UNIVERSITI PUTRA MALAYSIA

WELDING PARAMETER OPTIMIZATION USING TAGUCHI METHOD AND GREY RELATIONAL ANALYSIS FOR GAS METAL ARC WELDING A1008 BUTT-JOINT

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Master of Science

October 2013

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Master of Science

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October 2013

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Gas Metal Arc Welding (GMAW) is one of the most important metal joint processes in metal fabrication industries. In this technique and all types of welding process, the optimal selection of welding parameter is vital in achieving high quality joints. In this study, welding current, welding voltage and welding speed are selected as welding parameter specifications. Orthogonal array of Taguchi method were performed to drive the objective function in relation to parameter of weld joint strength and then followed by Grey Relational Analysis (GRA) to solve the multi-response optimization problem. The results then were verified to check the quality using Analysis of Variance (ANOVA).

The Finite Element Analysis (FEA) of residual stresses in butt-joint of two welding parameter is performed with ANSYS software and the optimum welding parameters gained from optimization was used in this study. A moving heat source model based on Goldak's double-ellipsoid heat flux distribution is presented. The residual stresses have been calculated and the result showed that optimum welding parameters reach a value of 266 MPa and increase to value of 270 MPa for non-optimum welding parameter. The residual stress distribution and magnitude in the axial direction was obtained and the results show good agreement between the optimum and non-optimum welding process parameter.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Master Sains.

MENGOPTIMUMKAN PARAMETER KIMPALAN MENGGUNAKAN KAEDAH TAGUCHI DAN ANALISA HUBUNGAN KELABU MENGGUNAKAN KIMPALAN GAS ARKA SAMBUNGAN TEMU A1008

Oleh

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Kimpalan logam gas arka adalah satu proses sambungan logam yang sangat penting dalam sektor pembentukan logam. Dalam teknik ini dan semua jenis proses kimpalan, pemilihan parameter maksima kimpalan adalah sangat penting untuk mencapai kualiti sambungan yang baik. Dalam kajian ini, spesifikasi parameter arus kimpalan, voltan kimpalan dan kelajuan kerja kimpalan digunakan. Tatasusunan ortogon kaedah Taguchi telah digunakan untuk mengerakan fungsi objektif berkaitan kekuatan parameter sambungan dan kemudian diikuti oleh analisis hubungan kelabu untuk menyelesaikan masalah pengoptimuman pelbagai respon. Keputusan akan disahkan dengan pememeriksaan kualiti menggunakan Analisis Varian (ANOVA).

Kaedah unsur terhingga terhadap tegasan baki dalam sambungan temu bagi dua parameter di lakukan menggunakan perisian ANSYS dan parameter maksima yang terhasil dari proses optimisasi digunakan dalam kajian ini. Model sumber pergerakan haba berdasarkan prinsip pengagihan haba fluks ellipsoid Goldak digunakan.Tegasan baki di kira dan keputusan menunjukan parameter kimpalan maksima mencapai nilai 266 Mpa dan meningkat kepada 270 Mpa pada parameter kimpalan yang bukan maksima.Taburan tegasan baki dan magnitud dalam arah paksi terhasil dan keputusan menunjukkan perkaitan yang baik antara kimpalan yang maksima dan bukan maksima yang di perolehi.

ACKNOWLEDGEMENTS

First of all, I would like to express my gratitude to my project supervisor Dr. Nuraini Abdul Aziz, for her motivation and assistance in this project. Her expertise and valuable advice and recommendation are played an important role in the successful completion of this project. Besides, I also would like to express my gratitude to my co-supervisor, Dr. Azmah Hanim Mohamed Ariff, for her advice and help in this project.

Secondly, I would like to thanks to my colleagues in the Department of Fabrication and Joining, University Kuala Lumpur, Malaysia France Institute for their support and assistance for preparation of my thesis project. I also would like to thank to Hazeme Abu Kasim, MSc. student from University Technologi Mara for his assistance and help in welding simulation software. Lastly, I would like to thanks for my parents and my family for their love and support.

I certify that a Thesis Examination Committee has met on 10 October 2013 to conduct the final examination of Zainal Abiddin Shah Bin Mattar on his thesis entitled "Welding Parameter Optimization Using Taguchi Method and Grey Relational Analysis for Gas Metal Arc Welding A1008 Butt-Joint" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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DECLARATION

I declare that the thesis is my original work except for quotations and citation which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any degree at Universiti Putra Malaysia or any other institution.

ZAINAL ABIDDIN SHAH BIN MATTAR

Date: 10 October 2013

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LIST OF SYMBOLS AND ABBREVIATIONS

The symbols and abbreviations used within the dissertation are listed below. In some cases, the same symbol is used for two different parameters. However, the explanations in the text and the context in which the symbols are used will make the meaning of all symbols explicit. Some other symbols are also used in the text and their meaning is clearly explained within the text.

Symbol	Description
a	Half width of heat source (mm)
b	Penetration depth of heat source (mm)
c	Radius distance in the welding arc (mm)
C	Concentration Coefficient (m^{-2})
E	Young's Modulus of Column
f_f	Fraction of heat in front ellipsoidal of heat source
f_r	Fraction of heat in rear ellipsoidal of heat source
I	Current (amperes)
Q	Arc power (W)
S	Weld speed (mm s^{-1})
T	Current temperature at cylinder surface
t	Plate Thickness
V	Voltage (volts)
w	Plate Width
α	Co-efficient of thermal expansion (per degree)
é	Density of material (Kg/ m^{-3})
f_f	Fraction of heat in front ellipsoidal of heat source

f_r	Fraction of heat in rear ellipsoidal of heat source
f_f	Fraction of heat in front ellipsoidal of heat source
$\sigma 2$	Longitudinal residual stress
Nâ	Maximum flux at the centre of the heat source (Wm^{-2})
η	Arc efficiency (%)
Nĉ	Surface flux at radius *r* (Wm^{-2})
c_p	Specific heat (J/kg K)
σ_p	Tensile stress (MPa)
$\sigma 1$	Transverse residual stress
σ_y	Yield stress (MPa)

CHAPTER 1

INTRODUCTION

1.0 Overview

In fabrication industries, Gas Metal Arc Welding (GMAW) process is among one of the most widely used where products required permanent metal joining in a large scale. Gas metal arc welding (GMAW) process Good settings of welding parameter are needed to produce good quality weld and to reduce a residual stress in welding processes.

1.1 Gas Metal Arc Welding

Gas Metal Arc Welding (GMAW) is the most widely used process. It is a versatile method which offers a lot of advantages whereas the technique is easy to use and there is no need for slag-cleaning and extremely high productivity. GMAW is used on all thicknesses of steels, aluminium, nickel, stainless steels and suitable both for steel and unalloyed, low-alloy and high-alloy based materials.

Gas metal arc welding uses an arc between a continuous filler metal (consumable) electrode and the weld pool. This process is also known as MIG welding or MAG welding. MIG (Metal Inert Gas) welding means the use of an inert (i.e. non active) gas. MAG (Metal Active Gas) welding requires the use of an active gas (i.e. carbon dioxide and oxygen). CO_2 is a more commonly used shortening of MAG welding gas as shown in Figure 1.1.

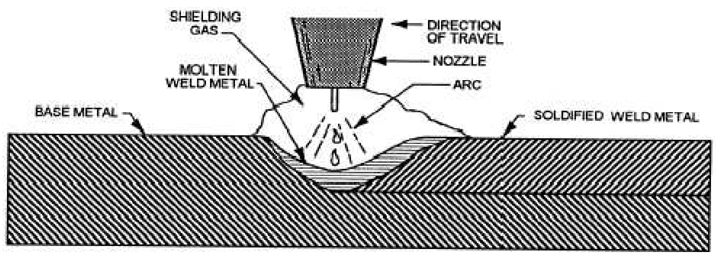


Figure 1.1 Schematic diagram of GMAW processes (ASM Handbook, 1993)

Another advantage is the extremely high productivity, allows welding in all positions, requires less operator skill than TIG welding, provides a uniform weld bead and allows long welds to be made without starts or stops,

1.2 Gas Metal Arc Welding Parameter

In arc welding processes a number of welding parameters exist that can affect the size, shape, quality and consistency of the weld. The major parameters that affect the weld include weld current, arc voltage, and travel speed.

The arc voltage has an influence on the bead width and shape as shown in Figure 1.2. Higher voltages will cause the bead to be wider and flatter. Extremely high arc voltage should be avoided, since it can cause cracking. The low arc voltage produces a stiffer arc that improves penetration. If the voltage is too low, a very narrow bead will result. Any variation in arc voltage creates a change in arc length. An arc voltage increase brings an arc length increase an arc voltage decrease brings an arc length decrease.

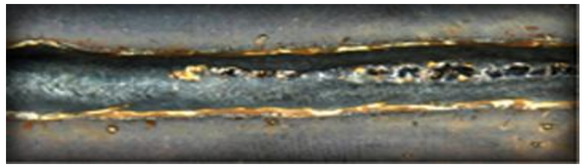
(a) A good weld

(b) Voltage Too Low

(c) Voltage Too High

Figure 1.2 Pictures Representations of Voltage Varied Weld (Miller. 2013)

In Robotic Gas Metal Arc Welding (GMAW), ampere and wire stick out speed from the nozzle are directly related to each other. When wire stick out speed is increased, amperage will also increase. If wire feed speed is reduced, amperage will also reduce. Amperage/wire feed controls wire melts off rate, depth of penetration and the amount of base metal dilution. Too high amperage and the amount/wire feed speed at a given travel speed will result in too high in depth of fusion or penetration as shown in Figure 1.3. Too high an amperage/wire speed for a given condition can cause excessive weld reinforcement, increased weld shrinkage, added stress and a greater chance of distortion. Too low amperage /wire feed results in inadequate penetration, lack of proper fusion, and insufficient joint fill (low deposition).



(a) Wire Feed Speed/Amperage Too Slow

(b) Wire Feed Speed/Amperage Too High

Figure 1.3 Pictures Representations of Amperage Varied Weld (Miller. 2013)

The speed the electrode travels along the joint has a direct influence on bead shape, depth of fusion, cosmetic appearance and heat input into the base metal as shown in Figure 1.4. Faster travel speeds produce narrower beads that have less penetration. This can be an advantage for sheet metal welding where small beads and minimum penetration are required. Travel speed also affects heat input, which in turn influences the metallurgical structure of the weld metal. The cooling rate increases or decreases proportionately with the travel speed. Also, the heat-affected zone will increase in size and the cooling rate decreases. If speeds are too fast, however, there is a tendency for undercut and porosity, since the weld freezes quicker. Proper speeds give gases time to escape from the molten meld before it solidifies, which reduces porosity. Very slow speeds will produce bead shapes that are subject to cracking.

(a) Travel Speed Too Fast

(b) Travel Speed Too Slow

Figure 1.4 Pictures Representations of Travel Speed Varied Weld (Miller. 2013)

1.3 Residual Stress in General

When steel structures are welded, a localized fusion zone is generated in the weld joint because of the high heat input from the arc and then non-uniform temperature distribution is induced due to the heat conduction. Therefore, non-uniform heat deformation and thermal stresses are included in the as-welded parts. As a result, plastic deformation is retained within the weldment and nonlinear plastic deformation and residual stresses exist after cooling of the welded joint. Different parameters determine the amount of the residual stresses and its distribution pattern in welded joints. The major parameters are (Leggatt, 2008);

a) The geometry of the parts being jointed
b) The material properties of the weld and parent materials, including composition, microstructure, thermal properties and mechanical properties

c) Residual stresses which exist in the parts before welding, resulting from the processes used to manufacture the components and fabrication operations prior to welding

d) Residual stresses generated or relaxed by manufacturing operations after welding or by thermal or mechanical loading during service life

1.4 Problem Statement

Currently most common problem faced by manufacturer is to control process input parameter to obtain a good welded joint with required quality in strength with minimal detrimental residual stresses and distortion. The process requires sufficient control parameter to provide electric current to melt both the electrode and a proper amount of base metal. Most of the research study in welding area by researcher related with welding optimization characteristic as mentioned in Gas metal arc welding optimization using Genetic Algorithm (Correla D.S et al., 2007), Optimization of weld bead geometry in TIG welding process using GRA and Taguchi method (Esme et al., 2009) and Finite element analysis of residual stress in butt welding two similar plate (Dragi Stamenkovic and Ivana Vasonic, 2009)

The researcher has agreed on their conclusion; in order to find the optimum quality of welded joint, it is necessary to predict the suitable amount of combination of welding parameter using optimization methods to minimize residual stress and distortion. By optimized and control the welding process parameter the quality of welds can be produced consistently at high production rates and lowest labour costs by unskilled operators.

1.5 Objectives of the study

Generally, this study concern about the welding process parameter on the welding joint which is influenced the strength of joining and metallurgy of welding structure. Specifically the objectives of the study are listed as below:

i. To determine welding parameter
ii. To determine values of optimized welding parameters
iii. To determine the residual stress of optimized and non-optimized welding parameters using finite Elements Analysis

1.6 Scope and Limitation

The research is subjected to the following scope and limitation:

i. The welding joint experiment is based on butt-joint weld using Robotic Gas Metal Arc Welding (GMAW) model OTC- AII- B4 (DAIHEN) and the material selection is Low carbon steel (A1008) which have thickness 6.0 mm.
ii. The welding parameter selection in this study is welding voltage (V) volt, welding current (A), and welding speed (S) cm/min.

iii. A Tensile Strength, Hardness and Elongation of Mechanical property was selected as a function variable in this experiment.

iv. The analysis and the modeling simulation are done by ANSYS Finite element software using three dimensional methods.

v. The finite element analysis is conducted in residual stress distribution.

The research has a few assumptions:

i. Others variables such as nozzle to plate distance and amperage are neglected

ii. The machine system used is assumed stable

1.7 Thesis Organization

This report consists of five chapters.

Chapter 1 gives brief introduction about Gas Metal Arc Welding (GMAW), Finite element analysis, the project objective and scope of the project.

Chapter 2 discusses about welding quality, welding parameter optimization, finite element welding simulation and Grey relation Analysis (GRA) procedures as the parameters estimation technique.

Chapter 3 describe the methodology used in this projects, data acquisition and how collecting the data. This chapter discusses about operational framework, step in specimen preparation, Gas metal arc welding process and steps to make tensile shear test. Procedure to running welding simulation and their data equitation also was described.

Chapter 4 presents the results of performance characteristic (tensile strength, hardness and elongation) as the part of the welding optimization. The result of validating and confirmation by Analysis of Variance (ANOVA) and thermal analysis results as a part of welding simulation also was presented.

Chapter 5 consist of the conclusion and the recommendation of the project for future work

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