UNIVERSITI TEKNIKAL MALAYSIA MELAKA

DIGITAL IMAGE CORRELATION ON ADHESIVE USED IN AUTOMOTIVE INDUSTRY

This report is submitted in accordance with the requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor of Mechanical Engineering Technology (Maintenance Technology) with Honours.

By

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This report is submitted to the Faculty of Mechanical and Manufacturing Engineering Technology of Universiti Teknikal Malaysia Melaka (UTeM) as a partial fulfilment of the requirements for the degree of Bachelor of Mechanical Engineering Technology (Maintenance Technology) with Honours. The member of the supervisory is as follow:

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ABSTRAK

Penyelidikan ini membuat kajian ke atas keadaan dan prilaku mekamik bahan pelekat yang digunakan dalam industry automotif dengan mengaplikasikan Digital Image Correlation (DIC) yang mengunakan perisian sumber terbuka Ncorr yang dibina di platform matlab. DIC adalah kaedah optikal bukan sentuhan yang digunakan dan berkembang di hamper kesemua industry dan diseluruh dunia. DIC mengunakan gambar digital yang diukur untuk mengukur perubahan bidang penuh dari sesuatu bahan. Prinsip dasar analisis adalah untuk membandingkan gambar rujukan (sebelum perubahan) dan gambar semasa (semasa atau selepas perubahan) dan mampu menganalisis kumpulan gambar serentak. Kajian ini mengunakan Casio EXILIM EX-ZR 1200 yang merupakan kamera digital untuk mengukur semua gambar perubahan bahan kajian selama pengujian dengan bervariasi berdasarkan tingkatan pengurkuran dan daya yang dikenakan kepada bahan kajian. Dalam penyelidikan ini, bahan pelekatnya adalah sikaflex (poliuretan) dengan kadar kelajuan pengukuran yang berbeza. Penyelidikan ini juga untuk membuktikan bahawa DIC adalah kaedah yang tidak memerlukan kos yang tinggi dengan mengaplikasikan DIC untuk menghasilkan pengukuran anjakan yang bagus pada bahan kajian. Penyelidikan ini juga menyiasat kesan perubahan pada pengukuran anjakan dengan memanipulasikan siz subset. Tambahan lagi, kekangan dengan keupayaan resolusi dan keljuan kamera yang rendah adalah punca penghasilan keputusan kurang tepat. Mesin tegangan yang digunkana adalah Shimadzu Precision Universal Tester AG-X Series. Mesin tegangan ini digunakan untuk menguji bahan kajian dan menghasilkan pengukuran anjakan . keputusan yang dihasilkan akan dibandingkan dengan hasil yang diperolehi dari pada cara DIC untuk pengesahan ukuran akhir. Perbezaan dan ketidaktepatan yang dihasilkan dalam ukuran anjakan hasil akhir akan dibahas dalam penulisan ini.

ABSTRACT

This research focusing on the mechanical properties of the adhesive material (sikaflex) under tensile test which used in the automotive industry. Sikaflex is an adhesive which contains polyurethane as chemical based which categorize as polymer. There are various of application of sikaflex adhesive in the automotive industry such as bonding material at joining parts. In term of safety, the sikaflex adhesive react without no sudden catastrophic joint failure. Sikaflex is a ductile, high mechanical strength and stiffness adhesive material. This research also analyses the deformation of sikaflex stress-strain relationships and failure modes under tensile loading. Tensile test is testing for sikaflex adhesive to obtain mechanical characteristic varying by the rate of measurement and force applied to the specimen. The test generates stress-strain graph, strength of material and deformation of the material. The tensile testing machine used is Shimadzu Precision Universal Tester AG-X series. Digital Image Correlation (DIC) is a non-contact technique of Non-Destructive Test (NDT). Digital Image Correlation which is an open source Ncorr software using Matlab platform which used to measure full-field deformation of the sikaflex adhesive. The analysis basic principle is to compare the reference image (before deformation) and current image (after deformation) to analyse the full-field displacement. This experiment used Casio EXILIM EX-ZR 1200 which is a digital camera to capture specimen deformation during the testing. This research also to prove that a digital image correlation is low cost method which by utilize the digital camera to generate a good result of full-field displacement on the specimen. The result generates by the machine been compared with the result that obtained from the DIC method for validation of the final result. The deviation and error in displacement measurement of the result is discussed in this paper.

DEDICATION

This study is wholeheartedly dedicated to my parent that always encourage and who has been my inspiration and gave me strength not to giving up and continuously provide their spiritual, moral and emotional support during this research. I also dedicated my work to my friends that has been always share their word of advice to finish this study. Every challenging work, make me realize that it need self-efforts as well as guidance and help from elders. To my supervisor and co-supervisor who guided me through the entire process and advise me to overcome most of the difficulties and challenge in order to finish this study. All the guidance and encouragement from them, I am able to finish this study proudly.

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All praise belong to ALLAH (SWT). Without the health, strength and perseverance He gave, I would not be able to complete this study. I have truly put an effort to this study and manage time wisely to complete this research. However, this study would not be complete without my supervisor. I would to express a deepest appreciation to my advisor, Ts Ahmad Fuad AB Ghani for his encouragement, advice and endless support that teach me throughout my research. He gave me a necessary suggestion for providing information regarding this study I also would like to thank Mr. Azizul Ikhwan Bin Mohd for the guidance and providing the equipment during the experiment. I would also like to thank the University Teknikal Malaysia Melaka and specifically the Department of Mechanical and Manufacturing Engineering Technology, for supplying with the financial and providing an advance equipment in the laboratory that been used to ensure this study completed. Finally, I would like to thank my family and my friends for their motivation to go through all the hard work and encouragement while carrying out this study. In additional, I am thankful for those who giving me an information from basic principle idea of this study. Without all the help I have received, I would never be able to finish this study.

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CHAPTER 1
INTRODUCTION

1.1 Project Overview

This study using the Digital Image Correlation (DIC) which is one of a Non-Destructive Test (NDT) technique that been used widely to measure the strength of material and monitoring tool in the engineering field. It requires high speed camera to capture the specimen and analyze by Ncorr software by using Matlab platform. This study specifically analyzes adhesive (sikaflex) used in automotive industry. The adhesive (sikaflex) widely used in automotive industry because of the advantages of the material that benefit the industry. The project focusing to utilize the DIC technique under tensile test, study the mechanical characteristic of the adhesive and to analyze the stress strain relationship including failure modes of the adhesive.

1.2 Background Study

Adhesive bonding is widely used in automotive industry application such as automotive joint, coating product, structure and windshield application (Amstutz, Bürgi, and Jousset 2018; Clemitson 2008; Galvez, Abenojar, and Martinez 2019; Janik, Sienkiewicz, and Kucinska-lipka 2014; S. J. Park and Seo 2011). Sikaflex is an elastomeric adhesive contain polyurethane (Loureiro et al. 2010). According to (S. J. Park and Seo 2011), polyurethane is in the group of polymer which as an elastomer has advantages in the mechanical properties to fulfil the requirement in application such as bumper beam, hoods, body panel, tyres and wheels. Moreover, polyurethane also used for wear and impact resistance coating. Sikaflex is an adhesive which is a

ductile, high mechanical strength and stiffness (Banea and Da Silva 2010; Loureiro et al. 2010; Najib and Nobari 2016). According to (Clemitson 2008; McKeen 2014; Sealant 2017), suggested to conduct tensile test followed by ASTM D412, Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers.

The basic and most common used method for finding the material properties is tensile test (Nguyen et al. 2017). Axial tensile test applies the tensile (pulling) force to the specimen with the standard form and dimension (Stoilov, Kavardzhikov, and Pashkouleva 2012). The specimen placed between the "grips "which clamp and hold the material during testing performed. The basic principle of the testing is by applying the load at the end of the specimen (pulling) and static at the other end of the specimen. The elongation is increasing until the specimen break and the force is continuously increase (Tensile Test Polym. 2015). The end of the test is indicated by a sudden decrease of the force. The testing parameter can be determined such as rate of measurement and minimum load started or maximum load ended as desired. As result, the tensile testing generates in stress-strain graph, strength of the material and deformation of the specimen, the result generate also can be determine as desired.

Digital image correlation is a method to measure the deformation of the material included in-plane displacement, subsequently and strain measurement (Pankow, Justusson, and Waas 2010) DIC was first invented at the University of South Carolina in early 1980s (Fayyad and Lees 2014; Kujawińska, Malesa, and Malowany 2013; Pankow, Justusson, and Waas 2010) influenced by plane photogrammetry (1850-1900), analog photogrammetry (1900-1950), analytical photogrammetry (1950-1984) and digital photogrammetry (1985-present) according to (Sutton, Orteu, and Schreier 2009) research. There are tremendous history behind the digital image correlation, refer (Sutton, Orteu, and Schreier 2009) book.

2D- Digital Image Correlation has studied, develop and widely used for in-plane deformation (Pan 2009). There are many improvements in the numerical algorithm and has been tested, implemented to improve the quality of the result since 2000 (J. Blaber, Adair, and Antoniou 2015a; Sutton, Orteu, and Schreier 2009). In the industries, there are several software that can be used to performed the measurement,

one the software was 2D subset-based digital image correlation software package (Ncorr) which implemented in the MATLAB (A. F. Ab Ghani et al. 2016; J. Blaber, Adair, and Antoniou 2015a; Harilal, Vyasarayani, and Ramji 2015; Pan 2009). Combined modern algorithm with the MATLAB for numerical computing through the DIC program to analyze the digital image and thus will develop an algorithm. Computer intensive algorithms are written in C++ and incorporated via the MEX interface into MATLAB for greater efficiency. The analysis can be supported by a high-quality Graphical User Interface (GUI) (J. Blaber, Adair, and Antoniou 2015a). To be able to run the full processing, all the software must emerge together to allow the DIC analysis to analyze the data. There are many advantages that can be highlight due to image correlation and Ncorr such as by incorporating subset shape functions in the matching algorithm, it can ease the cope with the complex deformation fields (Sutton, Orteu, and Schreier 2009). Moreover, in term of cost, it definitely brings a major different compared to others and the effectiveness has been proven by many studies in the past (Poissant and Barthelat 2007).

1.3 Problem Statement

The adhesive of sikaflex as know is widely used in automotive industry because of the material produce low catastrophic damage and failure to the other part which bonding with the adhesive. However, there are less emphasis in utilizing DIC in the adhesive material field study on the sikaflex particularly as strain measurement.

There are many NDT process can be used, 2D-DIC is one of the NDT technique to measure the deformation on the material or surface of an object or equipment. 2D-DIC can ensure the technique is more less cost and economical compared to other technique which requires higher cost, higher skill to operate the equipment and more complex system to operate. The 2D-DIC is used to measure deformation based on the surface of the material only. Moreover, the technique is uncomplicated technique and require less skill to operate the equipment and to generate the analysis.

1.4 Objective

The objective of this project are following as:

i. To implement Digital Image Correlation technique as monitoring to adhesive material used in automotive industry.
ii. To study mechanical characteristic of sikaflex under tensile test.
iii. To access deformation of sikaflex stress strain relationships and failure modes of sikaflex under tensile loading.

1.5 Scope of Study

The main objective of this study is to perform the Digital Image Correlation on the sikaflex material. Moreover, this study also focusing on performing image correlation to produce displacement measurement using open source Ncorr which emerge with 2D-Digital Image Correlation (DIC) to archive an optimal quality of the result in displacement distribution in a material deformation. The material will be prepared as followed ASTM requirement which ‘dog-bone’ shape. This study will be utilizing the digital camera as hardware equipment to record the material images on the full deformation on the material. 2D-DIC using Ncorr software will analyse the deformation and measure the full-field displacement measurement onto the material.

CHAPTER 2
LITERATURE REVIEW

2.1 Sikaflex Adhesive in Automotive Industry

2.1.1 Introduction to Sikaflex

Sikaflex adhesive is an adhesive used for bonding and sealant joint which is widely used in many engineering field such as automotive and structural etc. There are many benefits of the adhesive such as low manufacturing cost, good resistance to statics load, and impact resistance etc. Sikaflex contain chemical based of polyurethane (Loureiro et al. 2010) which is a versatile group of material which can be implemented in many application field. There are two group under the polymer which is organic and silicone. Polyurethane are organic polymer which are normally group with rubbers (Clemitson 2008).

2.1.2 Application of Sikaflex

Sikaflex is a flexible adhesive material that have a many advantages comparing to other adhesive, low modulus and large strain is some of the characteristic that desired by various of application in the industries(Créac'hcadec et al. 2014) From past decade, sikaflex is of the material that has been research, analyse and develop in many applications including aeronautic, building construction and automotive (Créac'hcadec et al. 2014; Kadioglu and Adams 2015) and according to (Naraghi and Nobari 2015) the adhesive also used widely in structural application as joining medium because the adhesive have verity of advantages.

The focus of this study is in the application of automotive, according to (Loureiro et al. 2010), in the aerospace industry has implemented the adhesive for more than a decade ago, thus the automotive industry also using the same adhesive to the products. Most of the manufactures tried to produces low cost and lighter in weight for joining component and materials in automotive industrial (Lee, Pine, and Jones 2001). Adhesive are widely used in automotive industries (Grant, Adams, and Da Silva 2009). Moreover, it can be categorizing into 4 which is, as sealants, low-strength adhesive, medium strength adhesive and high-strength adhesive (Grant, Adams, and Da Silva 2009; Loureiro et al. 2010) and high-strength adhesive commonly used in critical joining part and focusing on the strength of a structure, however there are less application in car body shell. (Grant, Adams, and Da Silva 2009). The fundamental problem with the use of adhesive in automotive industries, such as direct bonding with oily steel, has been overcome (Hong and Boerio 1995).

This adhesive widely used also in windshield of a vehicle nowadays (Sheet and Data 2009) including replacement technique and maintenances. According to (Huveners et al. 2007) this adhesive also a good joining between glass and steel framework. The adhesive is a good resistance to static and dynamics load, improve damage tolerances and a good stress, vibration distribution (Galvez, Abenojar, and Martinez 2019).

2.2 Digital Image Correlation

2.2.1 Introduction to Digital Image Correlation

Digital image correlation (DIC) is a non-destructive test (NDT) and non-contact to measure displacement and strain.(Hohmann et al. 2012). It is a very useful tool to captures digital image of an object and then analyse the image to produce deformation and measurement.(Pan et al. 2009). According to (Sause 2016), this technique is very easy to conduct, cost effectiveness and more accurate than other manual measurement methods thus it is an advance method in any application. In

various application such as material characteristic, stryctural monitoring, fatigue crack growth, etc., digital image correlaton has been widely used for displacement and strain field estimation (Harilal R and Ramji M 2014). Basically this techinique required references image (before load) and several image while the specimen deformed. By the compared references image and deformed image, a dot pattern will produced to show the differences between the images. These pattern differences can be calculated by correlating the reference image pixels and calculating any deformed image and a full-field displacement measurement (A. F. Ab Ghani et al. 2016). Based on the dot pattern characteristic, the correlation can compare the subset, displacement and strain information can be calculated and obtained.

There are many method of Non-Destructive Test (NDT) such as ultrasonic, AE technique, thermography etc and many software of DIC avaiable but based on Matlab paltform, opensource is an impressive tool for researchers to use displacement and strai measurement techniques at an affordable cost compared to high-end equipement and post-processing software.

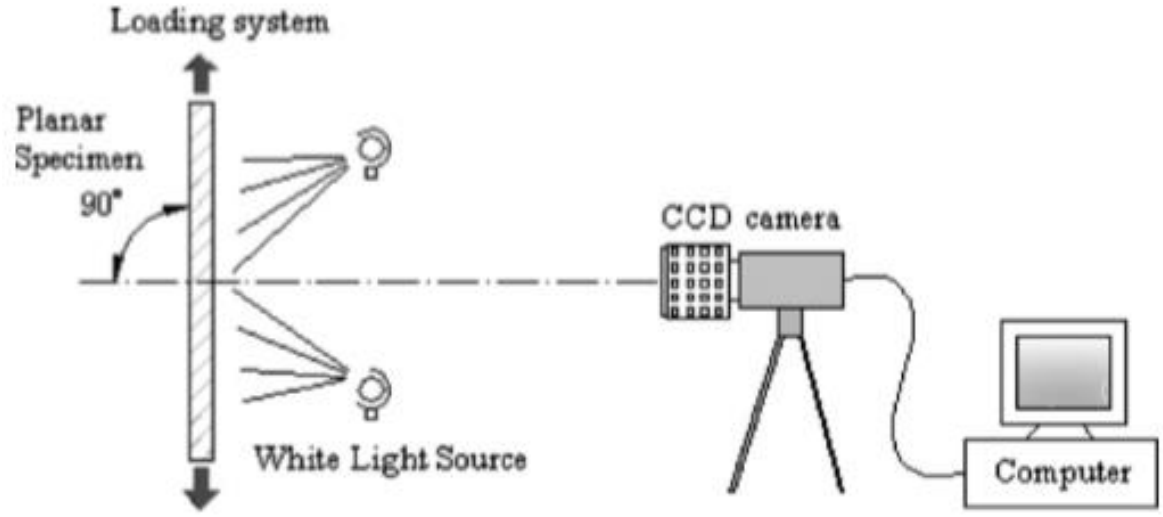

Figure 2.1: Setup for deformation measurement digital correlation image (2D DIC method)(Pan et al. 2009)

2.2.1 Basic Principle of 2D DIC

Digital Image Correlation (DIC) is a simple technique to perform a measurement. Minimum two digital image required to perform the measurement. Quality resolution of the camera and the spackle pattern paly an importance part to produce a quality result. Moreover, it can be proceeding without any special surface preparation or special lighting. For proceeding this method specimen preparation is one of the procedure that must be followed to obtain an accurate result by spray a background with either black or white before the speckle are applied. Concept of correlation is used to obtain the strain from the deformation, in order to defined any displacement, one of the image as references and another one or more as deformed image recorded and store in the computer. Figure 2.2 shown an illustration of DIC. These image are compared by searching for a match point from one image to another image to detect displacement. A multiple pixel points is used to perform the matching process because using a single pixel is almost impossible and take a longer time to process (Yoneyama 2016). The image in multiple pixel which contain a grey level value to the material surface random pattern called the speckle pattern (Barranger et al. 2010). In the references image contain subset which contain many variation of light intensity (gray level) inside the subset which does not change during the deformation. After deformation, the displacement of the subset on the image is found in the image by locate the same light intensity distribution area with the subset (Yoneyama 2016). The location of the subset can be located once the location of the subset in the deformed image founded. Matching subset are required on the surface of the object to determine the displacement of the subset as shown in figure 2.3. Image process produce position of the coordinate before and after deformation that enable correlation to calculate the strain.

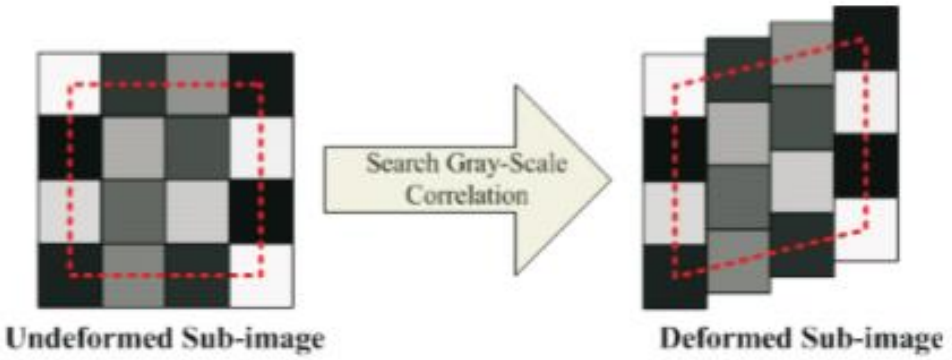

Figure 2.2: illustration of the working principle of the digital image correlation (Tung and Sui 2010)

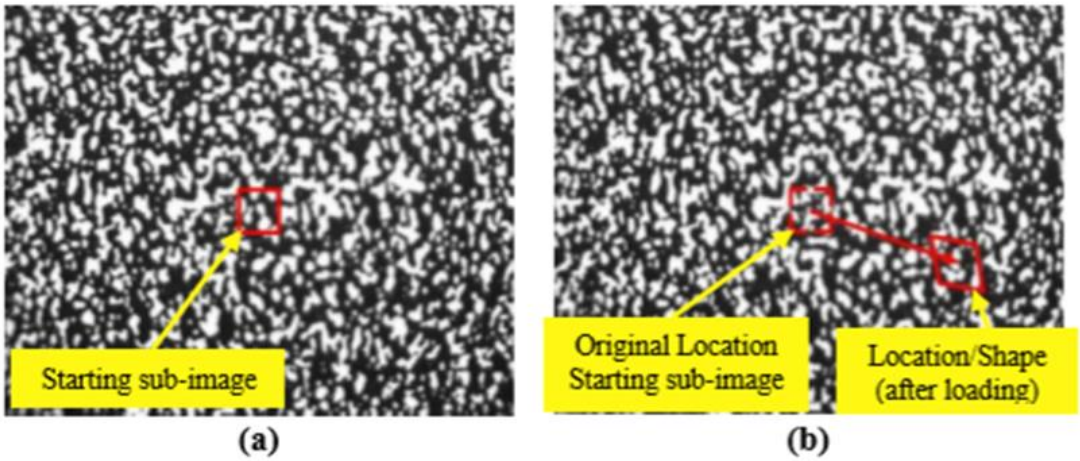

Figure 2.3: Spackle pattern for DIC. (a) before deform; (b) after deform (Chu and Poudel 2014)

2.2.2 Subset Size Selection

The movement and deformed of the specimen can be detected by small subset of the image. Subset is a component that are moved to track the pattern in the deformed image matches as closely as possible to the reference image. Thus, the subset is an importance element to provide an accurate result and it may affect the result due to subset size and shape. However, the subset size must be selected by manually from several pixels before can proceed to track the pattern. In term of sizing, the size of subset should be sufficiently large to allow a sufficiently unique intensity pattern to be recognized from another subset. However, large subset may lead to larger error in deformation approximation(Pan et al. 2008). If large subset size selected, increasing the pixel included in the subset. This shown that size selection is a critical component that must be priority to ensure that the analysis of correlation is reliable. If the subset selected is smaller, thus the coefficient of all pixel is smaller are one while others are zero(Liang et al. 2015). Thus, it will probably produce less information of speckle to correlate and represent the specimen(Correlated Solutions 2017). Figure 2.4 shown an example of subset size.

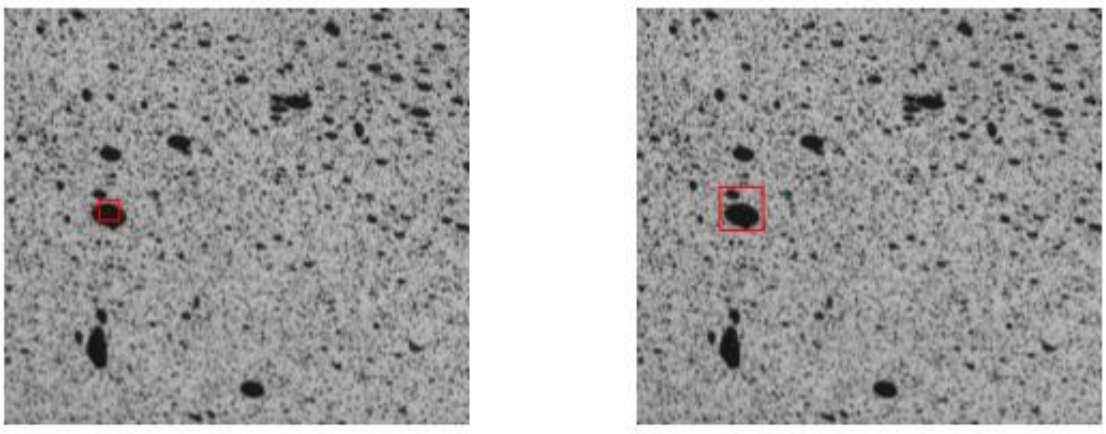

Figure 2.4: Example of too small subset and larger subset(Byrne 2010a).

According to (P. Reu 2015) research, undersized speckles can be consider, however, additional noise to the measurement and to the specimen surface at random condition. The condition of the surface also may affect the quality of the image speckle pattern. However, according to (Yaofeng and Pang 2007) there is an advantage of the small subset which may lead to high accuracy of displacement measurement for

images with larger contrast. Within the same specimen, subset size and actual deformation state, it may also produce contrast result due to speckle size, and different speckle pattern and distribution which operate by different people, thus subset size are one of the critical part of the process (Pan et al. 2008). Furthermore, based on (Lava and Debruyne 2015) the subset size must be choose depending on the pattern and 3 features per subset as minimum to obtain accurate result.

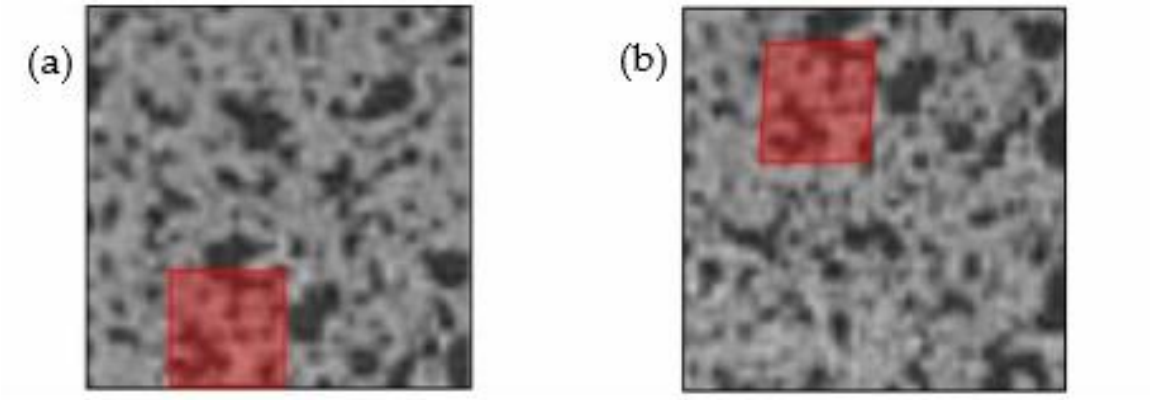

Figure 2.5: (a) references image and subset. (b)deformed image and matching subset. (Poissant and Barthelat 2007)

2.2.3 Speckle Pattern

Speckle pattern is an intensity pattern generated by a set of waveforms interfering with each other or generated by volume fraction and speckle size changer (J. Park et al. 2017). Based on (Carter, Uchic, and Mills 2015) conclusion, for the desired spatial and intensity resolution, the speckle pattern distribution (spacing, size, shape) used for DIC analysis should be utilized. Moreover, measurement in-plane displacement of the specimen with the subset size may effected due to speckle pattern (Lecompte et al. 2007). Based on studies by (Lecompte et al. 2007), small speckle resulting in more accuracy of the subset displacement and larger speckle larger correlation peak which complicated to locate the position.

Speckle pattern has to deform numerically to define the efficiency of it. The speckle pattern is applied to the specimen so that DIC measures the correlating