

CERTIFICATION OF APPROVAL

**Residual Stress Measurement Using X-Ray Diffraction**

by

Muhammad ‘Ammar bin Kassim

A project dissertation submitted to the  
Mechanical Engineering Programme  
Universiti Teknologi PETRONAS  
in partial fulfilment of the requirement for the  
BACHELOR OF ENGINEERING (Hons)  
(MECHANICAL ENGINEERING)

Approved by,

---

(Dr. Azmi bin Abdul Wahab)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

December 2010

## ABSTRACT

The project was carried out to study the use of X-ray diffraction (XRD) technique for residual stress measurement. This project used mild steel as the material for study. An annealed sample of mild steel was used as the reference. Residual stresses were then introduced to the samples by mechanical means via cold-working and by thermal process through welding. The cold-worked sample was prepared by cold-rolling the mild steel plate in the roll machine. For the welded sample, two mild steel plates were welded together in a butt joint. The cold-worked and welded samples were scanned in the X-ray diffractometer, and the results were then compared to the baseline reference of the annealed sample. Residual stress measurements were made from deviations measured from measurements of XRD peaks. From the results obtained, the diffraction peaks shifted to lower angles (increasing interplanar spacing  $d$ ) for the welded sample while for the cold-worked sample, the diffraction peaks shifted to higher angles (decreasing  $d$ ). An increase in  $d$  indicates tensile stress while a decrease in  $d$  indicates a compressive stress. Residual stress for the cold-rolled sample was determined to be 906MPa in compression, while the welded sample yielded a tensile residual stress of 338MPa.

## ACKNOWLEDGMENTS

The dissertation you hold is not simply a product of mine, but instead collaboration between me and Universiti Teknologi PETRONAS (UTP) who I have known over the past five years. I am especially thankful to technicians and technologists who were pleased to welcome me in their laboratory. I am grateful for their consideration and helpfulness.

My sincere thanks goes to my supervisor, Dr. Azmi bin Abdul Wahab who help me a lot during this entire project. He carefully read over my manuscript and suggested many important changes. In addition, my co-supervisor, Dr. Saravanan Karuppanan also helped me reviewed and checked several of the activities.

Many of the photographs in this dissertation were taken not by professional photographers but amateur photographers including myself. For these efforts, I am thanking Mr Faisal, Mr. Irwan, and Mr. Anuar.

And finally, I give love and thanks to my friends and families for their patience and support throughout. They were always there, even, on the late of nights.

## TABLE OF CONTENTS

<b>CERTIFICATION</b>	.	.	.	.	.	.	.	.	i
<b>ABSTRACT</b>	.	.	.	.	.	.	.	.	ii
<b>ACKNOWLEDGEMENT</b>	.	.	.	.	.	.	.	.	iii
<b>CHAPTER 1:</b>									
	<b>INTRODUCTION</b>	.	.	.	.	.	.	.	1
	1.1	Background	.	.	.	.	.	.	1
	1.2	Problem Statement	.	.	.	.	.	.	1
	1.3	Objectives	.	.	.	.	.	.	2
	1.4	Scope of Study	.	.	.	.	.	.	2
<b>CHAPTER 2:</b>									
	<b>LITERATURE REVIEW</b>	.	.	.	.	.	.	.	3
	2.1	Residual Stress	.	.	.	.	.	.	3
	2.2	X-Ray	.	.	.	.	.	.	3
	2.3	Diffraction	.	.	.	.	.	.	5
	2.4	Constructive Interference	.	.	.	.	.	.	6
	2.5	Bragg's Law	.	.	.	.	.	.	7
	2.6	Determination of Crystal Structure	.	.	.	.	.	.	9
	2.7	Measurement of Residual Stress	.	.	.	.	.	.	10
	2.8	Crystal Quality	.	.	.	.	.	.	12
	2.9	Residual Stress Measurement Methods	.	.	.	.	.	.	13
<b>CHAPTER 3:</b>									
	<b>METHODOLOGY</b>	.	.	.	.	.	.	.	17
	3.1	Project Methodology	.	.	.	.	.	.	17
	3.2	Gantt Chart	.	.	.	.	.	.	18
	3.3	Sample Preparation	.	.	.	.	.	.	21
	3.4	Removing the Oxide Layer	.	.	.	.	.	.	21
	3.5	Run XRD	.	.	.	.	.	.	22
	3.6	Preliminary Treatment of Data	.	.	.	.	.	.	25
<b>CHAPTER 4:</b>									
	<b>INITIAL RESULT AND DISCUSSION</b>	.	.	.	.	.	.	.	26
	4.1	Data Gathering and Analysis	.	.	.	.	.	.	26
	4.2	Discussion	.	.	.	.	.	.	34
<b>CHAPTER 5:</b>									
	<b>CONCLUSION</b>	.	.	.	.	.	.	.	36
<b>REFERENCES</b>	.	.	.	.	.	.	.	.	37
<b>APPENDICES</b>	.	.	.	.	.	.	.	.	39

## LIST OF FIGURES

Figure 1	Schematic showing the basic components of a modern x-ray tube	4
Figure 2	Plane wave fronts approach a barrier with an opening or an obstruction	6
Figure 3	Diffraction of x-rays by a crystal and Bragg's Law	8
Figure 4	Free body diagram of rod stressed by a force.	11
Figure 5	Flow of the project from the beginning	18
Figure 6	XRD Machine Bruker – AXS D8 Advance at laboratory	22
Figure 7	Sample 1 after annealing process	23
Figure 8	Sample 2 after annealing process	23
Figure 9	Sample 1 after cold working process	24
Figure 10	Welded butt joint sample	25
Figure 11	XRD Reading for sample 1 before annealing process	27
Figure 12	XRD Reading for sample 1 after annealing	28
Figure 13	XRD Reading for sample 1 before and after cold work process	31
Figure 14	XRD Reading for sample 2 and 3	33

## LIST OF TABLES

Table 1	Comparison of residual stress measurement techniques	16
Table 2	Gantt chart	19
Table 3	Gantt chart continued	19
Table 4	Theoretical data obtain from Bruker XRD Machine – AXS D8 Advance library	26
Table 5	Data for sample 1 before annealed	29
Table 6	Data for sample 1 after annealed	29
Table 7	<i>d</i> spacing for all the peaks in sample 1 after cold work	30
Table 8	Residual stress at each peaks for sample 1 before cold work	30
Table 9	Summarize data for all peaks in sample 2 and 3 after welding	32
Table 10	2 $\theta$ reading and stress at each peak for sample 2 before welding	32