MEASUREMENT OF RESIDUAL STRESS IN COLD WORK AUSTENITIC STAINLESS STEEL 316L WITH DEFLECTION METHOD

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This dissertation is submitted to Faculty of Mechanical Engineering in partial fulfilment of the requirements for the degree of Bachelor of Mechanical Engineering (Structure & Materials)

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DECLARATION

"I admitted that this report is truly mine except the summaries and extractions where both I clearly knew its sources."

Signature :……………………………………….

Supervisor Name :……………………………………….

Date :……………………………………….

APPROVAL

“I admitted that I have read this work and from my opinion it is adequately based on the scopes and quality for the degree of Bachelor of Mechanical Engineering

(Structure & Materials)

Signature :…………………………………………..

Writer :…………………………………………..

Date :…………………………………………..

DEDICATION

I dedicated this Final Year Project to my beloved parent, Haji Zulkafli Bin Baharuddin, Hajah Asmah Binti Md. Nor and my family for keep supporting and encourage me throughout my studies. Much appreciation dedicated to my supervisor Dr Wan Mohd Farid Bin Wan Mohamad and my friends for helping and guiding me in completing this project.

ABSTRACT

Residual stress refers to as potential or locked in stress inside an object without the presence of external load. Residual stress also plays an important role in structural integrity. This paper is mainly focussing on measurement of residual stress in cold work austenitic stainless steel 316L with deflection method. A mechanical process is done to produce different thickness of equal sizes specimens.

The thicknesses are reduced to 10% up to 50%. Based on general hypothesis, residual stresses tend to reduce strength. Therefore, a measurement is done using deflection method as it is said to be most precise method to predict the residual stress. This whole process is rather delicate, requiring much time, patience and expenses. In this paper, the effects of thickness reduction with the values of residual stresses are discussed.

ABSTRAK

Tegasan baki merujuk kepada potensi atau tenaga yang wujud di dalam objek tanpa kehadiran daya luar. Tegasan baki juga memainkan peranan penting dalam integriti sesuatu struktur. Risalah ini memfokuskan hanya kepada pengiraan tegasan baki di dalam *stainless steel* austenite jenis 316L menggunakan cara pembengkokan. Proses mekanikal telah dilakukan untuk menghasilkan spesimen yang sama saiz tetapi berbeza ketebalan.

Ketebalan spesimen dikurangkan 10% hingga 50% dari ketebalan awal. Berdasarkan hipotesis, tegasan baki punca cenderungnya kekuatan berkurangan. Oleh itu, pengiraan menggunakan cara pembengkokan digunakan kerana ianya merupakan cara yang paling tepat untuk mengjangkakan tegasan baki. Keseluruhan proses adalah sangat teliti, memerlukan banyak masa, kesabaran and perbelanjaan. Risalah ini membincangkan kaitan diantara ketebalan spesimen dan juga tegasan baki.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Residual stresses are the stresses which exist within a body of materials without being subjected to any external forces. As referred, residual stresses are locked-in stresses within a metal object, even though the object is free of external forces (M. Pfeifer). These stresses arise in most metallic objects by four different methods that are mechanical, thermal, plating and machining which cause the metal to yield and deformed to plastic. However, the yielding or plasticity is in-homogenous. Further, these stresses occurred due to some region of the metal objects are being constrained and prevent it from expanding, contracting or releasing elastic strain (M. Pfeifer). They play a critical role for structural integrity of materials in term of service performance, strength, fatigue life and dimensional stability (Tadić and Mišović).

Example of mechanical methods that will induce residual stresses in metal objects are short peening and rolling. This would cause a localized inelastic region that deformed in metal objects. This method uses external loading and unloading which later causes both tensile and compressive residual stress as shown in Figure 1:1. Thermal methods include forging, casting, welding, quenching, carburizing and many other processes. It is the same as machining and plating. However, plating sometimes nullifies the residual stress that occurred within metal objects by combining with some other processes. The goodness of residual stresses may depend on processes and usage. Sometimes residual stresses might be bad for certain usage for example machined metals are prone to fatigue fracture. The integrity of metal objects will vary after some mechanical processes and it is important to know the limitations of the residual stresses.

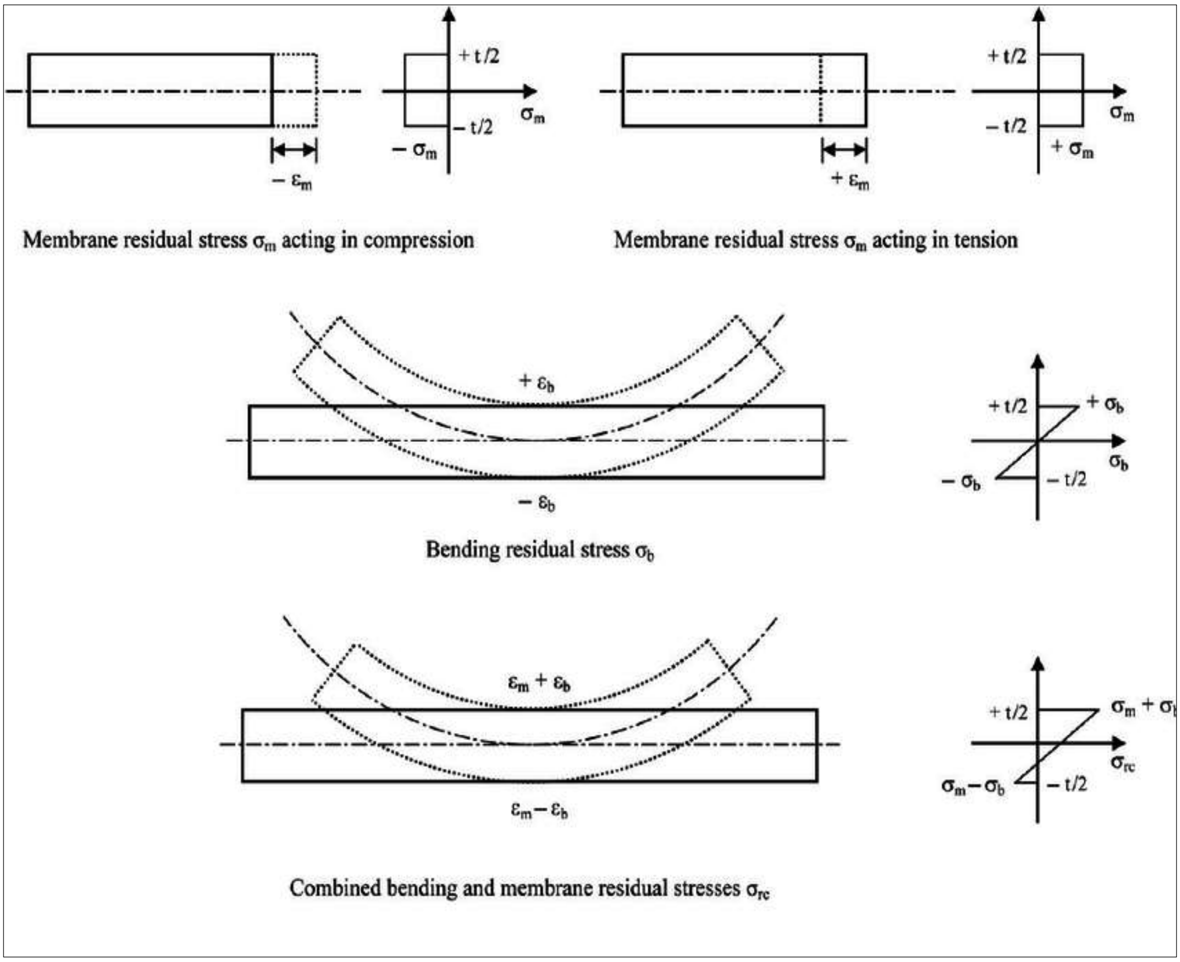

Figure 1:1 : Compressive and tensile residual stress.

Over the years, many researches have been done and experimented to measure the residual stresses. Many techniques can be used to measure the residual stresses as it unforeseen with bare eyes. Measurement techniques can be divided into three categories which are non-destructive, semi-destructive and destructive techniques. For non-destructive techniques, it will be done to analyse the effect of residual stresses with metals' crystallographic properties. For example neutron diffraction, synchrotron diffraction, x-ray diffraction, ultrasonic and magnetic. As for semi-destructive techniques, it follows the "strain release" principle where the specimen used is cut only a bit and measure the deformed shape which leaves the overall materials' integrity remain intact.

This technique includes ring core, deep-hole drilling and centre-hole drilling. The last technique which most costly is the destructive techniques such that they result in a large and irreparable structural change to the specimen (Engineering & Engineering, 2016). This technique also follows the "strain release" principle however the cut specimen is much bigger than the semi-destructive technique. This technique includes block removal, slitting, Sach's boring and contour methods. Residual stresses can be measured by several different methods, as well as by combining various techniques (D. Walker).

1.2 PROBLEM STATEMENT

Residual stress arises mostly in metal that undergoes mechanical process such as rolling and cutting. However, the residual stress cannot be foreseen with naked eyes and this stress unfortunately plays an important role with the integrity of the materials. There is no absolute way to measure the residual stress. So, there are many methods available to estimate the residual stress such as deflection method, x-ray diffraction and crack compliance method.

Rolling process has induced and increased the residual stress, the hardness, tensile strength and the ultimate strength. Both hardness and strength can be measured directly using reliable measurement tools such as tensile test machine and hardness test machine. However, residual stress cannot be measured directly like other properties even though residual stress has large effects on materials' integrity.

There are two ways to estimate the value of residual stress either by experimentally or through simulation.

Therefore, a precise measurement tool is used to predict the value of residual stress through deflection method. Solution (Adlers 300 series stainless steel etchants) is used to deflect the stainless steel sheet. After that, a probe or profile projector can be used to record the deflection.

1.3 OBJECTIVES

The objective of this project is to predict residual stress induced through mechanical process using a deflection method.

1.4 SCOPE OF PROJECT

The scope for this project are :

1. Machining of 80 x 20 mm is done to the metal sheet.
2. To do mechanical treatment to induce residual stress and reduction done are in range.
3. To measure the changes in dimension using precision measurement tools.

4. To do etching process for material to deflect using Adlers 300 series stainless steel etchant.

1.5 GENERAL METHODOLOGY

The action that need to be carried out are as listed :

1. Literature Review
   Anything that related to residual stress and deflection method will be reviewed.

2. Mechanical Process
   Mechanical process such as machining and rolling will be done to create 12 specimens. Each specimen will be in 80 x 20 mm rectangular with different thickness. 12 specimens will be divided equally into thickness of 2.0 mm, 1.8 mm, 1.4 mm, and 1.0 mm.

3. Measurement
   Measurement of important parameters will be measured using precise measurement tools.

4. Analysis
   Analysis will be done to measure residual stress by using different thickness of steel sheets.

5. Report Writing
   A final report will be written at the end of this project.

The methodology is summarized as in Figure 1:2 and as Gantt Chart in Figure 1:3.

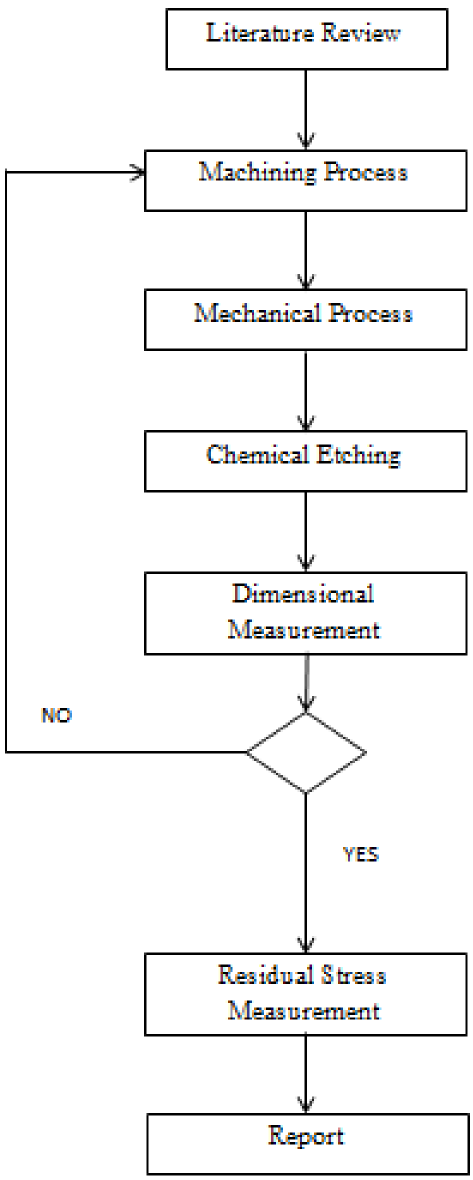

Figure 1:2 : Flowchart of methodology.

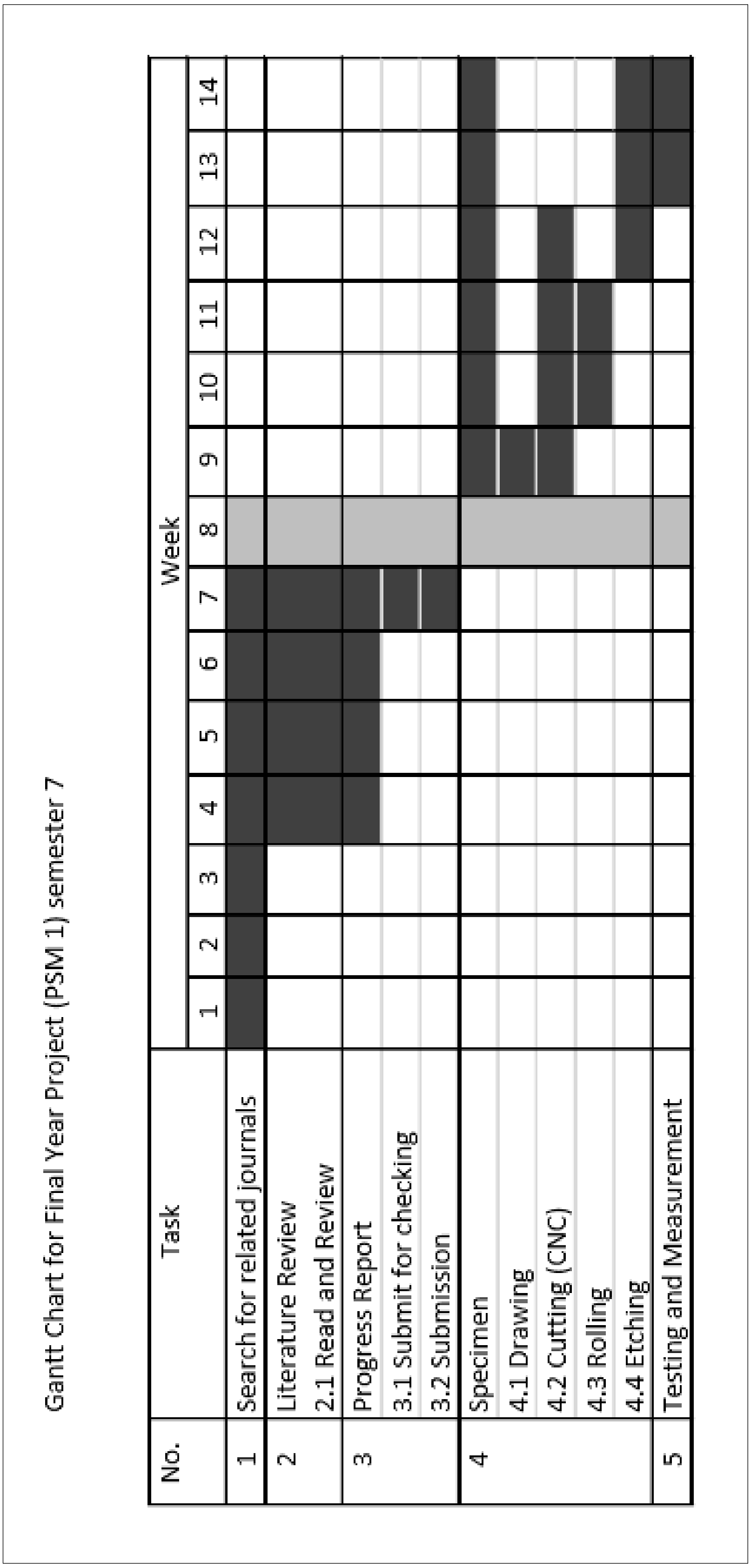

Figure 1:3 : Gantt chart for PSM 1.

CHAPTER 2

LITERATURE REVIEW

The existence of residual stresses would affect the non-homogenous plastic deformation in metals. This occurred due to the irregular distribution of residual stresses. Even though the residual stresses are not affecting the changes of the shape when they were symmetrically balanced in their cross section, they still can affect in future production or mechanical phases. The residual stresses are spatially balanced but they are also latently unstable (Milan, MT., Tarpani, Jr., Bose Filho, 2005).

There are a discussion about residual stresses concerning how it affect the changes of the shape and dimensions when their balance is disturbed by using x-ray diffraction and deflection method. Apparently, the residual stresses needed to be relaxed as if it were exposed to a superposition of external loads might cause the reliability of the component to be damaged or reduced. One way is to remove or completely transform the residual stresses into more appropriate form so that it will not cause any permanent consequences.

Residual stresses are internal stresses exist in metallic components. The value of residual stresses cannot be determined using naked eyes. Therefore, there are many ways to determine the value of residual stresses either by using destructive or non-destructive methods. Mostly, a test or experiment is done using non-destructive methods as it is to reduce cost.

One way to determine both near surface and through the thickness is by applying crack compliance method which is easy yet powerful to implement. The residual stresses that were introduced to the crack or slot area are measured by strain gauges attached to specific region of the part. Assuming the slot is narrow, from that, linear elastic fracture mechanics equations can be employed to establish a relationship between the measured strains, ε, and the corresponding residual stress intensity factor, K_r (Schindler, 1995 cited in Milan.MT. et.al, 2005).

$$K_{Ir}(a) = \frac{E\prime}{Z(a)} \frac{d\varepsilon M}{da} \quad \text{(Eqn. 2.1)}$$

where ε_M is the measured strain at point M during cutting procedure, a is the slot length, *E'* is the generalized form of Young's modulus *(E' = E for plane stress and E' = E/1-v²)* for plane strain) and *Z(a)* is the "influence function" which depends on the testpiece geometry, cut plane and strain measurement position, but it is independent on the residual stress profile.

For a rectangular plate, where L>2W, and taking strain measurements at the back face point M, Z(a) is given as (Schindler and Bertschinger, 1997 cited in Milan.MT. et.al, 2005):

for a/W<0.2

$$Z(a) = \frac{-2532}{(W-a)}\sqrt{1-25\left(\frac{a}{W}-0.2\right)^2}\left[5.926\left(0.2-\frac{a}{W}\right)^2-0.288\left(0.2-\frac{a}{W}\right)+1\right] \quad \text{(Eqn.2.2)}$$

for 0.2<a/W<1

$$Z(a) = \frac{-2.532}{(W-a)^{1.5}} \quad \text{(Eqn.2.3)}$$

$$K_{Ir}(a) = \int_{ao}^{a} h(x,a)\sigma(x)dx \quad \text{(Eqn.2.4)}$$

where *h(x,a)* is the weight function, which is available for several geometries (Fett and Munz, 1997 cited in Milan. MT et.al, 2005). Therefore, the weight function for a single edge crack in a finite width of rectangular plate is :

$$h(x,a) = \sqrt{\frac{2}{\pi a}} \frac{1}{\sqrt{1-x/a}} \left[1 + \frac{1}{(1-\frac{a}{W})^{3/2}} \sum_{v,\mu} A\,\mathrm{v},\mu \left(\frac{a}{W}\right)^{\mu} (1-\frac{x}{a})^{v+1}\right] \quad \text{(Eqn.2.5)}$$

where $A_{v,\mu}$ values can be found on Table 2.1.

Table 2:1 Weight function coefficients for rectangular testpieces (Fett and Munz, 1997 cited in Milan. MT. et.al, 2005).

v	μ = 0	μ = 1	μ = 2	μ = 3	μ = 4
0	0.4980	2.4463	0.0700	1.3187	-3.067
1	0.5416	-5.0806	24.3447	-32.7208	18.1214
2	-0.19277	2.55863	-12.6415	19.7630	-10.986

Through Eqn.2.4, the value or residual stress can be obtained. If incremental stress method is used (Schindler, 1995 cited in Milan. MT. et.al, 2005), the stress profile can be depicted schematically by a series of small steps. By applying the prolonging crack hypothetically, discrete form of Eqn.2.4 will be as follow :

$$K_{Ir}(a_i) = \sum_{j=1}^{i} \sigma_j \int_{aj-1}^{aj} h(x, a_i)dx \quad \text{(Eqn.2.6)}$$

These procedures are not only able to determine the initial residual stress profile but also able to determine the redistributing residual stress profiles by changing the integration limits.

Another research has been done regarding on microelectromechanical systems based devices that faced problems caused by residual stress especially during film deposition and post-fabrication processes. During phase transformation, film nucleation occur during deposition process are the causes of residual intrinsic stress, including growth stress. Thermal stress arises from mismatch of film-substrate thermal expansion coefficients developed by the residual extrinsic stress. These would cause undesirable consequences such as cracking, deflection and buckling in the released microstructures.

The residual stress were treated and improved by controlling it, and etch release effects during the fabrication process. This journal studied on how residual stress can be controlled and improved through fabrication and characterisation of suspended microstructure of tantalum. Both wet and dry etching techniques have been examined for the release of the final device in the form of doubly supported beams with length ranging from 100 to 400 μm (A Al-masha'al et al, 2016). The influence of beam geometry, length, width, and thickness is examined by looking on the final deflection profile of the fabricated and simulated structures.

Based on journal, the experiment is done from beams fabrication, buckling analysis and residual stress measurement. During fabrication, the sacrificial layer is considered and cured by heating at 350̊C for 30 minutes and let cooled in room temperature. The second layer, low temperature of SiO_2 is developed by PECVD system at 120̊C. The tantalum has film with thickness of 500 nm deposited by DC magnetron sputtering system. In the analysis, buckling takes place when the axial load exceeds the Euler buckling limit.

$$P_c = \frac{4\pi^2 EI}{L^2} \qquad \text{(Eqn 2.7)}$$

Where L and EI are respectively the length and flexural rigidity of the beam. The buckling occurs at particular length based on the critical stress.

$$\sigma_{cr} = \frac{E\pi^2 t^2}{3L^2} \qquad \text{(Eqn 2.8)}$$

Where E, t and L are elastic modulus, thickness and length of the beam. Once the beam is release from substrate, it will buckle according to residual stress

$$\sigma_{res} = \frac{\pi^2 E}{L^2}\left[\frac{A^2}{4} + \frac{t^2}{3}\right] \qquad \text{(Eqn 2.9)}$$

Where A is the amplitude of buckling and can be measured interferometrically. The sinusoidal shape of buckling represent by :

$$y(x) = \frac{A}{2}\left(1 - cos\frac{2\pi x}{L}\right) \qquad \text{(Eqn 2.10)}$$

Where $-L/2 \leq x \leq L/2$, y and x both represent the deflection and position along the beam.