DEVELOPING VIDEO MEASUREMENT OF STRAIN FOR POLYMERS USING LABVIEW

By

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TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Objective

The study is mainly focused to measure strain of PET by using non-contact measuring technique and correlate the strain with images of PET which is observed under polarized light.

1.2 Techniques of measuring strain

For measuring strain there are many different techniques available. Two types of techniques are reported in general. One is displacement transducers and another is optical systems. In Displacement transducers, the test specimen is directly connected to the setup while there is no direct contact between the test specimen and sensors in optical systems. A displacement transducer measures the displacement of deviation under load of the specimen and then calculates the strain. The most common displacement transducers are extensometers, liquid metal strain gauges, mall effect strain gauges etc. On the other hand, by using cameras, optical systems track the position of markers which are placed on the surface of the test specimen. As there is no contact with specimen, there are many advantages using optical systems. One of them is there is no effect on loading response of the specimen. And by saving the video captured by the camera, strain can be measured by on-line and off-line analysis. For measuring strain in non-contact technique, cameras or laser beams are used as

sensors. [6]

1.3 Cameras and lens in non-contact strain measurements

Cameras with appropriate lens are widely used for non-contact strain measurements. Cameras are used to capture the images while a lens helps cameras view the region of interest clearly and accurately. In Figure 1.2, a simple diagram of a thin lens is shown. It is an example when the angles are small [7].Two important terms for lens systems are **Depth of Field** and **Field of View**. The displacement in front of and beyond the object after adjusting the lens focus is called depth of field. By changing the image magnification, object distance, and aperture diameter depth of field (DOF) is changed [1]. Depth of Field should be considered to capture good quality images specially while studying the fringes. The angular amount of a region
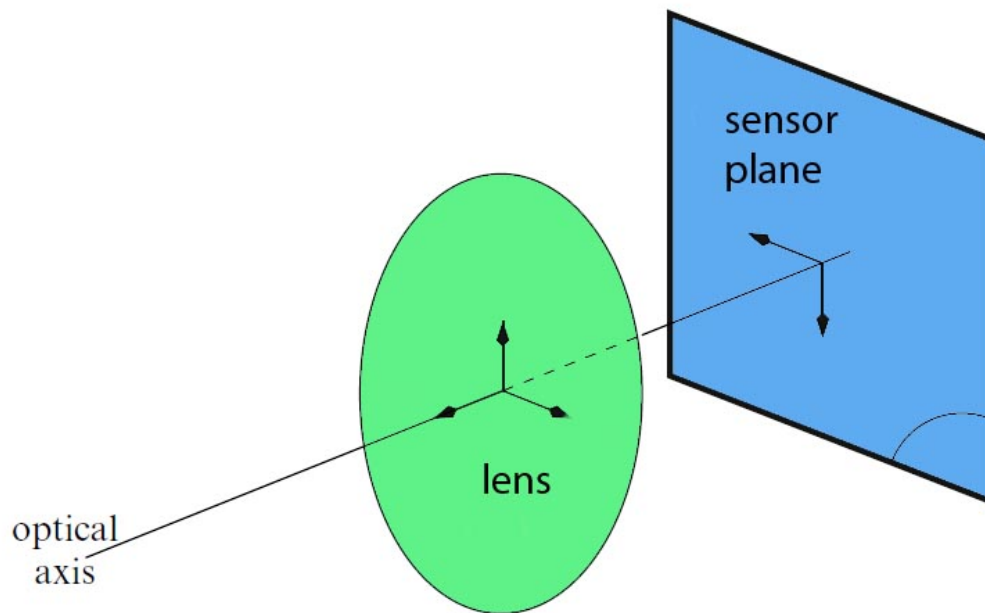
Figure 1.1: lens with sensor plane [reproduced from [1]].

of interest captured by a camera is called Field Of Fiew [1]. By adjusting the FOV we can use the full resolution of the camera to study our interest.

The most common opto-electronic device, camera, is the charge coupled device (CCD) camera to acquire digital images. By CCD camera the illumination is converted into an electrical signal [8].Using A/D converter, the CCD signal is converted into a discrete digital intensity array data. The classical model of a camera is based on perspective projection concepts using a thin lens pinhole camera. By matrix operation the world ordinate system of the object is transformed to camera's system and furthermore the camera's system is transformed into the Image plane coordinate system, and then the image plane coordinate to sensor coordinate system [9]. In practice, it is impossible to install an optical system in front of a camera in which rays intersect the image plane perfectly. So the deviation can be found between the image and the actual environment. As a matter of fact, a distorted image is captured by the camera. There are several kinds of distortion. Spherical, coma-distortion, Astigmatism, curvature of field, linear, radial and de-centering are the main distortions. The distortions are a disadvantage of using cameras for measuring displacements. There are proposed some procedure to correct distorted images. Image Calibration is done to compensate for distortion. [9] By using an equally spaced grid of dots, a camera is calibrated. First, the amount of distortion is analyzed by comparing the distorted image of that grid diagram and real grid dots. After learning the deviation, the distorted image can be filtered.

1.4 Three dimensional camera vision

Using a pinhole camera, points of 3D object can project into points of 2D image plane. One camera can collect some 3-D information if it is translated a known distance. However, the precision is limited to the knowledge of how far the one camera is moved. On the other hand by using two cameras it is possible to recover the third dimension position of the true object. [2] shows how to recover third dimension parameter by using matrix operation of the coordinate of two cameras and the object. As there are

3
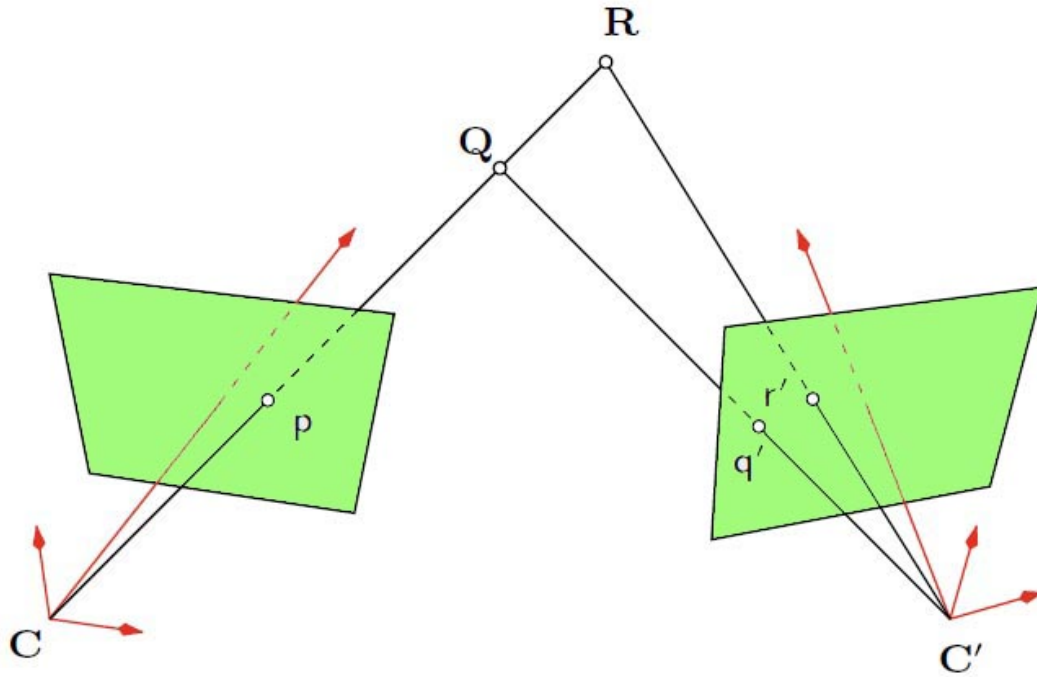
Figure 1.2: Recovering the third dimension by using two cameras [reproduced from [2]].

two cameras used in this system, it is harder to calibrate these whole systems. Unlike 2D vision using one camera, the calibration for 3D vision is complex. Two approaches commonly used for calibration of stereo vision system are: a) independently calibrate each camera in a stereo vision arrangement using motions of the same target pattern and b) considering both cameras as a single measurement system [2].

1.5 Digital Image Correlation

Digital image Correlation (DIC) is a method which is used to measure the surface displacements and displacement gradients in materials under deformation [10]. It is a non-contact method which can be applicable for both infinitesimal and large deformations [11]. DIC is commonly used for measuring deformation for relatively soft

materials where strain gauges are not a good choice for measurement. It is also useful when the specimen is situated in high temperature and for capturing 2-D strains. DIC was first introduced by a group of researchers at the University of South Carolina et al [12] [13] [14] [15] [16] . Later, Vendroux and Knauss et al [17] [18] [19] and Vendroux et al [20] improvised the basic algorithms used for two dimensional DIC [11] [10]. DIC is a non-contact optical technique and obtains full field deformation. After processing images of material one by one and then calculating the deformation at any point of that full field, this technique finds the deformation and strain values. Basically DIC obtain 2-D full field deformation by recording the specimen under stress and tracking the motion of speckle patterns on the specimen surface before and after the deformation takes place. While measuring displacement applied stresses change both thickness and optical properties and of materials. DIC uses both of them to measure strain. For using DIC technique High resolution of one camera (2D displacement) or two cameras (3D displacement) are needed. Optically ordinary incoherent light is sufficient for this technique. As a whole DIC is less demanding than other optical techniques [12].

First of all, the surface of the specimen should be prepared for DIC technique. It
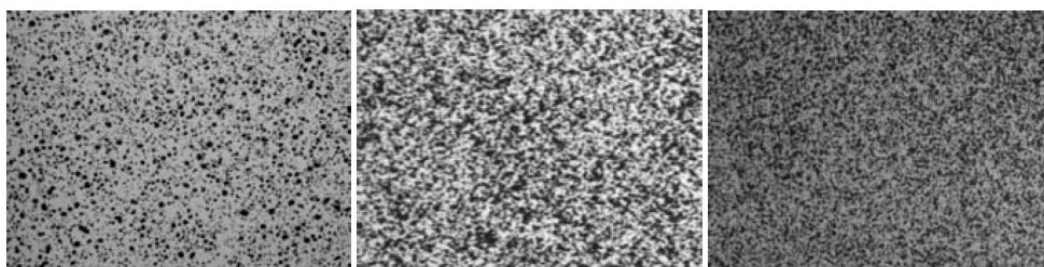
Figure 1.3: Example of typical speckle pattern [scanned from [3]].

needs speckle on the surface of the specimen. Sometimes the material properties of specimen provide the requiring speckle, while otherwise surface of the specimen needs to be sprayed by paint. Digital camera will take picture of the surface of the specimen. Images are digitalized using CCD array and these images are used for further

image processing. Using the speckle motion and intensity of the pixel of the images displacement field is generated. Accuracy is up to 0.02 pixels [21]. By spraying a target pattern is made. The intensity pattern matching method known as correlation is used to locate the target pattern. Mainly, pattern matching is done by defining the subset of pixels that surround the key feature on target. If two patterns are matched, the target displacement is found [15].

It is obvious from the technique that the shape and size of the speckles plays a crucial role. If there are some same types of target, it would be impossible to distinguish one from another. So, the speckles should be unique for each point. It can be seen that at least 3x3 pixels area should be covered with a speckle. For small speckles, white paint is sprayed while carbon particles are sprinkled. For moderate speckles, white paint is also sprayed while black paint is sprayed with a light pass. Again, for large speckles, white paint is again sprayed while black paint is brushed. When very high resolution is needed, fluorescent paint is used. Actually, speckle matching is done by using the algorithm for matching the intensity field of many speckles where intensity data is rich compared to individual speckle matching [3].

Gray scale digital images contain many pixels with different gray scale values. In the gray scale images, the distinguishable intensity change can be observed easily. It is needed to smoothen the data over the entire field in all images. The process of smoothing the intensity data is called interpolation. Two types of interpolation are generally used- a) Bilinear and b) cubic. Both of these types of interpolation approximate the value of intensity of any point that lies between the pixels. Coarse-Fine method and Newton-Raphson method are used to determine the displacement vector. The calibration for the camera discuss in earlier section is also needed to get rid of distortions [14].

1.6 In plane displacement and out of plane displacement
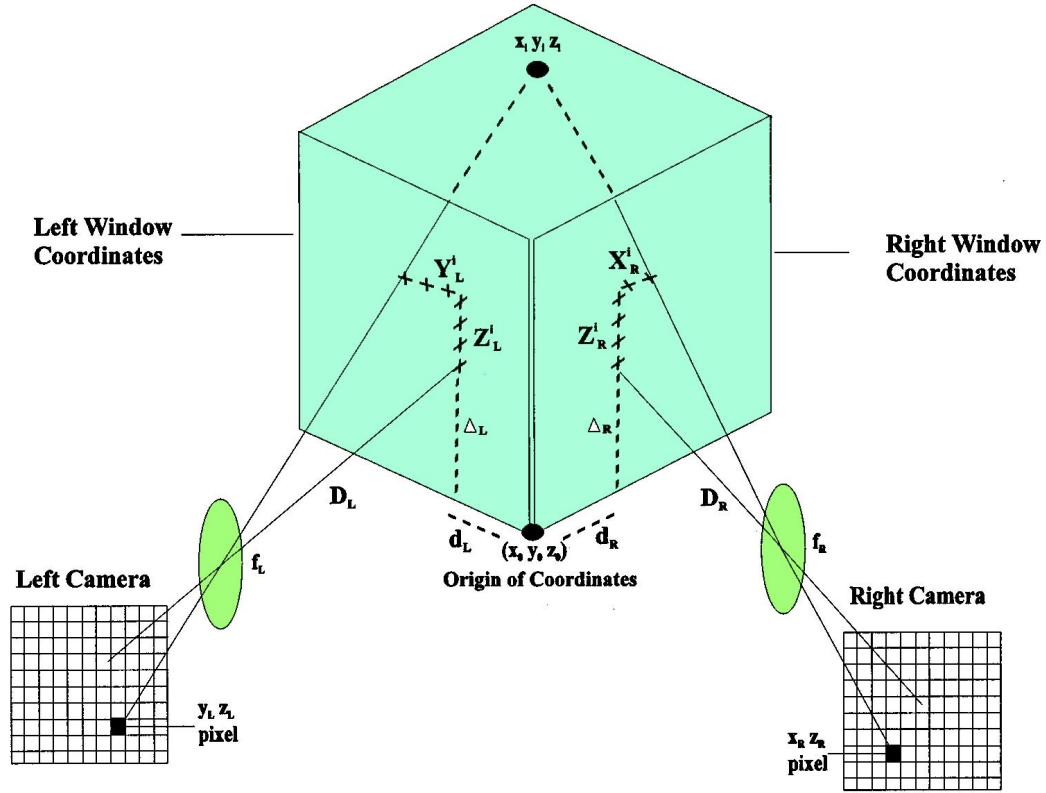
Figure 1.4: Stereo imaging technique setup [reproduced from [4]].

In-Plane displacement measurement of DIC refers to 2D displacement measurements using digital image correlation. Using one camera setup and appropriate lens distortion corrections, in-plane measurement is performed. Some journal paper describes the in-plane measurement system in different approach [22] [10] [23] [24]. In the article [22], 2D displacement measurement is described with lens distortion correction. A single cross-grating is used as a calibration reference. On the other hand, out of plane two CCD cameras are employed to measure the 3D component on a specimen. The procedure is to get image from both cameras and develop stereo image by using stereo imaging. After that, image correlation process was performed. [25] shows the effect of out of plane motion on 2D and 3D digital image correlation measurements. In this paper, the measurement of displacement with in-plane system

and out-of-plane system is compared.

1.7   Video strain measurement system

Video strain measurement is another commonly used non-contact displacement measurement system. For delicate specimens, a video extensometer is more suitable [26]. Video extensometers have been becoming more popular for last decades to record the plastic behavior of polymers and metals [27]. This provides good accuracy of measurement of true-strain of ductile materials over large plastic strain. [26] shows how the mechanical properties are determined at very low strain levels using video-extensometry.

The apparatuses needed for video-extensometry are a) a fast processor PC, b) a universal testing machine (example: INSTRON), c) analog/digital interface for connecting the extensometer to the testing machine, d) a high precision CCD video camera, e) post application software for processing the image (example: LabView) [26]. Two markers are attached on the surface of the specimen and the main source of the system is to track multiple markers and automatically capture the information on the computer [6]. The camera is focused on the marker of the specimen. The camera can take either gray scale or color images. A zonal area is selected so that the processor will search the marker in that area. The markers are searched using their shape and intensity of color[27]. While testing, the distance between the camera and specimen should remain constant as any relative movement of this distance can cause distortion of the image size of specimen. Therefore, the alignment and orientation of the specimen is very important and specimen should be rigidly fixed within the universal testing machine [26]. The change of intensity of glares, shadows or reflection in the image is the main disadvantage in this system [28]. In [26], it is recommended to light the specimen from the back and special care is taken to ensure a constant intensity of illumination. The even light distribution in the background is very important here.

For markers, paint can be used and also thin strips of paper with small width can be used. If the strip of paper is used, it should be attached with specimen with very small amount of glue [28]. Glass-beaded retro-reflective tape can be used as marker when the temperature is within 200 degree F. If temperature goes above 900 degree F, Aluminum-backed strip might be used [29].
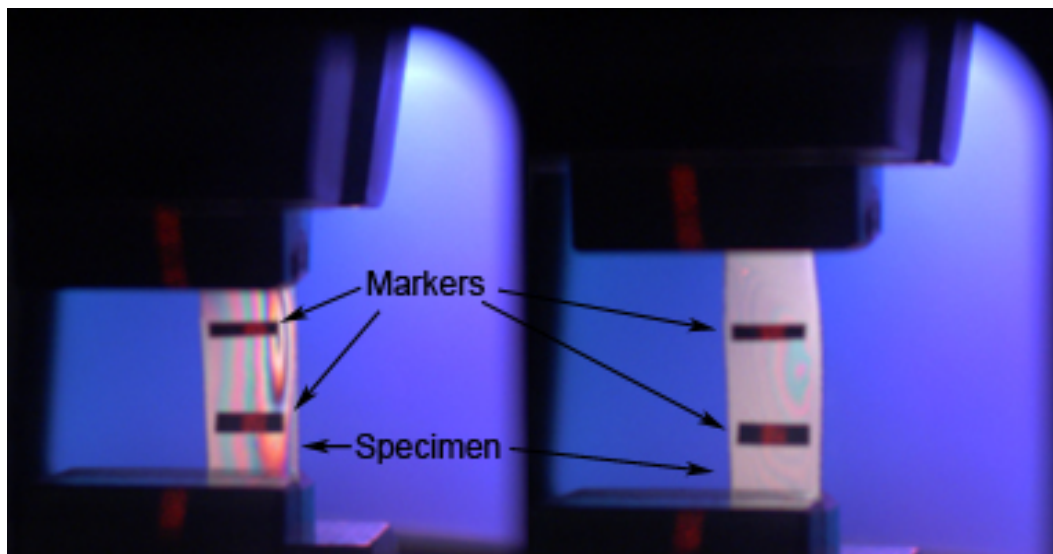
Figure 1.5: Specimen attached with markers in Video extensometer system

For video extensometer system, [26] shows that there is no influence of the specimen length measuring the strain. The reliability of extensometer is also tested in this paper. There is no problem with knife-edge slip here too. Even there are no detectable errors due to inertia of moving parts. It can also be used in environmental chambers over a wider temperature range [27]. In [6], the accuracy of video strain measurement system is discussed. There are two kinds of error while measuring strain using this technique. They are: a) static error and b) dynamic error. The static error is the movement reported by markers which are not in motion. If the two markers are not in motion, the relative displacement between two markers should be zero in any span of time. Any changes of distance between them represent static error. Dynamic error is the error reported while the markers are in motion [6]. [6] shows the

error with respect to the marker size. It is hard to track smaller markers. There is a optimum width of the marker which can be tracked more accurately, which is beyond the scope of this thesis. Loading rate is also important for this system. If the loading rate is high, the error increases [6].

There are also other non-contact techniques to measure the strain of the materials. The laser speckle extensometer can also be used here. This procedure involves two dimensional strain measurements in real time. The measuring principle is based on the analysis of the speckle patterns of the markers when the surface of the specimen is illuminated by coherent laser light. One or more cameras are used to take the patterns. Using Fast Fourier Transformation correlation analysis the strain is evaluated [30]. [31] proposed a new extensometer which needs not attachment of line markers or mechanical tracers on a specimen. Instead of the markers, an expanded beam from a laser diode was attached on the specimen. [30]

1.8   Polarized light and fringes

Generally, when light waves come directly from a source, the electric field of these light waves vibrates impartially in all directions at right angles to the wave normal. When light is polarized, this wave does not vibrate in all directions rather, it vibrates one or two specific directions. If light is plane polarized, the components of the vibrations in some plane are transmitted or reflected to the exclusion of the other components. Our eye is not able to detect such a selection of components. The intensity is reduced to one half in the most efficient polarizer. However, its rotation does not cause change in intensity. Again, if a second polarizing device operates on the polarized light, it will transmit or reflect only the cosine components in its plane of vibration. This second polarizer is called an analyzer. This is how the polarization light is created, and with the help of this polarizer light we can see the

fringes of the film while it is under load. [32]. There are three kinds of polarization in
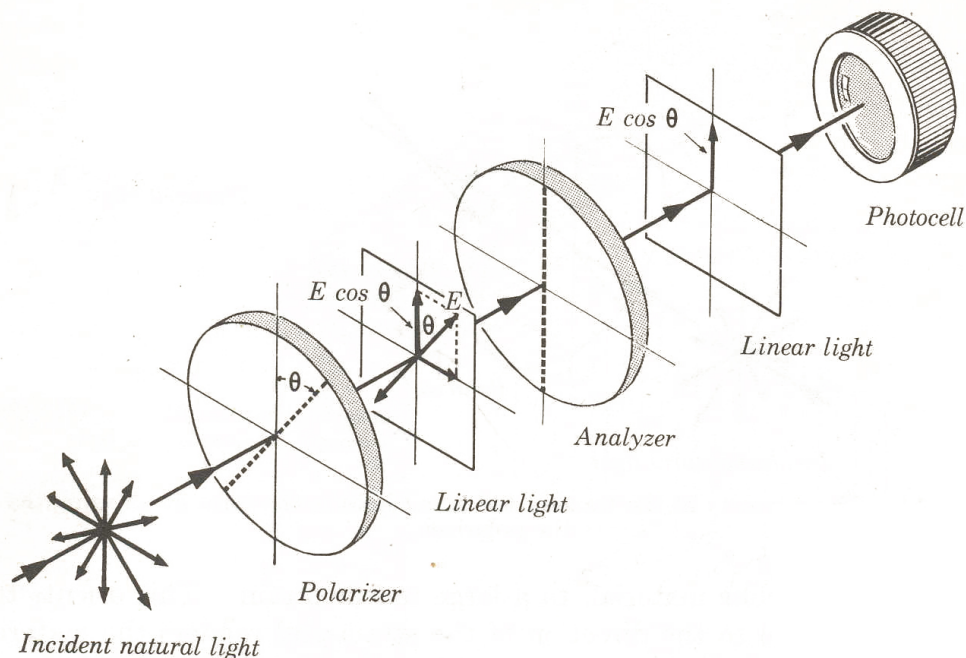
Figure 1.6: The polarizer and analyzer effect on natural light and polarized light [scanned from [5]].

photo elasticity. They are referred to as (a) linearly or plane polarized, (b) circularly polarized, and (c) elliptically polarized [33]. When all components of the light vector lie in a single plane, plane polarized or linearly polarized occurs. Circularly polarized light is obtained when the tip of the light vector moves in a path of circular helix as light propagates along the direction of from source to destination. Elliptically polarized light is found when the tip of the light vector describes an elliptical helix. Certain transparent materials like crystals and stressed plastics have the ability to resolve an impinging light vector into two orthogonal components. These materials are used to make the polarizer and analyzer [34]. When a photo-elastic specimen is placed in a polariscope and subjected to either state of stress and strain, we can observe isoclinic or isochromatic fringe patterns. If a pohotoelastic model machined from a sheet of a suitable polymer, it works as an optical element. Initially the model

11

or this specimen is stress-free and exhibits a constant index of refraction at all points. When load is applied on the model or specimen, a plane state of stress is developed which changes the optical properties of the model material. The refraction index of the points of the model or specimen are different from each other. This model become optically anisotropic and acts as a doubly refraction depend upon the magnitude of stress at each point in the plate. This is the reason we can see different fringes. It can be easily found, the mathematical relation between the stress and the change of refraction indexes. With the help of fringes, we can evaluate the change of refraction index, and by this we can get the relative stress on the plane. [33]. Even strain analysis can be performed using moir method [34]. In the article [34], two dimensional strain measurement is described by using the fringes.

CHAPTER 2

METHODOLOGY

2.1　Hardware

For this study, some instruments and tools are used. Those are: INSTRON, Laser extensometer, cameras, desktop computers, different kinds of lens, polarizer, and analyzer.

2.1.1　INSTRON

The INSTRON is used to apply load in a specimen. This is a universal testing machine. We can evaluate the mechanical properties of materials and components. For example, tension, compression, flexure, fatigue, impact, torsion and hardness tests are the tests we can do with an INSTRON. Though for this study we mainly used the tension test. The range of the load measured by INSTRON is wide. Using INSTRON a tension force is applied to film and the preform specimens. There is a load frame transducer in the INSTRON. The Load frame transducer will measure the load and generate an electronic AC signal accordingly. Using a data-logger, the digital tension load of the INSTRON is captured and sent to computer. This is how we can measure the load given by INSTRON into the computer. [35]

2.1.2 Laser Extensometer

A Laser Extensometer is also used to measure displacement optically. Two markers are placed on the specimen. There is a laser light line which should be place on those two markers. Using specific settings we can measure the offset displacement of the two markers. The Laser-extensometer sends the displacement to the data-logger again. The data-logger then sends this data to a desktop PC. [29]

2.1.3 Computer

A computer was used to run the developed software. Image processing and data analysis were performed with this same computer. The computer had Core 2 Duo processor with 2.13 GHz CPU speed. The model of CPUS was Intel(R) Core(TM)2 CPU 6400 series. It had 1 GB physical memory (RAM). The display adapter was Intel(R) Q965/Q963 Express Chipset Family.

2.1.4 Cameras

For capturing the image of the specimen during the application of load cameras are used. Two sets of camera with lens are used to take the images. Both of them are CCD dragonfly cameras. First one is Black and White camera with lens coming with this camera. This camera has 512x384 resolutions and the frame rate is up to 24 fps. Latter, color camera with several lens are used. This camera's resolution is up to 640x480 and it has up to 30 fps. While using color camera different kinds of lens is used to find the better option. 16mm lens, 32mm lens and 50mm lens is used to figure out which gives the best result. Using Labview's Measurement and Automation Explorer we can have good flexibility to maintain the camera setting. Exposure, brightness, frame rate, grain, gamma, hue, saturation, sharpness, all of these can be set to manual (relative), manual (absolute), auto. For different specimen
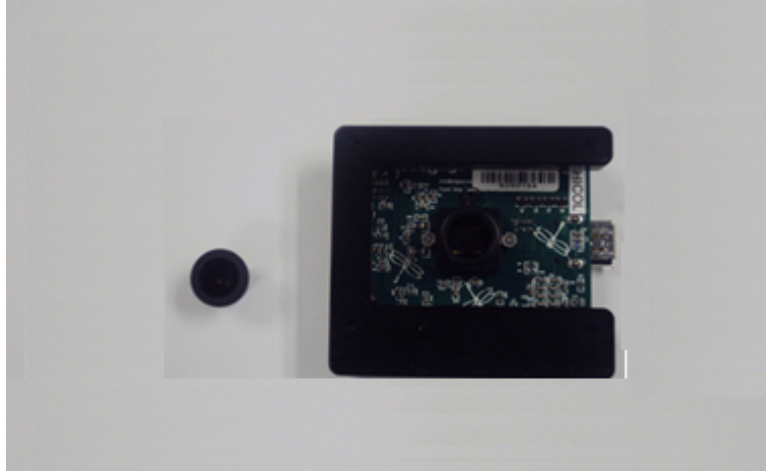
Figure 2.1: 512x384 resolution black and white camera ant its lens.
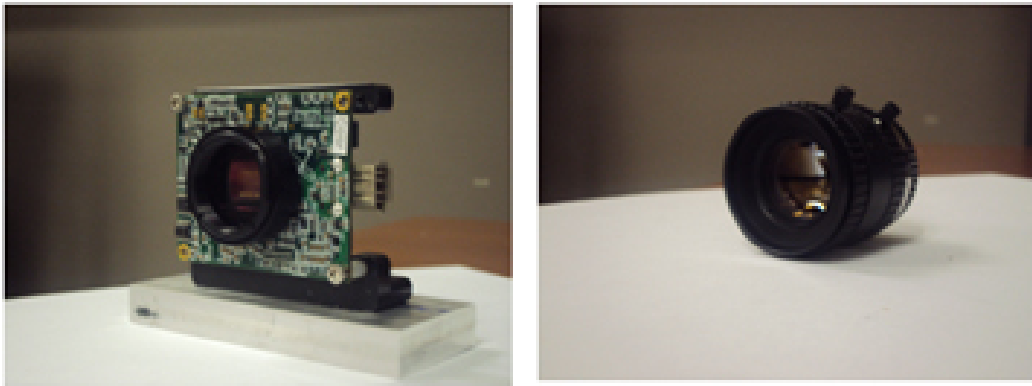
Figure 2.2: 640x480 resolution color camera and 16mm lens.

we can change these options to get the better results.

2.1.5   Polarizer / Analyzer

To see the fringe change of the film specimen and preform specimen, Polarizer and Analyzer is used. A polarizer light is generated with a polarizing film. The specimen is set between the polarizer light and analyzer. From a suitable distance, the camera is set so that it can capture the fringe change while the specimen is under tension load. As the light exerted by the light source of that polarizer was not good enough for this study, we used external light source with high intensity light.
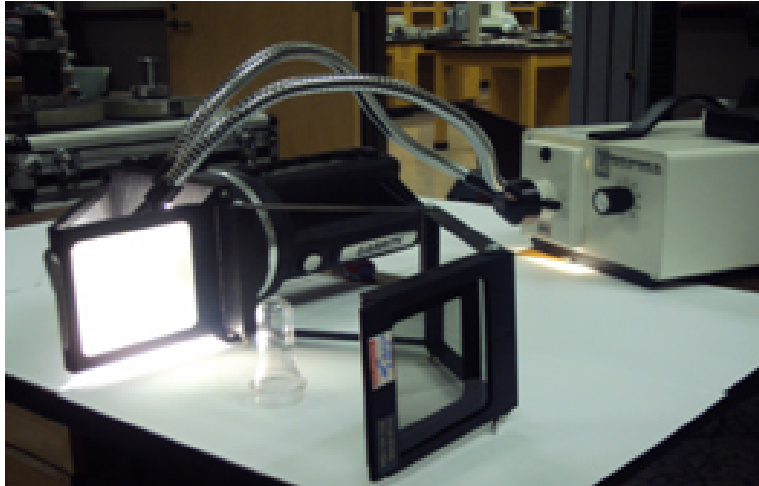
Figure 2.3: Polarizer / Analyzer setup.

2.2 Software

Labview is used mainly to interface the hardware. Labview will control the camera to capture the image. Labview is data-flow programming language. Graphical block diagrams are used to write the program in this software. The blocks are connected with wires which propagate the value of variables. When data reach any block, that block is then executed. Three panels are used in Labview: a block diagram, a front panel and a connector panel. Controls and indicator is used in the front panel where operator can input and see the output of the program. Using block diagram,
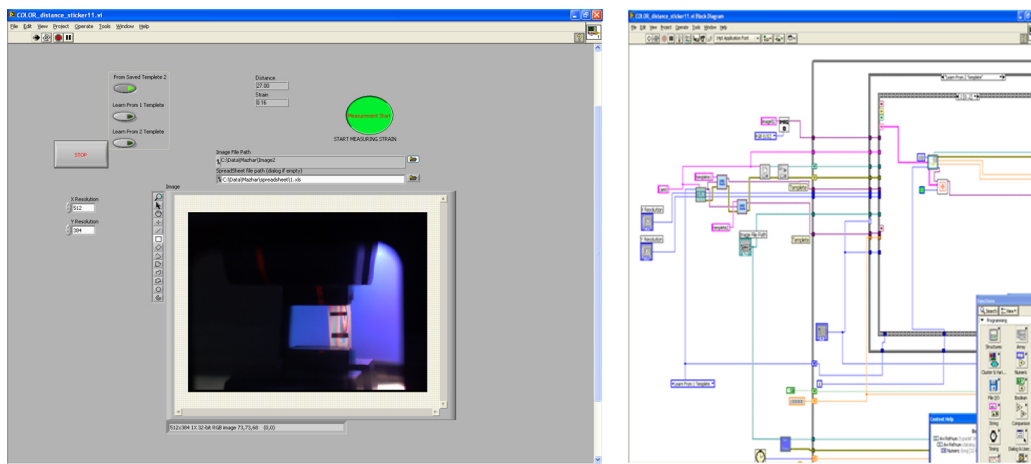
Figure 2.4: Labview software for this study.

16

the program is written. The algorithms and other special program are written in this block diagram panel. The main program is called VIs. Many sub-VIS. can be attached to main VIs files. In our study, we used Labview to get the input picture and as well as process the image. Implementing the algorithm in block diagram panel, the image is processed and the outputs are found. The flowchart of the algorithm is shown in Figure 2.5. Moreover, a user manual of this software was written so that anybody could learn the software easily.
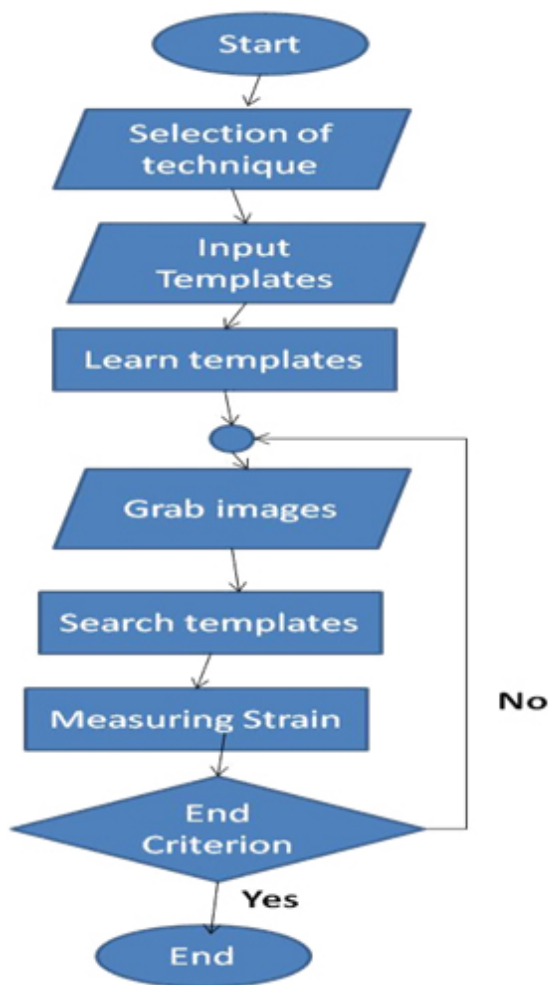
Figure 2.5: Flowchart of the solftware

2.3 Algorithm

The algorithm to track the marker attached on the specimen is implemented in Labview software. Mainly, 3 algorithms are used: pattern learning algorithm, pattern searching algorithm, measuring displacement algorithm. First, we need to set the template. To set the template, the program should learn the template first so that it can recognize it latter. In the pattern learning algorithm of our study, we use the shape setting to learn the template. After learning, the learned template data is stored after that this data is used to search. Next algorithm we used is pattern searching algorithm. In every frame the image is processed so that it can compare this frame with learned template data. The search technique is used left to right and then top to bottom. It also uses Bi-linear interpolation while capturing the data. For measuring the displacement between two markers, timers are uses to start the
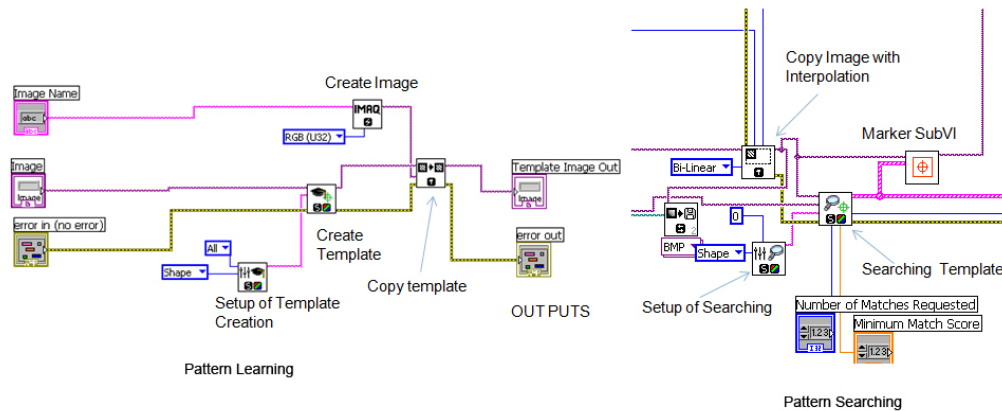
Figure 2.6: Block diagram of pattern learning and pattern searching.

measurement technique. The initial displacement is measured in pixels. Latter the algorithm is developed so that the strain is measured using current displacement and old saved initial displacement.

CHAPTER 3

STRAIN MEASUREMENT TECHNIQUE

In our study, we use different types of algorithms to track the markers. After that, the comparison is made. In one technique two markers are almost look the same and only one searching criteria of same markerwas used. However, two different searching techniques are used in the different approachs. Another approach was tested where the template was changed dynamically after every specific number of frames.

3.1 Template creation procedure

A template is created by allowing the operator to select the region from the current image captured by the camera. The operator will select a specific area which will be later used for searching. There are several ways in our study we used to learn the template. One way is that operator will select the template image and latter this image is saved into memory. Another approach is to use the previous saved template to learn. However, another approach is used to use more than one template to find the markers. After selecting the template, Labview will learn about the template and make a data which will then compare with the every frame latter. Using the shape/color/interpolation technique the template is learned by the Labview software. In our study, shape is used and Bi-linear interpolation is implemented to scan the image.
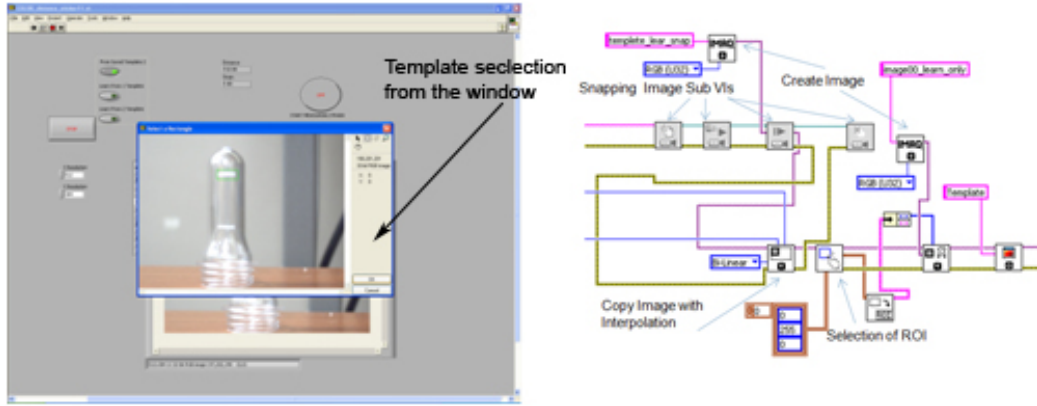
Figure 3.1: Template selection and its block diagram

3.2 Strain measurement by searching same template twice.

3.2.1 Technique

In this procedure, almost two identical markers are attached to the specimen with a small distance separation (usually 15–25 mm). The user will select only one template to let the software learn about that template. While searching procedure is performed, the same type of template is searched in every frame twice in the whole image. In this technique, the software will find two searching areas. Then displacement is measured by computing the distance between the centers of those two center areas.
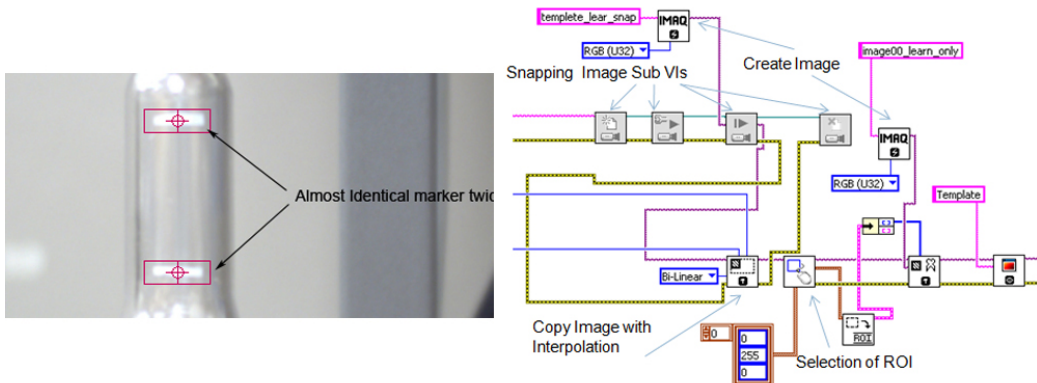
Figure 3.2: Strain measurement by searching identical marker twice and its block diagram.

3.2.2 Limitation

The two markers should be the same in shape and in orientation. It is hard to set both of the markers in same orientation on the specimen. While the specimen started to deform or under load, one of the template loses its orientation, and that time this technique could not find the 2 markers separately. Again, there is a change of orientation and shape accuracy in the program. But if we allow too much orientation and shape change, sometimes the marker is found in the environment where the marker is not there but only noise.

3.3 Strain measurement by searching two different templates

3.3.1 Technique

Two different types of markers are attached on the specimen in this procedure. Two sets of template are learned by the software. For every frame, two search techniques are performed. One is to find first marker and another is to find second marker. After processing the frame, two different templates are tracked. The displacement is measured by calculating the distance of the centers of these two markers found in each frame. After that, strain is measured by calculation.

Figure 3.3: Strain measurement by searching two different templates.

3.3.2   Limitation

If two markers are almost similar, while searching, the program might find same marker twice. Again, while the specimen is under load or in state of deformed, it even cannot find any marker at all. Basically, when the specimen is in plastic deformation, it loses track of the marker as the marker changes or most often, it tracks the same areas twice.

3.4   Strain measurement by searching two different templates in two separate regions

3.4.1   Technique

This procedure is like the last procedure. But In this procedure, two templates are searched in different areas. The region of interest of template 1 differs from the region of interest of template 2. As the searching areas are different, there is not a possibility to find the same marker twice. After searching, the displacement is measured in same technique stated above by calculating the distance between the centers of two different found areas.

Figure 3.4: Strain measurement by searching two different templates in two separate regions.

3.4.2 Limitation

In this technique the program can track the markers long way, but when the specimen is under the significant plastic deformation, the markers become so disoriented that the program could not track them at all.

3.5 Strain measurement by changing the template dynamically

3.5.1 Technique

Like previous stated technique, in this technique the template is learned at the beginning. But unlike other technique, after specific time, the new template is learned. The last areas found by searching technique are learned to make new templates so that these new templates are used for latter search. This is how after every specific time or frames, templates are changing. In this technique, the region of interest is also set for different markers. In this procedure, the program can track the markers till the end of the experiment.

Figure 3.5: Strain measurement by changing the template dynamically.

3.5.2 Limitation

The process time is slower than others. As the template is changing time to time, the center of the template changes every time due to orientation of the templates. So there is possibility to have error in strain measurement.
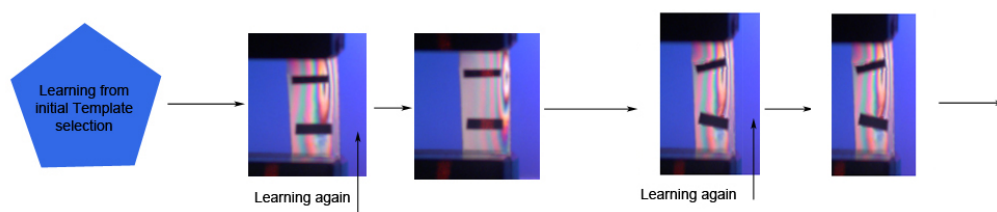
CHAPTER 4

OBSERVING FRINGE UNDER POLARIZED LIGHT

4.1   Instrumental setup

The specimen of film and preform are observed under polarized light. In the polarizer instrument, generally there is polarizer and analyzer screen. The specimen should be situated between polarizer and analyzer. However, in our setup only the analyzer is used. The sample was between the diffuser and the analyzer. At the beginning the light found from that machine is used to observe the fringe. Latter,the external high intensity light source is used as shown in the figure. While the INSTRON is used to perform tensile load on the specimen the polarizer instrument is set such a way that the camera can have the view of the specimen through the analyzer. The full experiment is done under this setup. So, the fringe changes and movements are measured throughout the whole loading time.
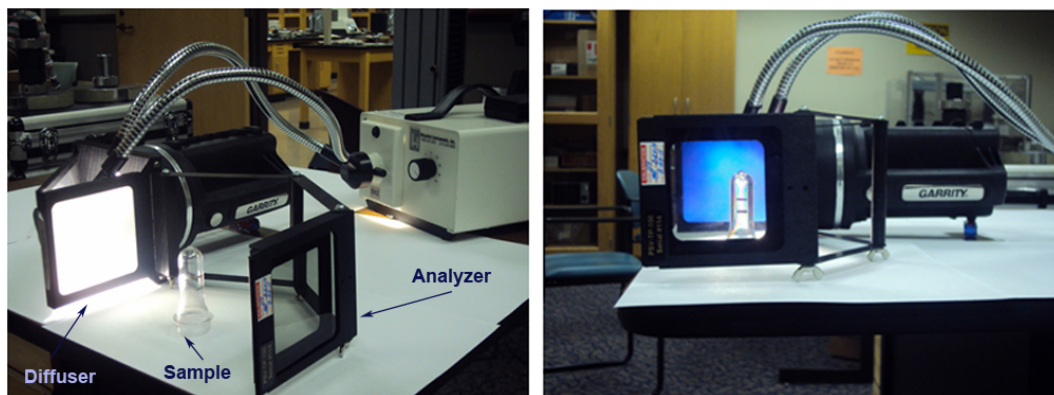

Figure 4.1: Instrumental setup for polarized light.

4.2   Fringes with low resolution Black & White Camera with its lens

When the black and white camera with resolution 512x384 is used, the fringe is found as shown in the figure. In this way, the fringes could not be captured well. The complexion is very ambiguous. That was very hard to track the fringe movement. It is also hard to decide about any material properties by seeing this images.
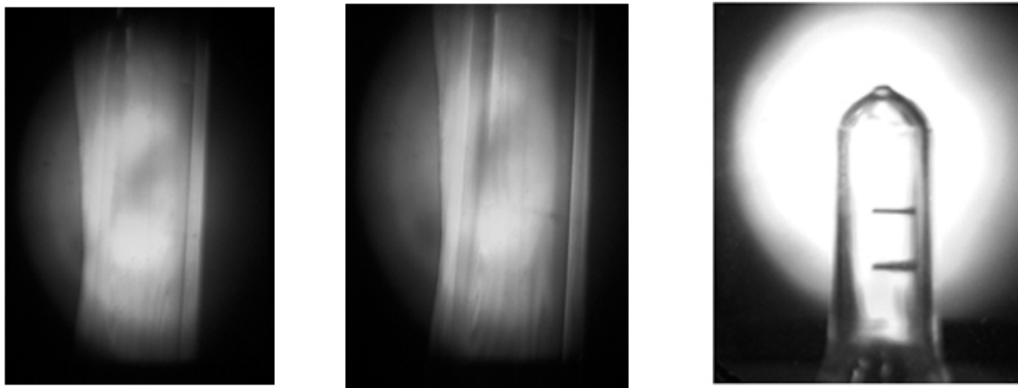
Figure 4.2: Fringes captured by low resolution Black & White Camera with its lens.

4.3   Fringes with high resolution color camera with 16mm lens

When the color camera with 16mm lens is used fringes are found just like figure below. This time fringes are seen well comparing previous scenario. While the specimen is under the load, the fringe movement can be figure out more accurately than before. Fringes can be tracked during the experiment. The 16mm lens with good aperture setting helped to capture the fringes like this.

4.4   Fringes captured using high intensity light sources

The light of the polarizer instrument is replaced by external light. This time lights are more incandescent. Here the fringes are found like the figures. Here, we can see that fringes are found in more detail. The movement of the fringe can be observed more
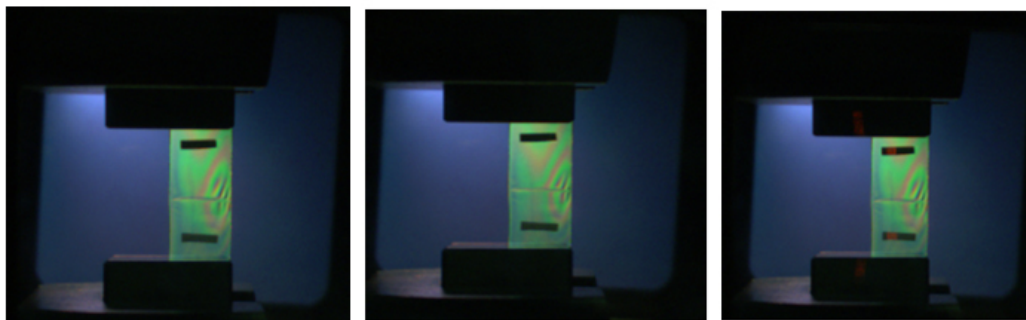
Figure 4.3: Fringes captured by low resolution Black & White Camera with its lens.

accurately than before. Even the degree of the fringes can be measured by capturing the images.

Figure 4.4: Fringes captured by low resolution Black & White Camera with its lens.

4.5   Observation of fringe during experiment (sample 1)

During one experiment the fringes are found like the figures. The chronological order of the fringes can be found if we see the diagram left to right then top to bottom. This is for a specific sample when external light is not used.
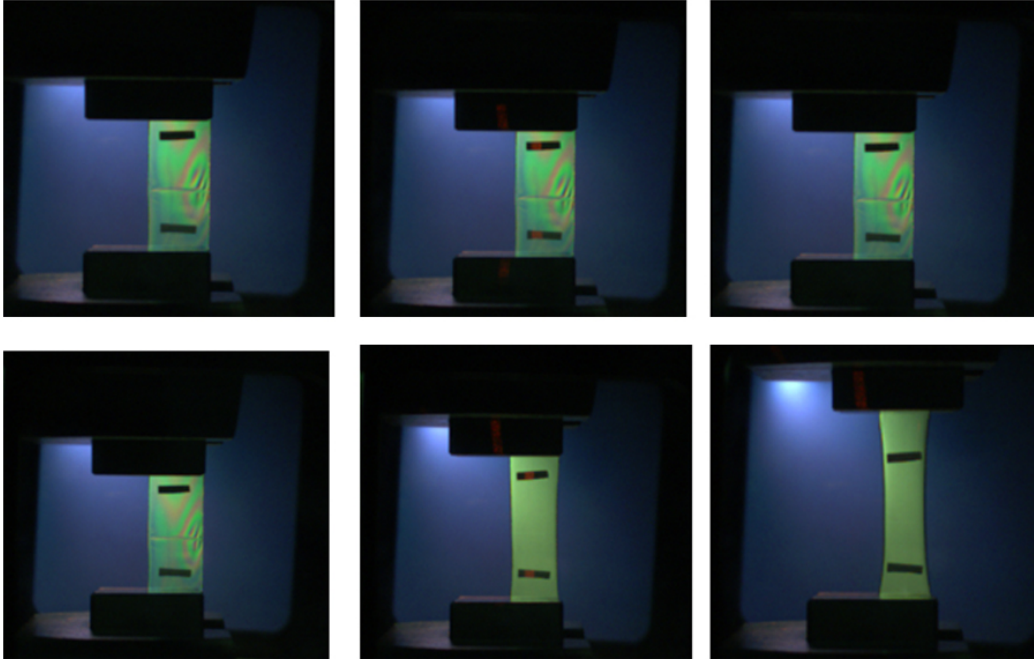
Figure 4.5: Observation of fringe during experiment (sample 1).

4.6 Observation of fringe during experiment with external light source (sample 2) .

During one experiment the fringes are found like the figures. The chronological order of the fringes can be found if we see the diagram left to right then top to bottom. This is for a specific sample when external light is used. We can see that the fringes can be seen more accurately here.
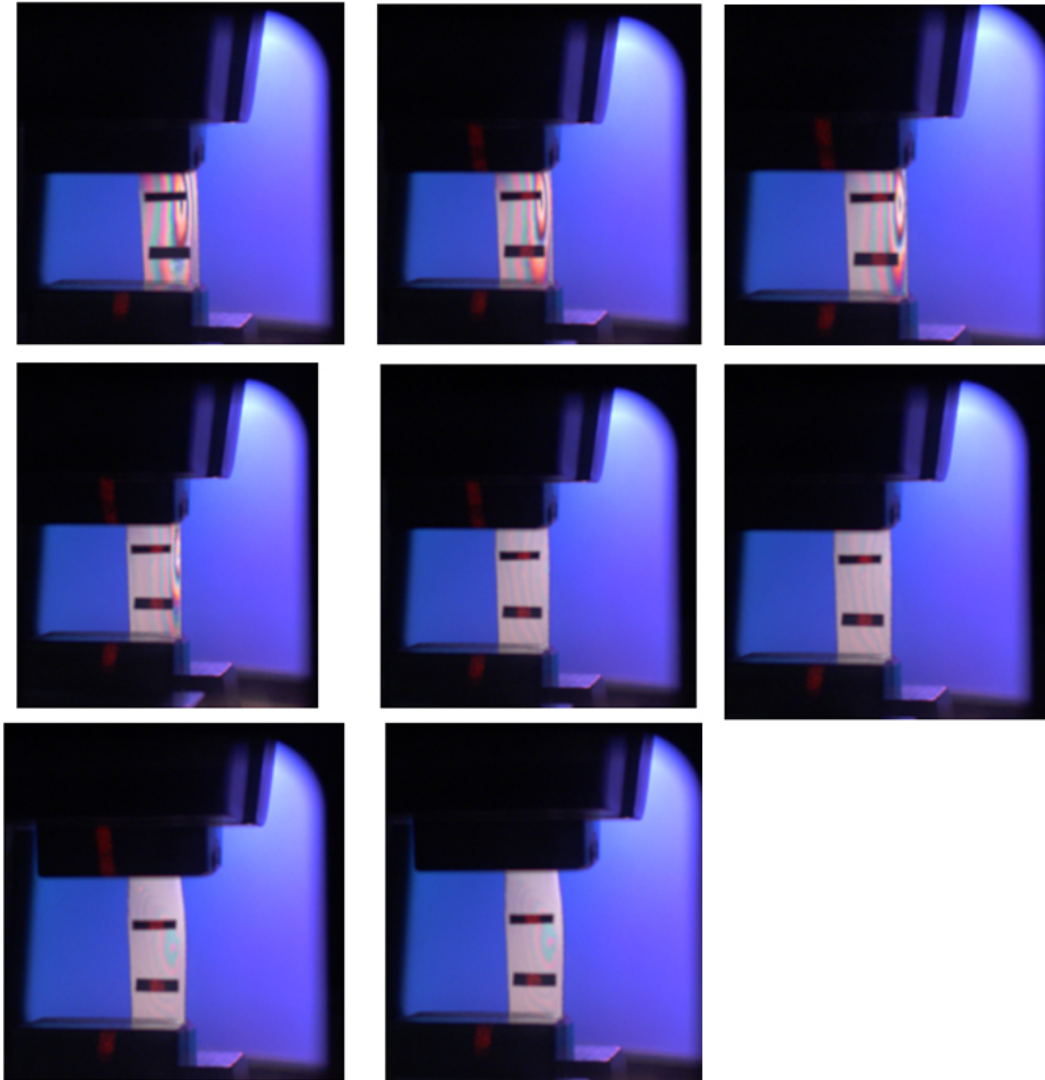
Figure 4.6: Observation of fringe during experiment with incandescent external light source (sample 2).

CHAPTER 5

RESULT AND DISCUSSIONS

5.1 Comparison in different technique of strain measurement
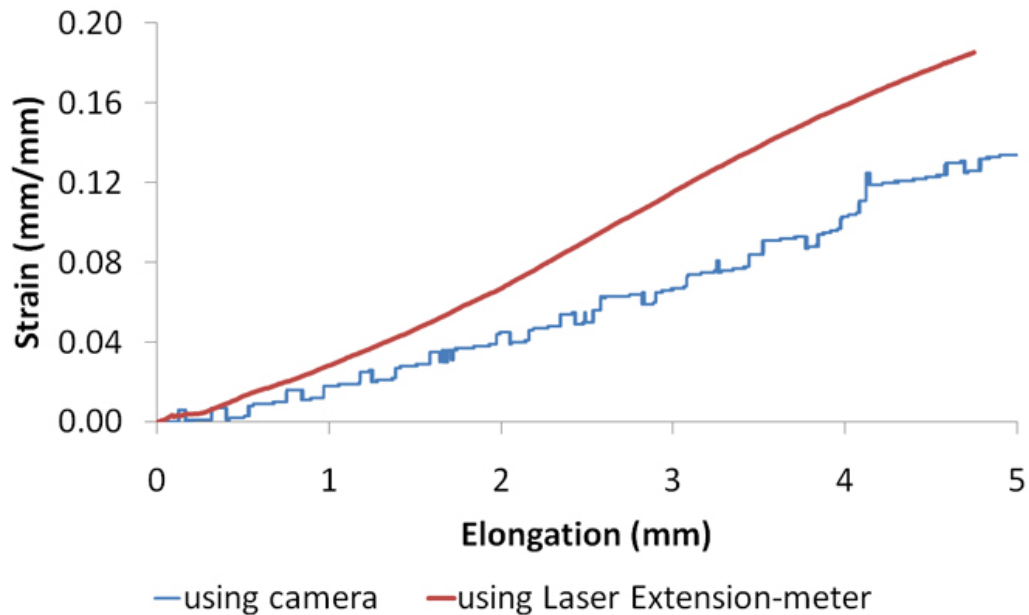
Figure 5.1: Comparison for Strain vs Cross-head elongation by searching same template twice.

Figure 5.1 shows the comparison for strain vs cross-head elongation curves by using camera with laser extensometer when same template was searched twice. It is obvious graph that from the very beginning the two curves are deviating from each other. More the strain increases the deviation between these two curves becomes prominent. The deviation of strain using this technique is greater than 15% compare to that of laser extensometer. The slope of the trend line of the curve for using Laser

Extensometer is 0.042 while the slope of the trend line of the curve for using camera is 0.029. The value of these slope reflected the difference between these two curves. So, the slopes of the trend line of the curves differ 31% from each other. Most of the case, it is very hard to make identical markers. So, one marker is learned and using this data another marker is searched. By allowing the tolerance, two markers have been tracked. This might be the reason for the deviation of the curve.

On the other hand, Figure 5.2 shows the comparison of strain vs cross head elongation curves by using camera with laser extensometer when two different templates and two separate regions are selected. In Figure 5.2, both graphs follow almost same path. The deviation of strain using this technique is less than 5% compare to laser extensometer. It means, using this technique of searching two different templates and two separate regions will increase the strain measurement accuracy. Moreover, the slope of the trend line of the curve for using Laser Extensometer is 0.0285 and the slope of the trend line of the curve for using camera is 0.0282. So, the slopes of the trend line of the curves differ 1% from each other. This techniques provide more consistent result compare to other techniques.

While templates are being changed dynamically, Figure 5.3 is observed. In the figure, we can see that the deviation of the curved measured by camera and that of laser extensometer is observed often.Moreover, the slope of the trend line of the curve for using Laser Extensometer is 0.0177 and the slope of the trend line of the curve for using camera is 0.0183. So, the slopes of the trend line of the curves differ 3.2% from each other. The strain measured by camera is not consistent compare to other techniques. When the templates are searched and changed after specific times, the centers of the templates with respect to the shape of templates deviate every time. This is why Figure 5.3 shows inconsistent measurement of strain by
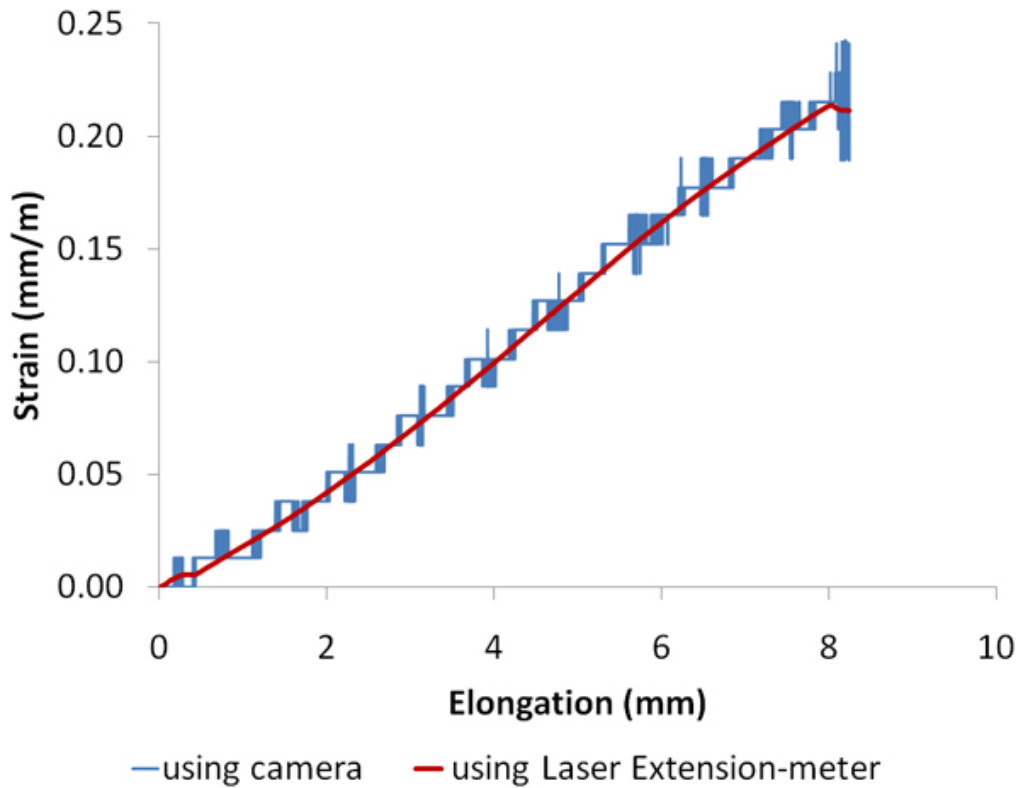
Figure 5.2: Comparison for Strain vs elongation by searching two different templates in two separate regions.

camera.The deviation of strain is greater than 10% compare to laser extensometer.

So, we can conclude that the strain measuring technique by searching two different templates in two separate regions provides 15% to 25% more accuracy comparing other techniques in this study. The accuracy also depends on the markers' sizes and shapes. Searching by two different templates provides 10% better tracking ability. If the difference between the shapes of two templates is at least 30%, the tracking ability becomes 10% to 15% better. Using a camera, it is easy to find the 2D field of strain while a laser extensometer can only measure the distance between two points on a line. Compare to laser extensometer, video extemsometry using a camera is cost effective. The price of a Laser Extensometer is very high (20x) compared to a CCD camera. However, some commercial video extensometry systems cost 2x the
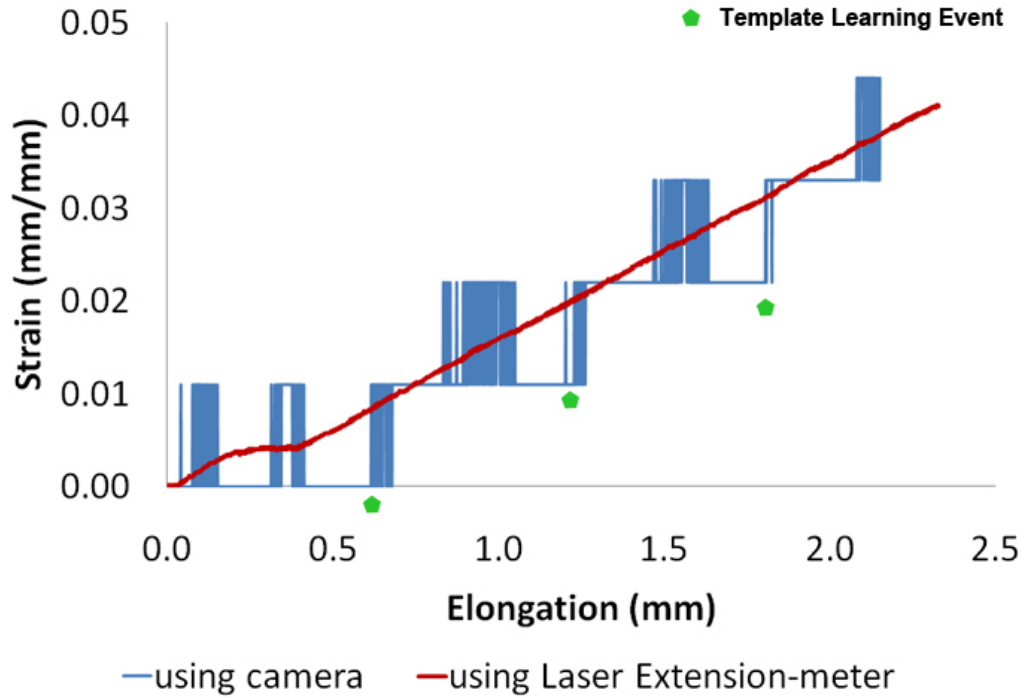
Figure 5.3: Comparison for Strain vs elongation by searching two different dynamically changed templates in two separate regions.

laser system. Figure 5.4 shows the comparison of strain measured by the camera with INSTRON when two different templates are searched in two separate regions. The percentages of error are also reflected in Figure 5.5. It can be seen that when the initial length increases, the percentage of error decreases. We can also observe that the percentages of error for the 640x480 pixel cameras are generally less that 5%. If the resolution of the camera increases, the error might be even less, however the difference between methods tested here would still be relevant.

5.2 Observation of fringes under polarized lights

It is observed that the fringes change due to increase of stress. The fringe becomes thinner while more stress is applied which means that the stress upon the whole area is also increasing. By using fringes , the stress distribution through the 2D
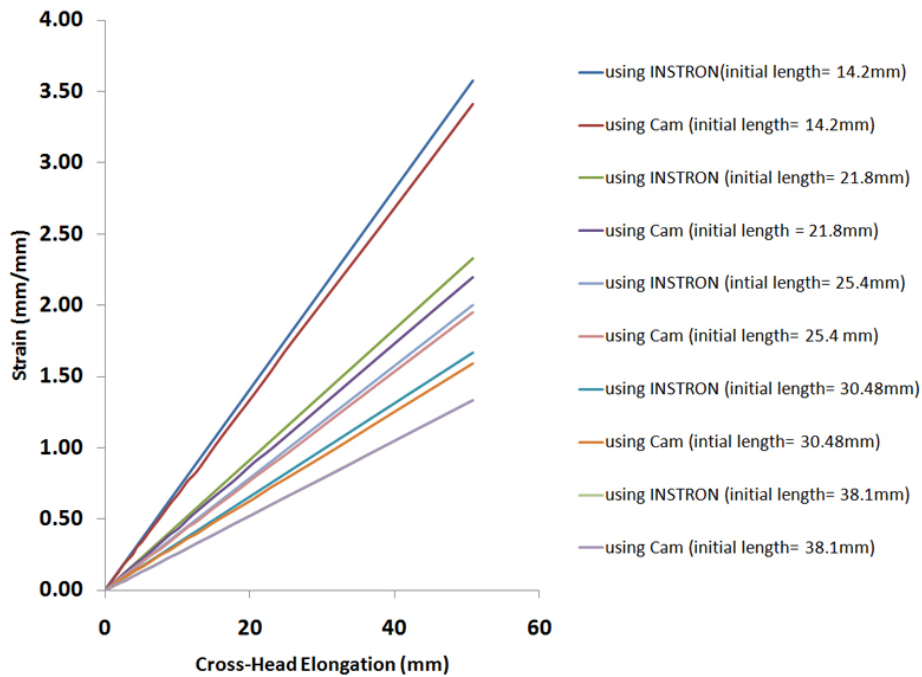
Figure 5.4: Comparison of strain measured by the cam and INSTRON by varying initial length.

space can be measured with accurate calculation. This is why the observation of fringes contribute an important role in the experimental mechanics. When the stress increases the refractive index of PET changes which will change the fringes.

In Figure 5.7(a), Figure 5.7(b), Figure 5.8(a) and Figure 5.8(b), Stress vs Strain Curves are shown. The points when the fringes disappear for every curves are also shown by star marks. All these curves are shown in Figure 5.6.

Generally, there is some permanent deformation in the PET like crazing that caused scattering so that visible light does not penetrate well. Then the optical polarization is broken up and the fringes disappear. It is interesting that the fringes disappear at similar stresses on each of the graphs and that is near at yield point. It is also clear that after plastic deformation some non-linearity is observed in the change of the fringe spacing. It is also observed that fringes will change more during the linear part of the curve and less in the plastic part of the curve. In Figure 5.6,
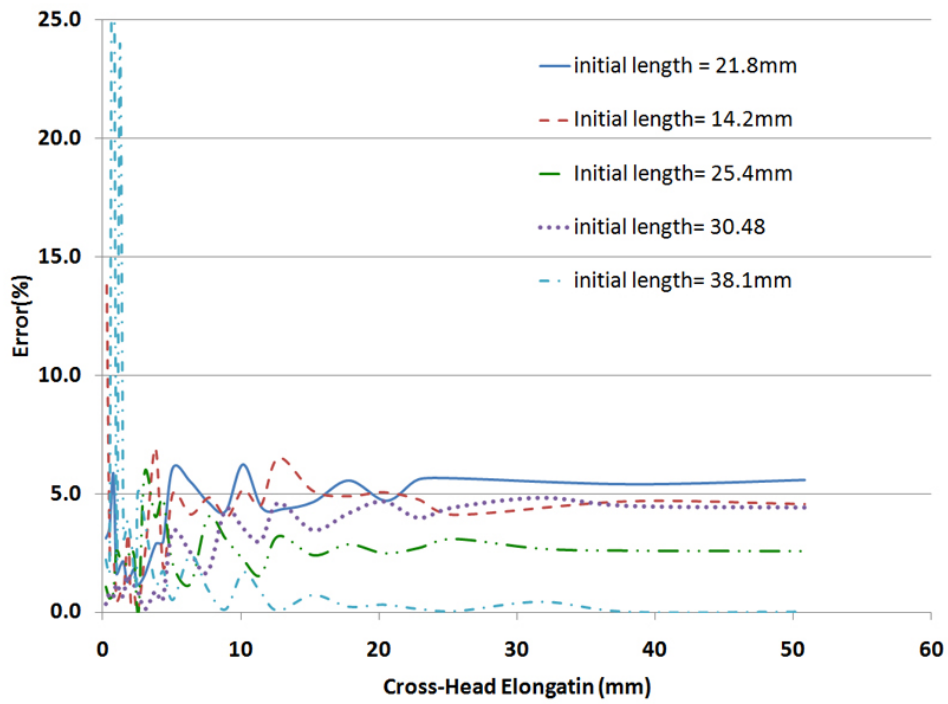
Figure 5.5: Error percentage of strain measured by the cam and INSTRON by varying initial length.

the slopes of the curves are slightly different from each other. This might be due to the change of the pressure difference of the gripper which hold the specimen during the experiments.
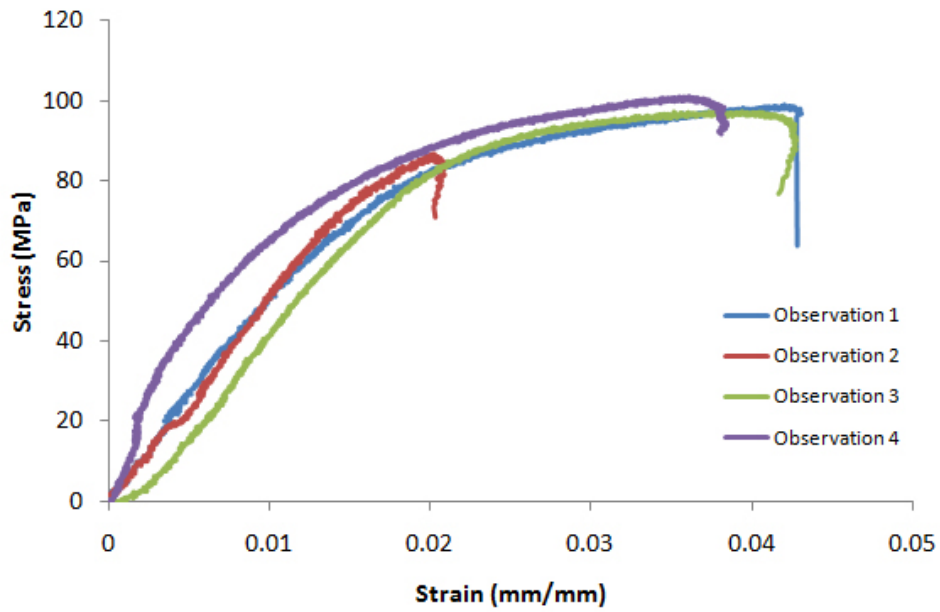
Figure 5.6: Stress vs Strain Curves.
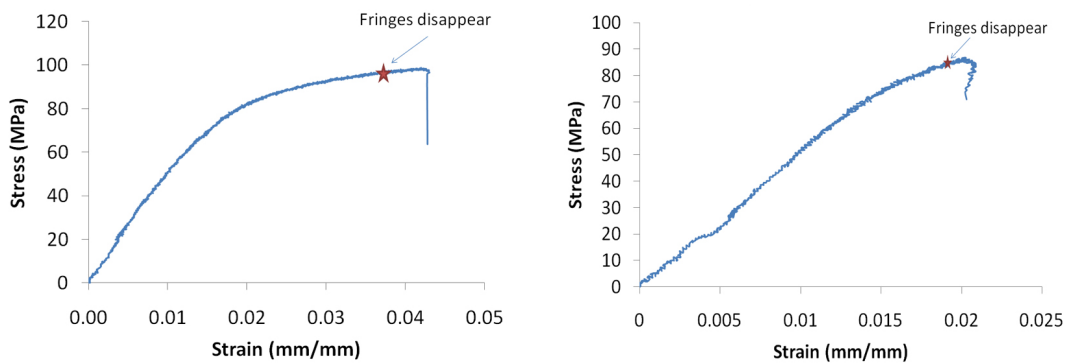
(a) Stress-Strain Curve (sample 1).

(b) Stress-Strain Curve (sample 2).

Figure 5.7: Stress-Strain Curve showing the point when fringes disappear.
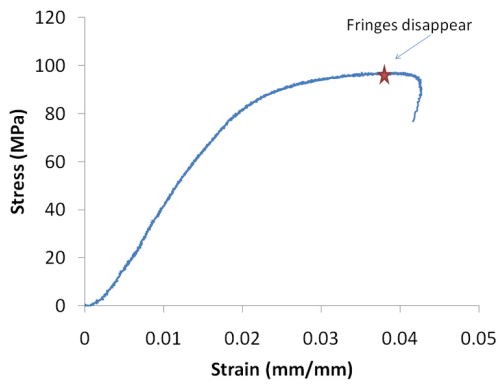
(a) Stress-Strain Curve (sample 3).   (b) Stress-Strain Curve (sample 4).
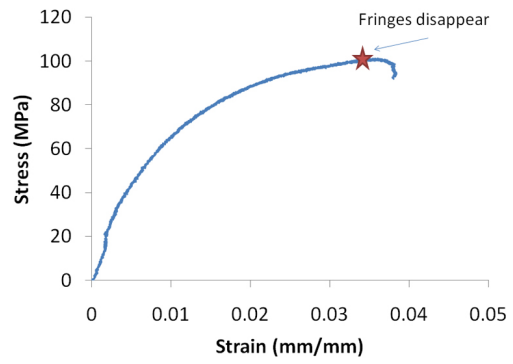
Figure 5.8: Stress-Strain Curve showing the point when fringes disappear.

CHAPTER 6

CONCLUSIONS

- LabVIEW code developed here is successful at performing video exntesometry.

- The technique where strain was measured using two different templates in two separate regions had 15% to 25% more accuracy comparing other techniques in this study. Here, changing the template dynamically did not give good results.

- If two different templates were used to measure the distance between them, the accuracy of tracking the marker became 10% better.

- If the difference between the shapes of two templates is at least 30%, the tracking ability becomes 10% to 15% better when searching two different templates are used.

- The accuracy of the slope of trend line of proposed technique was 99% using a camera with 640x480 resolutions compared to Laser Extensometer.

- The error of measuring strains was generally less than 5% when a camera with 640x480 resolutions was used. Higher resolution cameras have the ability to measure strain more accurately, but the difference between methods tested here would still be relevant.

- Compared to the Laser Extensometer, video extensometry using a camera is cost effective. The price of a Laser Extensometer is very high (20x) compared to a CCD camera. However some commercial video extensometry systems cost 2x the laser system.

- A laser Extensometer can only measure the distance between two points on a line. Using a camera, it is easy to find the 2D field of the strain.

- By using a camera, the strain can be measured on-line. However, by capturing images with a camera, strain can be measured off-line also. Cracking, fringes, or other behavior can also be studied.

- A camera provides a good opportunity to observe the fringes when the PET is under polarized light.

- It is observed that before the yield point the fringes disappear. The fringes disappear due to permanent deformation in the PET. So, by observing the fringes, we may find when the permanent deformation occurs.

CHAPTER 7

FUTURE WORK

- The developed software can be extended to sub-pixel level.

- Image Calibration can be included in the developed software.

- Using zoom lens with a higher resolution camera, the accuracy of the proposed technique can be verified more accurately.

- The developed software can be extended to make it suitable for determining the Poissons Ratio.

- The Software can be updated such a way that can measure the fringe width.

- Validation of relationship between the fringes and deformation is another good scope of this study.

BIBLIOGRAPHY

[1] H. W. S. Michael A. Sutton, Jean-Jos Orteu, *Image Correlation for Shape and Deformation Measurements: Basic Concepts, Theory and Applications*, pp. 17–21. Springer, 1st ed., 2009.

[2] H. W. S. Michael A. Sutton, Jean-Jos Orteu, *Image Correlation for Shape and Deformation Measurements: Basic Concepts, Theory and Applications*, pp. 70–78. Springer, 1st ed., 2009.

[3] H. W. S. Michael A. Sutton, Jean-Jos Orteu, *Image Correlation for Shape and Deformation Measurements: Basic Concepts, Theory and Applications*, pp. 83–85. Springer, 1st ed., 2009.

[4] F. M. P. C. Mark D. Bethea, James A. Lock, "Three-dimensional camera calibration technique for stereo imaging velocimetry experiments," *OPTICAL ENGINEERING*, vol. 36, no. 12, pp. 3445–3454, 1997.

[5] F. W. Sears, *Principles of physics series: Optics*, pp. 167–202. Addison Wesley Press, Inc, 3rd ed., 1949.

[6] L. J. B. E. G. W.P. Smutz, M. Drexler and K. An, "Accuracy of a video strain measurement system.," *J. Biomechanics*, vol. 29, no. 6, pp. 813–817, 1996.

[7] E. Hecht and A. Zajac., *Optics.* Addison-Wesley, Reading, MA,, 1st edition ed., 1974.

[8] L. C. Weiwei Feng, "Relative orientation accuracy analysis of the polarizers in a polarization ccd camera," *Optik - International Journal for Light and Electron Optics*, vol. 121, pp. 1401–1404, 2010.

[9] H. W. S. Michael A. Sutton, Jean-Jos Orteu, *Image Correlation for Shape and Deformation Measurements: Basic Concepts, Theory and Applications*, pp. 27–45. Springer, 1st ed., 2009.

[10] H. Lu and P. D. Cary, "Deformation measurements by digital image correlation: Implementation of a second-order displacement gradient," *Experimental Mechanics*, vol. 40, no. 4, pp. 393–400, 2000.

[11] S. Periasamy, "Digital image correlation for deformation measurements near a crack," *Thesis*, 2002.

[12] W. Peters and W. Ranson, "Digital imaging techniques in experimental stress analysis.," *Opt. Eng.*, vol. 21, pp. 427–432, 1982.

[13] W. W.-P. W. R. W. Sutton, M.A. and S. McNeil, "Determination of displacements using an improved digital image correlation method," *Image Vision Computing*, vol. 1, no. 3, pp. 133–139, 1983.

[14] C. M.-P. W. C. Y. Sutton, M.A. and S. McNeil, "Application of an optimized digital image correlation method to planar deformation analysis," *Image Vision Computing*, vol. 4, no. 3, pp. 143–150, 1986.

[15] M. S. S. M. Bruck, H.A. and W. Peters, "Digital image correlation using newton-raphson method of partial differential correction," *EXPERIMENTAL MECHANICS*, vol. 29, pp. 26–267, 1989.

[16] C. Y. s. M. Luo, P.F. and W. Peters, "Accurate measurement of three-dimensional deformations in deformable and rigid bodies using computer vision," *EXPERIMENTAL MECHANICS*, vol. 33, pp. 123–132, 1993.

[17] G. Vendroux and W. Knauss, "Submicron deformation field measurements: Part 1, developing a digital scanning tunneling microscope," *EXPERIMENTAL MECHANICS*, vol. 38, pp. 18–23, 1998.

[18] G. Vendroux and W. Knauss, "Submicron deformation field measurements: Part2: Improved digital image correlation," *EXPERIMENTAL MECHANICS*, vol. 38, pp. 86–91, 1998.

[19] G. Vendroux and W. Knauss, "Submicron deformation field measurements: Part 3. demonstration of deformation determinations," *EXPERIMENTAL MECHANICS*, vol. 38, pp. 154–60, 1998.

[20] G. Vendroux, "Correlation: A digital image correlation program for displacement and displacement gradient measurements," *GALCIT Report No. SM90-19*, 1990.

[21] J. L. J.S. Lyons and M. Sutton, "High-temperature deformation measurement using digital-image correlation," *EXPERIMENTAL MECHANICS*, vol. 36, no. 1, pp. 64–70, 1996.

[22] K. K. Satoru Yoneyama, Akikazu Kitagawa and H. Kikuta, "In-plane displacement measurement using digital image correlation with lens distortion correction," *JSME International Journal*, vol. 49, no. 3, pp. 458–467, 2006.

[23] G. V. H. Lu and W. G. Knauss, "Surface deformation measurements of a cylindrical specimen by digital image correlation," *EXPERIMENTAL MECHANICS*, vol. 37, no. 4, pp. 433–439, 1997.

[24] H. X. Bing Pan, Kemao Qian and A. Asundi, "Two-dimensional digital image correlation for in-plane displacement and strain measurement: a review," *Measurement Science & Technology*, vol. 20, no. 6, 2009.

[25] V. T. H. S. J. O. M.A. Sutton, J.H. Yan, "The effect of out-of-plane motion on 2d and 3d digital image correlation measurements," *OPTICS AND LASERS IN ENGINEERING*, vol. 46, no. 11, pp. 746–757, 2008.

[26] K. K. D. Coimbra, R. Greenwood, "Tensile testing of ceramic fibres by video extensometry," *Journal of Materials Science*, vol. 35, no. 13, pp. 3341–3345, 2000.

[27] V. G. Ph Franois and R. Sgula, "Local-scale analysis of the longitudinal strains in strongly necking materials by means of video-controlled extensometry," *JOURNAL OF PHYSICS-CONDENSED MATTER*, vol. 6, no. 42, pp. 8959–8968, 1994.

[28] A. B. M. Wolverton and G. Kannarpady, "Efficient, flexible, noncontact deformation measurements using video multi-extensometry," *EXPERIMENTAL TECHNIQUES*, vol. 33, no. 2, pp. 24–33, 2009.

[29] E. I. Research, "Laser extensometers," Dec 2010. `http://www.e-i-r.com/`.

[30] P. R. Laraba-Abbes F, lenny P, "Determination of rivlin parameters for carbon black filled nr using laser speckle extensometer," *KAUTSCHUK GUMMI KUNSTSTOFFE*, vol. 52, pp. 209–214, 1999.

[31] I. T. Y. M. Yamaguchi I, Kobayashi K, "Noncontacting extensometer using digital speckle correlation," *MATERIALS EVALUATION*, vol. 64, pp. 724–730, 2006.

[32] J. Valasek, *Introduction to theoretical and experimental optics*, pp. 196–241. John Wiley and Sons Inc, 1st ed., 1949.

[33] J. W. D. Felix Zandman, Salomon Render, *Photoelastic Coatings*, pp. 1–30. Science Press, 1st ed., 1977.

[34] P. S. Theocaris, *Moir Fringes in Strain Analysis*, pp. 147–177. Pergamon press, 1st ed., 1969.

[35] INSTRON, "Instron, the difference is measurable," Dec 2010. `http://www.instron.us/wa/home/`.

[36] J.-H. P. Jong-Eun Ha and D.-J. Kang, "New strain measurement method at axial tensile test of thin films through direct imaging," *JOURNAL OF PHYSICS D-APPLIED PHYSICS*, vol. 41, no. 17, pp. 3341–3345, 2008.

[37] U. T. Systems, "Optical extensometer - features, performance and applications of laser extensometer."," 2010.

[38] M.-S. S. S.-J. L. S.-C. Y. K.-S. L. J.-E. H. S.-H. c. Jun-Hyup Park, Dong-Joong Kang, "Easy calibration method of vision system for in-situ measurement of strain of thin films," *TRANSACTIONS OF NONFERROUS METALS SOCIETY OF CHINA*, vol. 19, pp. S243–S249, 2009.

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The purpose of this study was to develop a computer assisted video extensometer to measure strain, primarily for transparent polymers such as PET. Two markers, which were attached to the specimen, were tracked by the video system. Different techniques were proposed to track these markers implemented in NI LabVIEW software. The accuracy of video extensometry depends on the template creation procedure, shapes of the markers, algorithm and camera resolution. Comparison of the different techniques was discussed in this study. The technique with two different templates in two separate regions provided 15% to 25% more accuracy compared to other techniques discussed in this study. The accuracy of the proposed video extensometer was also shown. The accuracy of the proposed technique was 99% using a camera with 640x480 resolution. Moreover, comparison with a Laser Extensometer and the proposed video extensometer were also shown. Fringes were also captured when the PET was in tensile stress and under polarized light. The pattern-changes of these fringes were recorded by NI LabVIEW software. The disappearance of fringes before the yield point in tension indicated permanent plastic deformation in PET.

ADVISOR'S APPROVAL: _____