UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Manufacturing Engineering

SIMULATION OF WIRE AND ARC ADDITIVE MANUFACTURING OF 308L STAINLESS STEEL WITH COLDARC GAS METAL ARC WELDING

Nur Aisyah Nabilah binti Mohd Jmmani

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NUR AISYAH NABILAH BINTI MOHD JMMANI

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in fulfillment of the requirements for the degree of Master of Manufacturing Engineering (Industrial Engineering)

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2021

DECLARATION

I hereby, declared this report entitled "Simulation of Wire and Arc Additive Manufacturing of 308L Stainless Steel with ColdArc Gas Metal Arc Welding" is the result of my own research except as cited in references.

Signature : ....

Name : NUR AISYAH NABILAH BINTI MOHD JMMANI

Date : 10/9/2021

APPROVAL

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

Signature : ……………………………

Supervisor Name : PROF. MADYA DR. NUR IZAN SYAHRIAH BINTI HUSSEIN

Date : 10/9/2021

DEDICATION

Dedicated to

my cherished father, Mohd Jmmani bin A. Jamil

my loved mother, Hadibah binti Rapiei

my adored sister and brother, Nurulizzati binti Mohd Jmmani, Muhammad Firdaus bin Mohd Jmmani, and Muhammad Syafiq bin Mohd Jmmani

for providing me with moral support, financial assistance, collaboration, motivation, and comprehension.

Thank You and I Will Always Love You

ABSTRACT

This objective is to study the effect of parameters on coldArc GMAW of 304L stainless steel plate using 1.2 mm diameter of 308L stainless steel welding wire. A Taguchi response of Design of Experiments (DOE) using Minitab software with 9 experiments following the Taguchi L9 Orthogonal Array Design was performed to optimize the output response of simulation data for length, width, and depth of weld bead dimension from MATLAB of Smart Weld Rosenthal's Steady-State 3D Isotherms. The simulation was conducted using input power (current and voltage) and welding speed with low, medium, and high which include 70 A, 75 A, and 78 A (arc current), 15 V, 16 V, and 17 V (voltage), 400 mm/min, 600 mm/min, and 800 mm/min (welding traveling speed). Based on the Taguchi analysis predicted the best result from the simulation work for weld bead dimensions (height and width) and depth of penetration would be obtained when the optimized values for weld parameters was 75 A, 16 V, and 800 mm/min. The most significant parameters to deposit stainless steel with coldArc GMAW were welding travel speed followed by arc current and voltage. These factors are critical in controlling the weld height, width, and depth of penetration, whereby high heat input affects mechanical and microstructure changes and decreases the weld efficiency of the finished product and create energy loss.

ABSTRAK

Objektif ini adalah untuk mengkaji kesan parameter pada ColdArc GMAW dari plat keluli tahan karat 304L menggunakan wayar kimpalan keluli tahan karat berdiameter 1.2 mm berdiameter 1.2 mm. Respons Taguchi dari Design of Experiments (DOE) menggunakan perisian Minitab dengan 9 eksperimen mengikuti Taguchi L9 Orthogonal Array Design dilakukan untuk mengoptimumkan tindak balas output data simulasi untuk panjang, lebar, dan kedalaman dimensi manik kimpalan dari MATLAB Smart Weld Rosenthal's Isoterma 3D Steady-State. Simulasi dilakukan menggunakan daya input (arus dan voltan) dan kelajuan kimpalan dengan rendah, sederhana, dan tinggi yang meliputi 70 A, 75 A, dan 78 A (arus busur), 15 V, 16 V, dan 17 V (voltan) , 400 mm / min, 600 mm / min, dan 800 mm / min (kelajuan perjalanan kimpalan). Berdasarkan analisis Taguchi diramalkan hasil terbaik dari kerja simulasi untuk dimensi manik las (tinggi dan lebar) dan kedalaman penembusan akan diperoleh apabila nilai yang dioptimumkan untuk parameter kimpalan adalah 75 A, 16 V, dan 800 mm / min. Parameter yang paling penting untuk meletakkan keluli tahan karat dengan ColdArc GMAW adalah kelajuan perjalanan kimpalan diikuti oleh arus arka dan voltan. Faktor-faktor ini penting dalam mengawal ketinggian, lebar, dan kedalaman penembusan kimpalan, di mana input haba yang tinggi mempengaruhi perubahan struktur mekanikal dan mikro dan menurunkan kecekapan kimpalan produk akhir dan mewujudkan kehilangan tenaga.

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LIST OF ABBREVIATIONS

AHSS	-	Advanced High Strength Steels
Al	-	Aluminium
AM	-	Additive Manufacturing
ANOVA	-	Analysis of Variance
Argon	-	Argon
ASTM	-	American Society for Testing and Materials
AWS	-	American Welding Society
C	-	Carbon
CMT	-	Cold Material Transfer
CNC	-	Computer Numerical Control
O_2	-	Oxygen
CO_2	-	Carbon Dioxide
Cr	-	Chromium
CR	-	Cooling Rate
Cu	-	Copper
DCEP	-	Direct Current Electrode Positive
EBM	-	Electron Beam Melting
FA	-	Ferrite-Austenite
Fe	-	Iron
GMAW	-	Gas Metal Arc Welding
GMAWAM	-	Gas Metal Arc Welding Additive Manufacturing
GTAW	-	Gas Tungsten Arc Welding

HAZ	-	Heat affected zone
HDR	-	High-Deposition-Rate
ISO	-	International Organization for Standardization
LAM	-	Laser Arc Melting
LCA	-	Life Cycle Assessment
LSC	-	Low Spatter Control
MAG	-	Metal Active Gas
Mg	-	Magnesium
MIG	-	Metal Inert Gas
Mn	-	Manganese
Mo	-	Moleybdenum
NDT	-	Nondestructive Testing
Ni	-	Nickel
OA	-	Orthogonal Arrays
OM	-	Optical Microscope
P	-	Phosphorus
PAW	-	Plasma Arc Welding
RVI	-	Remote Visual Inspection
S	-	Sulphur
Si	-	Silicon
SS	-	Stainless Steel
WAAM	-	Wire and Arc Additive Manufacturing
WEDM	-	Wire-Cut Electrical Discharge Machining
Zn	-	Zinc

LIST OF SYMBOLS

A	-	Ampere
GPa	-	Giga Pascal
I	-	Current
kg/hr	-	Kilogram per Hour
MPa	-	Mega Pascal
mm	-	Millimeter
mm/min	-	Millimeter per Minute
%	-	Percent
(S/N)	-	Signal to Noise
U	-	Voltage
v	-	Travel Speed
V	-	Volt

CHAPTER 1

INTRODUCTION

This chapter consists of a research overview about wire and arc additive manufacturing (WAAM) using 308L stainless steel wire by coldArc of Gas Metal Arc Welding (GMAW). Hereby states the research background, problem statement, and also the objectives of the research to make sure the report is well planned for the future experiment. Aside from that, the scopes of the study and the significance of the research are discussed.

1.1 Background of study

The welding process, welding technology, and the materials used in welding continue to develop in response to high demand from marine applications such as sub-sea installations, underwater naval requirements, and deep-sea mining, as well as shipyard constructions and shipbuilding. Due to its corrosion resistance, machinability, hardness, and dimensional stability, WAAM, one of the AM deposition methods that employs the basic principles of GMAW welding technique, was used for stainless steel (Midawi and Santos, 2017). The WAAM, a form of additive manufacturing (AM) that uses an electric arc to melt metallic wire, is extensively used for fabricating large-scale metallic components.

As stated by (Williams et al., 2016), as engineering provision towards surrounding improvement, one of the essential aspects is the reliability of welding techniques. The previous study (Elmer and Gibbs, 2019) the GMAWAM 308L, has found without major defects/cracks deposition efficiency can reach 91% thereby in the GMAWAM process, the amount of heat input is important, and 308L stainless steel is commonly utilised in industry equipment, chemical tanks, and sheet metal applications (Le et al., 2021). At present, rapid development has upgraded by applying preferable techniques and approaches. The WAAM offers many distinct advantages as one of the four high-deposition-rate (HDR) AM processes (Elmer and Gibbs, 2019). AM offers the production on automated using systems that require an automatic work process. Besides that, welding skills have become critical in many areas of interest. Therefore, in AM welding operations, the consistency of smooth weld can be produced (Jafari et al., 2021). Strategies for welding purposes focused on the most conservative estimation of appropriate welding parameters used (Wu et al., 2019). With that, the case of WAAM can minimize raw material waste and has the advantages of high molding performance, low cost, and fast commercialization compared to manual weld.

Active cooling is a good way to improve process quality and productivity, and it is an innovative way to reduce defects on GMAW-thin-walled AM's 308L stainless steel which is with the used of coldArc system which offers less in temperature to the weld system (Rafael A. Ribeiro et al., 2019). Thus, applying coldArc GMAW techniques compared to standard GMAW offers the with the least amount of heat possible, resulting in lower power consumption hence the effect on microstructure changes can be reduced (Karayel and Bozkurt, 2020).

However, at some point of view, the parts created using the AM process have dimensional limitations. According to recent studies, metal materials produced with AM can be combined with widely used welding methods to produce large parts. This eliminates this issue as wider AM technology has been able the used alternative route computer numerical control (CNC) machining-derived methods (Michel et al., 2019). According to (Rodrigues et al., 2019), through decades, constant developments and pervasive use of welding techniques have had a remarkable impact in the manufacturing industry regarding productivity facing the new era of industrialization the needs improvement manufacturing to a new level that concurrence to the concept of modern approach indicates of AM process towards higher production, minimizing down time, increase productivity and as a result of reducing uneven process. Convinced of that, (Liberini et al., 2017) claimed, since arc welding-based AM has the advantages of lower cost and higher deposition rate, the deposition rate of laser or electron beam deposition is usually lower, while the rates of deposition of arc welding technology are much higher.

In addition, the same study apparently by (Khan and Madhukar, 2020) complies that WAAM is a technique for fabricating metal parts with high deposition rates, good mechanical properties, and excellent impact accuracy. Therefore, applying coldArc GMAWAM is a time and money-saving method as less power consumption is needed and AM process is an automated machine so that the weld is perform in shorter period of time. This method works well for both thin-gauge and heavy-gauge metal welding. Steel (and its alloys), aluminum, and magnesium are the most common metals utilized; however other metals can also be employed. While some traditional welding methods could be used as an arc source, but using the GMAW solution is eligible because of its cost-effectiveness and integrated wire feeding.

In recent years, the idea of AM of metal products has gained popularity (Cunningham et al., 2017). A low-cost metal AM device has been created by integrating cold material transfer (CMT) welding equipment and a CNC milling machine instead of other laser or electron-beam-based technologies. Likely to elaborate, this hybrid manufacturing method allows the manufacture of metallic elements regardless of their geometric shape. It has the benefits of minimizing heat accumulation generated by conventional GMAW equipment and the ability to mill after the additive process onto the surface finish. Correspondingly (Prado-Cerqueira et al., 2018) frankly preferable that it is crucial to satisfy the stringent requirements of engineering applications. One of the challenges in AM of metallic materials is obtaining defect-free workpieces with outstanding physical, mechanical, and metallurgical properties. Regardless of the AM capabilities complemented by its high productivity and precision, a collection of metal products has been developed primarily in challenging applications such as aerospace (Liu et al., 2021) and the automotive sector. In which WAAM roles towards higher production, minimizing downtime, and increasing productivity. Specific onto that (Henckell et al., 2020), WAAM using gas metal arc welding is a viable option for developing large volume metal parts. The main difficulty is the arc's substantial and periodic heat input on the formed layers, affecting geometrical properties such as height and width and metallurgical properties such as grain size, solidification, and material hardness (Ribeiro, 2020).

1.2 Problem Statement

Stainless steel is the most widely utilized material in the manufacturing of industrial equipment, chemical tanks, and sheet metal applications (Ji et al., 2017). Due to its corrosion and wear resistance, stainless steel is also called an anti-corrosive material. In fact, because to the increased thermal conductivity of the alloying components in stainless steel, the 308L stainless steel type requires more heat input to weld (Bajaj et al., 2020).

Welding is a technique for joining materials that are similar and dissimilar. Stainless steel alloys of different sorts have varied compositions. As a result, when welding different stainless steels alloys, the weldment can result in undesirable or unfavourable conditions due to differences in thermal conductivity (Ghosh et al., 2017).

WAAM has been shown to be an effective welding procedure that can overcome the drawbacks of traditional welding processes like TIG and MIG (GMAW). There have been numerous studies and researches on WAAM for the construction of 308L stainless steel weld bead dimensions (Wanwan et al., 2020). GMAW of metal deposits on thin-walled 308L stainless steel created by GMAW-AM has been examined and researched by several scholars and researchers. However, there is still a need to research cold arc GMAW in welding applications. Cold arc GMAW has yet to be explored, although it offers a lot of potential for performing welding processes with less heat input (Sabdin et al., 2019).

(Choubey and Jatti, 2014) explained that when stainless steel is welded, the material's microstructure and weld bead dimension change, particularly in the Heat-Affected Zone (HAZ). The HAZ's mechanical strength will be weakened due to the high heat input from welding. When compared to the qualities of the material before welding, the final material properties will be different. The material will be influenced at zones where heat has been absorbed during the process as a result of the above phenomenon. In addition, the rate of heat input and heat reduction affect the width of the HAZ on the material. GMAW welding's rate of heat input and heat reduction will be affected by a few parameters at the same time. Voltage, current, and travel speed are a few of the parameters.

ColdArc is a type of arc welding that uses low heat and a short arc to achieve excellent dimensional stability. ColdArc is a GMAW welding method that is unique (Ahsan et al., 2018). For welding thin plates or any sort of material, the traditional GMAW can be modified and improved to have a low heat energy potential. For modest heat input, the arc in a standard GMAW can be balanced and controlled. Low thermal energy input reduces burn-through exposure, distortion, melt pool control, and sparks (Khaliq et al., 2020). As a result, welding producers have taken advantage of the situation and investigated the possibility of low-heat welding techniques. The research has led to the creation of innovative heat-reducing welding processes, such as ColdArc and Cold Material Transfer (CMT). Because existing CMT technology has been widely used in AM, thereby my study decided to attempt employing coldArc. ColdArc is most commonly used in welding, but it is still limited for AM.

Because this is a new material property, there are only a few types of study that can be done using 308L and 304L stainless steel with coldArc GMAW welding (Costanza et al., 2016). As a result, before proceeding with the experiment, a suitable and optimum parameter must be chosen and presented. In this context, employing coldArc GMAW procedures, the quality of welding in terms of weld bead diameter of dissimilar material deposition of 308L stainless steel filler wire and 304L stainless steel base plate material will be examined.