DIC method's poor performance.

The impact of the load on the experiment is evaluated throughout this test, which impacts the strain of the specimen. In addition, the influence of subset spacing and threads on strain measurement was investigated in this test. The study found that the higher the subset spacing and threads value, compared to the smaller size, the more successful it is. This is since the size of the speckle pattern influences the size of the subset; the larger the speckle pattern, the larger the subset required. The sparkle pattern's optimal scale should not be too large, and it should be adequately contrasted with the background so that the observer can easily catch the sparkle pattern motion.

Every one of the objectives achievements was concluded based on the results obtained from the data analysis. It was done using a DSLR camera and the Digital Image Correlation method as non-destructive testing and assessment on the material under uniaxial loading. The DIC was used on the carbon fiber layer in this study. The data of eight carbon fiber layer specimens was obtained, and the results were compared using a universal testing machine. On the Ncorr open-source platform, applying the DIC, it was confirmed that some parameters affect strain measurement. The result was shown in the contour of the Eyy strain using the Ncorr open source. To successfully apply the Ncorr open source, it was important to analyse the subset parameter, region of interest (ROI), and seed propagation.

5.2 **Recommendation**

The application of DIC technology, on the other hand, is a good method that can be applied, but it still must be improved. As can be seen, there are numerous ways to improve the effectiveness of DIC methods. In order to improve the DIC method, the user should also give importance on the subset size is chosen and how the specimen is positioned by the speckle pattern. This is because the correlation process, in order to create a successful outcome, requires the presence of these two factors. The difficulty of following the motion of the speckle pattern subset affects the outcomes if the speckle pattern is not properly measured for the procedure detail.

Furthermore, it is significant in DIC technology to improve camera and lens performance. High camera resolution can result in a large number of deformed images, which can help with DIC correlation. Meanwhile, the pixels on the camera must better match the lens resolution so that image noise may be minimized and DIC results can be enhanced.
Furthermore, for long-term DIC operations, the camera's speed must be upgraded. The lighting on the experimental location must enable a clear view of the lens in order to record the movement of the speckle pattern. The distance between the camera and the sample must also be considered, because when the distance is higher, greater camera resolution is required to record the object movement. Aside from that, the thickness of the specimen must be enlarged so that the seed can be placed inside the Ncorr software during running the tensile test in DIC methods.

Based on the experiment we found that DIC method able to generate strain results accurately to the universal testing machine results. In addition, the DIC method consume less duration and cheap costing as compared to universal testing machine. Furthermore, the DIC able to generate more accurate result without non-contact process of strain on a material and the result able to enhance by improving sensitivity of camera lens.

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APPENDICES

YEAR				2021													
#	Project Activities	Plan vs	MAR				APR			MAY				JUN			
Α	Bachelor Degree Project 1	Actual	3	4	1	2	3	4	5	1	2	3	4	1	2	3	4
1	Briefing	Plan		1													
		Actual		7													
2	Literature Review	Plan		164					_			1					
		Actual		12								1.1					
3	Chapter 2 Writing	Plan								1							
		Actual								1							
4	Identify Problem	Plan		_								- T					
		Actual															
5	Establish Aim and Objective	Plan						1.00			\mathbf{M}						
		Actual									A.						
6	Chapter 1 Writing	Plan									RF						
		Actual									K B						
7	Chapter 3 Writing	Plan									E						
		Actual			1			de la caractería de la			ST			1			
	Preliminary Finding	Plan			6				1000		Ë						
8		Actual	~~~	1.1		-	~~~	and the second distance	~	11	E -	100	10.9				
•	Submission First Draft PSM 1	Plan	100	6			14				\sim	1	10.00				
9		Actual									Ö						
10	Turnitin Check	Plan									W						
		Actual	- 1 -	TE L	CNH	LZ A	1.1	A 84	1 A	VC	LA M		N 12 1				
11	Correction	Plan			1.1.4.1	P.V-	L.L.	MM	1.1.14	1.0	IM IVI	and the state	ALC:				
		Actual															
12	Final Draft PSM 1	Plan															
		Actual															
13	Slide Preparation	Plan															
		Actual															
14	Presentation	Plan															
		Actual															

APPENDIX 1: Gantt Chart for PSM 1

YEAR				2021												2022		
#	Project Activities	DI		0	СТ				NOV		DEC				JAN			
В	Bachelor Degree Project 2	Plan vs Actual	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	
1	Briefing	Plan																
		Actual																
2	Writing Chapter 4	Plan																
		Actual	4															
3	Data Collection	Plan		1														
	Data Collection	Actual		10														
4	Data Analysis	Plan		7														
		Actual		1														
5	Proposed Enhancement	Plan		P						\mathbf{X}								
		Actual								I A								
6	Submit Work Progress	Plan								H H H								
		Actual																
7	Chapter 5 Writing	Plan					-			E E								
		Actual								L								
6	Submission First Draft	Plan								Ë								
8		Actual			1		1			EN		1						
9	Executive Summary	Plan								S								
		Actual			1			1										
10	Turnitin Check	Plan	20				A. Car		-		الكريك	100	200	0				
		Actual	1	0			1			3.		/	·	/				
11	Correction	Plan																
		Actual								-								
12	Final Draft PSM 2	Plan		E M		KZ.		M A		VSIA	M		$\Delta \mathbf{K}$	A	i —			
		Actual								CI OIM			_	-	i —			
13	Slide Preparation	Plan	İ	1		1		1	l				l					
		Actual		1														
14	Presentation	Plan		1														
		Actual																

APPENDIX 2: Gantt Chart for PSM 2



UNIVERSITI TEKNIKAL MALAYSIA MELAKA

BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA

TAJUK: DEVELOPMENT OF DIGITAL IMAGE CORRELATION (DIC) ON CARBON STRUCTURE

SESI PENGAJIAN: 2021/22 Semester 1

Saya NANTHAVAN A/L SUKUMARAN

mengaku membenarkan laporan PSM ini disimpan di Perpustakaan Universiti Teknikal Malaysia Melaka (UTeM) dengan syarat-syarat kegunaan seperti berikut:

- 1. Tesis adalah hak milik Universiti Teknikal Malaysia Melaka dan penulis.
- 2. Perpustakaan Universiti Teknikal Malaysia Melaka dibenarkan membuat salinan untuk tujuan pengajian sahaja dengan izin penulis.
- 3. Perpustakaan dibenarkan membuat salinan tesis ini sebagai bahan pertukaran antara institusi pengajian tinggi.
- 4. **Sila tandakan (✓)



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