Faculty of Manufacturing Engineering

THE EFFECT OF COLD ARC GAS METAL ARC WELDING (GMAW) HEAT INPUT TO THE 304L STAINLESS STEEL JOINT

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THE EFFECT OF COLD ARC GAS METAL ARC WELDING (GMAW) HEAT INPUT TO THE 304L STAINLESS STEEL JOINT

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DECLARATION

I declare that this thesis entitle "The Effect of Cold Arc Gas Metal Arc Welding (GMAW) Heat Input To The 304 Stainless Steel Joint" is the results of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

Name : ....

Date : ....

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Manufacturing Engineering (Advance Materials and Processing).

Signature :…………………………………..

Supervisor Name :…………………………………..

Date :…………………………………..

DEDICATION

This work is humbly dedicated to all my valuable treasures in my life:

To my beloved father,

Yuza Bin Mohamed Yassin

To my lovely mother,

Hasnah Binti Yunus

To my respected supervisor,

PM.DR.Nur Izan Syahriah Binti Hussein

My precious siblings,

My honourable lectures and my friends for

the infinity of support, encouragement, cooperation and understanding given.

Thank you so much

ABSTRACT

The Cold Arc welding is a modification from gas metal arc welding (GMAW) technology which resulted in narrow fabrication tolerances, enhanced the quality of the weld and improved the welding productivity. It is a processed that reduced the heat input which is gained by controlling the ‘short arc’ process or also known as short circuiting metal transfer mode. Heat input employed significance role in controlling the weld response and affected the weldment properties. It was responsible in controlling the factor for thermochemical occurrence that happen in weld pools, it makes way for the cooling to alter the chemistry of weld metal. Welding of thin sheet metal products is very susceptible to distortion and deformation, caused by the thermal expansion of the material due to the welding heat input. It is still a huge challenge today as the corrosion resistance and mechanical properties are being affected when there was change in the microstructural that occurs while welding and at the weld joint. Thus in this project, it focus on Cold Arc GMAW with the aim to investigate the effect of heat input of Cold Arc GMAW to the 304SS joint. Good well quality referred to minimum value of the weld width and maximum value of the penetration depth. The optimum value for the penetration depth and width of bead weld is found at welding voltage 20 V and welding speed 5 mm/s at sample 4. The maximum Ultimate Tensile Strength (UTS) is 546.701 MPa which is high heat input however due to the burn out the sample is rejected. Therefore, the best sample compare to other is the sample 4 with UTS of 477.606 MPa, heat input of 546.701 J/mms, welding speed of 5 mm/s and welding voltage of 20 V.

ABSTRAK

Kimpalan Cold Arc adalah modifikasi dari teknologi kimpalan arka logam gas (GMAW) yang menghasilkan nilai fabrikasi yang kecil, meningkatkan kualiti kimpalan dan produktiviti kimpalan. Ia adalah proses yang mengurangkan input haba dengan mengawal proses 'short circuit' atau juga dikenali sebagai mod pemindahan logam litar pintas. Input haba memainkan peranan penting dalam mengawal tindak balas kimpalan dan mempengaruhi kimpalan. Ia bertanggungjawab dalam mengawal termokimia yang berlaku di kolam kimpalan, yang mana ia memberi penyejukan untuk mengubah kimia logam kimpalan. Mengimpal produk logam yang nipis sangat sensitif terhadap distorsi dan bentuk, disebabkan oleh pengembangan haba bahan. Ini masih merupakan cabaran besar kerana ketahanan kakisan dan sifat mekanik terjejas apabila terdapat perubahan struktur mikro yang berlaku semasa kimpalan dan pada sambungan kimpalan. Oleh itu, projek ini, tertumpu pada Cold Arc GMAW dengan tujuan untuk mengkaji kesan input haba Cold Arc GMAW pada sambungan 304SS. Kualiti sumur yang baik adalah minimum lebar kimpalan dan maksimum kedalaman penembusan. Nilai optimum untuk kedalaman penembusan dan lebar kimpalan manik dijumpai pada voltan kimpalan 20 V dan kelajuan kimpalan 5 mm / s pada sampel 4. Kekuatan Tegangan maksimum (UTS) ialah 546.701 MPa yang merupakan input haba tinggi namun disebabkan oleh sample terbakar, ia tidak diterima. Jadi, sampel yang terbaik di antara sampel adalah sampel 4 dengan UTS 477.606 MPa, input haba 546.701 J / mms, kelajuan kimpalan 5 mm / s dan voltan kimpalan 20 V

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TABLE OF CONTENTS **PAGE**

CHAPTER 4

4. RESULTS & DISCUSSION

CHAPTER 5

5. CONCLUSION & RECOMMENDATION FOR FUTURE WORK

LIST OF TABLES

LIST OF FIGURE

LIST OF ABBREVIATIONS

A	-	Ampere
L	-	Low
H	-	Heat input
V	-	Voltage
wt.%	-	Concentration
C	-	Carbon
AISI	-	American Iron and Steel Institute
TIG	-	Tungsten Inert Gas
MIG	-	Metal Inert Gas
MAG	-	Metal Active Gas
CW	-	Cold Wire
FCC	-	Face Centered Cubic
I	-	Current
HAZ	-	Heat Affected Zone
SS	-	Stainless Steel
UTS	-	Ultimate Tensile Strength
MPa	-	Mega Pascal

CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter elaborate about the background of study, problem statement, objectives, research scopes and together with the significant of the project.

1.2 Background of study

Welding is generally the most preferable process in order to fabricate stainless steel (SS) structure. SS have been used widely in vast industry especially the austenitic stainless steels due to their superb performance in resist the corrosion, excellent in mechanical strength during high temperature, and high fracture toughness at low temperature (Mosa, Morsy, & Atlam, 2017). This steel are typically being include in applications to be use as nuclear structural material for reactor coolant piping, petrochemical industries, petrochemical industries, valve bodies, , dairy industries, vessel internals etc.

One of the welding processes that were popular in the arc welding is the gas metal arc welding (GMAW) method because it can be used in many ranges of applications and without drawbacks. However, thermal deformation occurred in welding the thin material because of huge amount of heat input to the material that give effect to the properties of the welded joint and it still a problematic to the industry (Gucwa *et al.,* 2019). Not only that the formation of coarse grain and carbide usually happened in common arc welding which located along the grain boundaries in heat affected zone (HAZ) (Tabish *et al.*, 2014). Hence, the Cold Arc welding method is a suitable welding process and it is an alternative version of the GMAW method, with low heat input, low spatter and controlled short circuit transfer.

The Cold Arc welding is a modification from gas metal arc welding (GMAW) technology which resulted in narrow fabrication tolerances, enhanced the quality of the weld and improved the welding productivity (Sabdin, 2019). It is a processed that reduced the heat input which is gained by controlling the ‘short arc’ process or also known as short circuiting metal transfer mode (T.Chen , S.Xue , B.Wang, 2019). The process controlled the short circuit is generated between workpiece and filler type electrode of Metal Inert Gas (MIG) or Metal Active Gas (MAG) welding. The benefit of this welding came from the combination of new type of inverter switching which is highly dynamic together with digital current control which is very fast. When the short arc are re-ignited, it will reduced the peak power in the arc and it happened because the digital signal processor manage in the instantaneous extraction of the power just before re-ignition in a period of less than 1 μs (Dompablo, 2013). Figure 1.1 shows the comparison between the waveform of the conventional process with the Cold Arc process.

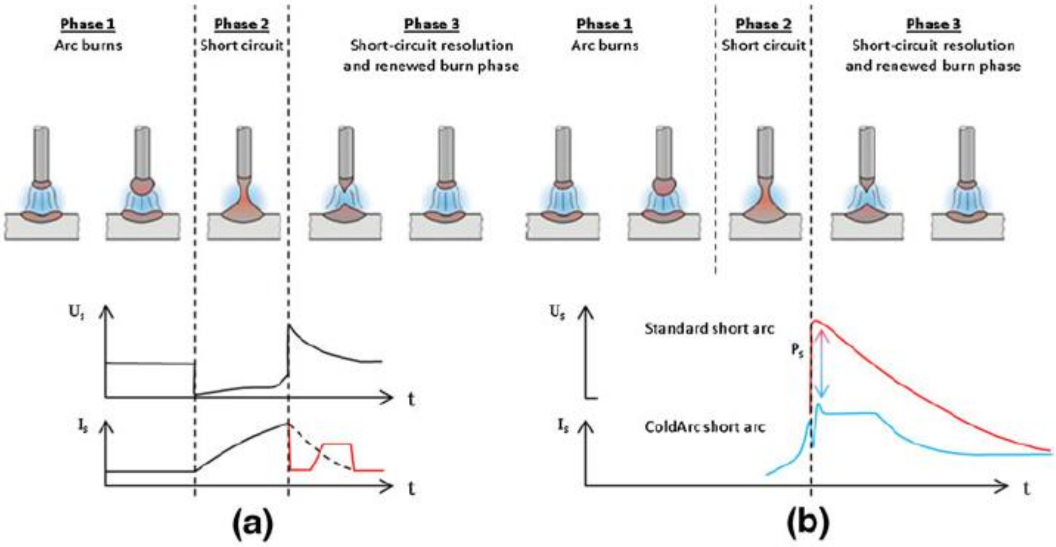

Figure 1.1: (a) The principle of a Cold Arc voltage and current waveforms, (b) Re-ignition power on Cold Arc process (Kah, Suoranta, & Martikainen, 2013)

Based on the figure in Cold Arc process it tells that the initial two steps was same with the conventional short circuiting where the current and voltage was fixed at the required steady level when the electrode approaches the workpiece in the phase of the arc burning. When the electrode reached the workpiece the arc phase stops. The pinch effect occurred when there are sharply increases in current and drop of the voltage to almost zero. The spatter is prevented due to when the bridge of the molten metal have smooth break that occurred when the current is dramatically decreased. The output was reduced immediately after the arc ignites in a dynamic and controlled method as shown in figure 1(a).In short period of time after the arc has been stabilised, there are slightly increased in current which in other terms being called as melt pulse in order to generate a separation that is regular. The melt pulse make the electrode melts at the edge and give an assurance to the process so it is smooth continuity (Kah *et al.*, 2013). Thus, by using Cold Arc welding by the time the arc is re-ignition the power output is reduced compare to a typical short arc process.

There are several parameters that involved in welding process which affected the weldment properties. Among them, heat input hold the most significance role in order to control the weld response because it was responsible in controlling the factor for thermochemical occurrence that happen in weld pools, it make way for the cooling to alter the chemistry of weld metal (T. Abioye, 2017). Heat input (H) is described as the electrical power provided by the weld arc to the workpiece (S.Rizvi & Ahamad, 2018). It is expressed as the following equation:

$$H = (I \times V) / S \tag{1.1}$$

Where I is the welding current in ampere; V is the arc voltage in volt; and S is the welding speed or arc travel speed in mm/s. The increasing in heat input can caused cooling rate of the welding joint to be slower (Vahman *et al.,* 2020). In order to maintained the welding mechanical resistance and corrosion properties the welding energy should be high enough to create suitable amount of austenite and prevent precipitation of undesired phases (Souza *et al.,* 2019).

The heat input is still a major problem in the welding industry as the manufacturers are adopting the use of light and thin materials. Welding of thin sheet metal products is very susceptible to distortion and deformation, caused by the thermal expansion of the material due to the welding heat input. It is still a huge challenge today as the corrosion resistance and mechanical properties are being affected when there was change in the microstructural that occurs while welding and at the weld joint.

For this project, the Cold Arc process will be done on the 304L stainless steel joint where the plate is 3 mm thick. AISI 304L is known as an austenitic stainless steel Chromium-Nickel that offers the perfect combination in terms of corrosion resistance, ductility and strength (Abioye *et al.*, 2019). The L grades contain less than 0.03 wt. C where the carbon content is low in volume compare to other grade which is H and straight grade, becoming vulnerable to formation of carbide precipitation during the welding process and improved weldability.

18-8, or 18/8 stainless steel is the most basic form of 304L SS which mean that the stainless steel contains of 18 percent chromium and 8 percent nickel in the element. 304 SS can withstand corrosion from most oxidising acids and useful for cryogenic applications where it is result from their strong impact strength at low temperatures (Gite & Pawar, 2016; Thameem & Kumaraan, 2017). In the solution of annealed condition the austenitic grades are non-magnetic because of it austenitic microstructure was a primary crystalline structure (face centered cubic, FCC) and the heat treatment will not make the crystalline structure austenitic steels hardenable thus making them non-magnetic (Kumar *et al.*, 2015; Lee, Hwang, Yang, & Kim, 2019) .

According to few past researches, 304L SS is often joined through gas tungsten arc welding (GTAW), GMAW , shielded metal arc welding (SMAW) ,Cold Metal transfer

(CMT) and others (Costanza, Sili, & Tata, 2016; N. Switzner, H. Querioz, J. Deurst, 2017; Selvi, Vishvaksenan, & Rajasekar, 2018; Singh & Shahi, 2018). However there was no study found using the Cold Arc welding on the 304L SS.

Sabdin *et al.,* (2019) found that ideal combination of welding parameter is needed so that there was absence in the mechanical failure for the heat affected zone (HAZ) and it will maintain the corrosion performance. Since the welding parameter which is welding speed, voltage and current was influence by the heat input, the amount of heat input should be controlled by adjusting the welding parameters.

Thus for this project, it will focus on Cold Arc GMAW which aim to investigate the effect of heat input of Cold Arc GMAW to the 304SS joint. Analysis of the strength of the joint also was discussed to look for good weld joint quality.

1.3 Problem Statement

304 Stainless Steel come from Austenitic Stainless Steel (SS) group and it being extensively used in wide variety of industries since the middle of the 20th century (Taiwade, Patil, Ghugal, Patre, & Dayal, 2013). In the engineering application, the usage of those SS reactors have increasingly gaining attention, for example in oil and gas which was utilize in pipeline welding, in the chemical industries that was utilize in the pressure vessels and also in the fusion of construction of structural parts (T. E. Abioye et al., 2019). 304L SS will have excellent properties in resisting the corrosion furthermore with the combination of mechanical properties that is acceptable at elevated temperatures (Teker &

Kuṛsun, 2017). The basic form of 304 SS is 18-8, or 18/8, stainless steel, it consists of 18 percent chromium and 8 percent nickel (Thameem & Kumaraan, 2017). 304L SS are usually used when intergranular corrosion is concern. However during welding process when it was put at critical temperature range which is between 600°C to 800°C, the chromium precipitates from the matrix and produce the chromium carbides at the edges of the grain. The condition then creates a chemical inhomogeneity in the surrounding grain that was resulted from the formation of chrome carbides. The chromium content depleted with respect to the base material. The material is then become susceptible to the corrosion when the surrounding have chromium content less than about 13 wt. % due to the precipitates occurrence (Kondapalli Siva Prasad, 2014; Sabdin, 2019) . The issue of the heat input in welding become worse as manufacturers are adopting the use of light and thin materials. Large value of heat input to the material will affected the properties of the welded joint and is problematic in welding thin-walled elements because of thermal deformation (Singh & Shahi, 2018). As for the metal industry especially when dealing with thin material, Cold Arc welding method is the suitable welding process compare to conventional arc welding because it is a processed that reduced the heat input. Beside that the conventional arc welding, such as GMAW, GTAW and other arc welding is often lead to more challenges. These challenges involve, a large heat affected zone (HAZ), hot cracking, worse quality of the joint and failure to meet the rapidly increasing production throughput requirements (Yazdian, Mohammadpour, Kong, & Kovacevic, 2018). Not only that, there will be coarse grain created and rise in formation of the carbide along the edge of the grain in HAZ. Both of the formation in coarser structure and carbides can worsen the mechanical properties of the weldment joint because it was rich in chromium. It is observed that no research work is available which reports about the effect of heat input of

Cold Arc GMAW welding on the 304L SS. Thus in this research, investigation on the effect of heat input to the 304SS joint was done by using Cold Arc technology. Hence, it required genuine selection of welding parameters to gained a good quality welds because generally, the welding parameter will directly influenced the quality of a weld joint which is during the welding process (Swami, Jadhav, & Deshpande, 2016).

1.4 Objectives

The objectives of this study are:

i. To analysis the effect of parameter of the Cold Arc welding towards width of bead and depth of penetration by using Smart Weld simulation.

ii. To investigate the effect of heat input of Cold Arc welding to the 304 Stainless Steel joint.

iii. To analyse the strength of the 304 Stainless Steel joint.

1.5 Scopes of the study

The purpose of this research is to justify how the heat input will affected the austenitic Chromium-Nickel SS which is the 304L SS joint by using the Cold Arc GMAW. In aiming to find heat input that will enhance the quality of the weld joint; the study was conducted with the selected parameters. Since there are limited information about Cold Arc welding the preliminary experiment was done in order to gain suitable parameter. Smart weld simulation was used to predict the penetration depth between the joint and the width of the weld bead.

As for the first objectives, to analysis the effect of parameter of the Cold Arc welding towards weld bead width and the depth of penetration the value of the parameter gained was key-in the Smart Weld simulation . Parameters that will be used are welding current, current speed and welding voltage. Smart Weld is a set of science based software applications which ease us to predict the width of bead size and depth of penetration. Not only that, it can estimate the impact of welding on the design.

Next, in order to investigate the effect of heat input of Cold Arc welding to the 304 SS joint, the sample will undergo the welding process with the selected parameter. The heat input then was calculated by using equation 1.1 and was analysed based on visual observation on the specimen which using different parameters that are designed during the experiment.

The specimen was cut in dog-bone shape using wire cut on electric discharge machine (EDM) and was tested on Universal Tensile Machine (UTM) for the tensile test to achieve the third objective which is to analyse the strength of the 304 Stainless Steel joint.

1.6 Significance of the study

There are some potential benefits that can be gain from this study. The appeal benefit is that the issue of heat input on thin material will decreased because this Cold Arc welding is a processed can make the amount of heat input on the base material much lower than other process. The thermal deformation wills not occurred and welding thin-walled elements no longer a big deal. Others is it can give the excellent corrosion resistant joints , resulted in narrow fabrication tolerances, enhanced the quality of the weld and improved