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THERMAL SIMULATION OF DIFFERENT WELDING SPEED AND METAL THICKNESS FOR BUTT-JOINT WELDING WITH ANSYS

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by

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Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Mechanical)

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Mechanical Engineering Programme
Universiti Teknologi PETRONAS
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BACHELOR OF ENGINEERING (Hons)
(Mechanical)

Approved by,

____

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January 2015

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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MUHAMAD SAFUAN BIN SYUKRI

ABSTRACT

Welding deformation in shielded metal arc welding (SMAW) frequently related to the appearance of the weld specimen such as porosity, weld splatter, poor fusion, shallow penetration, and cracking. Deformations on the weld area will influence the joining strength and will produce a weld that prone to cracking. Deformations on the on the weld usually caused by heat input during welding process that produced uneven heating and cooling on the metal plate resulting residual stress and distortion on the weld metal. To deal with this problem, study on few welding parameters that affect the heat input delivered during joining process will be done. ANSYS Parametric Design Language (APDL) software will be used to simulate actual welding condition and the effect of variation of welding parameters in Butt-joint SMAW. Results and data interpretation from the thermal model in APDL will be acquired to get the optimum selection of welding parameters for SMAW.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

SMAW is one of the world's most popular welding process in nowadays industries. The simplicity of the process and the mobility of welding equipment gave an utmost advantages compared to other wedding process. Because of that, SMAW have been used widely in industrial fabrication, steel construction, maintenance and repair industries. The process is used primarily to weld iron, steels including stainless steels and various type of alloys such as aluminium, nickel and copper.

The basic principle of SMAW is that it uses a consumable electrode coated in flux to lay the weld as shown in Figure 1.1 [1]. An alternating current or direct current supply will produce an electric arc between the electrode and the metals to be joined. Welding is performed with the heat of an electric arc that is maintained to melts the base metal, the electrode core rod and the coating. As the molten metal droplets are transferred across the arc and into the weld pool, flux coating of the electrode will disintegrates, giving off gas that serve as a shield and providing a layer of slag which protect the weld area from atmospheric contamination during solidification [1].

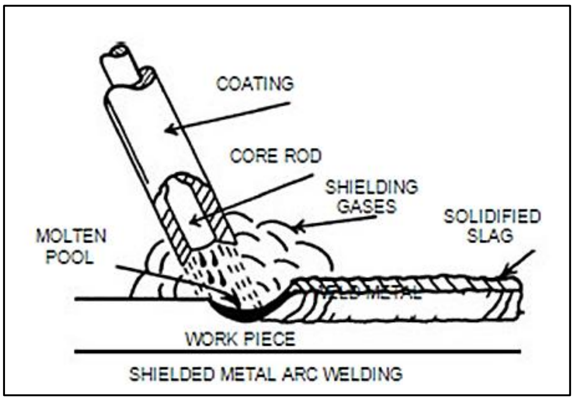

FIGURE 1.1. Schematic Diagram of SMAW [1]

Despite the simplicity of the process and the mobility of the welding equipment, SMAW process can produce undesirable joining quality. Deformation and residual stress on the weld component are among of the problem that caused by the excessive heat input generated in welding process. Welding speed is the key parameter that caused this problem and it is significant interest to simulate the basic process of SMAW in butt-joint welding. In the thermal simulation, behaviour of the distribution of the heat input will be used to analyse the optimum welding speed for the process. With the help of advance computation of Finite Element Method (FEM) by APDL, thermal effect on the metal plate will be technically illustrated.

1.2 Problem Statement

SMAW is furthermost commercial welding process in nowadays industries. Quality of the welding varies with the level skill of the operators. For beginners, producing a decent welding quality is quite challenging. Different from other welding process that required less operator skill to yield a satisfactory welding quality.

Heat input from the welding arc in SMAW will caused uneven heating and cooling on the weld metal. Because of this complex thermal stresses and strains, it will produced residual stresses resulting changes on the weld metal microstructure, which lead to the welding deformation.

Furthermore, the most common deformation in SMAW frequently related to the appearance of the weld specimen. Deformation such as porosity, weld splatter, poor fusion, shallow penetration and cracking on the weld usually caused by unsuitable welding parameters that have been selected for the welding process [2].

1.3 Objectives

- To simulate the effect of different welding speed and metal thickness in SMAW on the Butt-joint welding using APDL.
- To get optimum welding speed in SMAW according to metal thickness

1.4 Scope of Study

In this project, a brief study on SMAW will be conducted to understand the effect of welding parameters focusing on how welding speed and metal thickness will affect the manufactured goods of the welding process. Advance software based on FEM which is APDL will be used in the simulation to illustrate SMAW welding condition on Butt-joint welding. Thermal simulation of Butt-joint SMAW will demonstrate actual welding condition on the metal plate and how different welding speed and thickness of metal plate will influence the finish good of the welding process.

Interpretation of 3-dimension (3D) SMAW model on APDL will show the optimum welding speed according to different thickness of metal. To simulate actual SMAW process, welding parameters assumption based on previous study need to be prepared to accomplish a 3D model with sufficient thermal simulation accuracy. A proper heat input equation and other welding parameters such as electrical power supply, electrode selection and welding speed need to be determine based on actual welding process in the industries.

CHAPTER 2

LITERATURE REVIEW

2.1 Residual Stresses and Distortions in SMAW

Uneven heating and cooling process in SMAW caused residual stress and distortion on the weld metal due to intricate thermal stresses and strains. Similar to other conventional welding process, heat input delivered during SMAW process will affect the characteristic behaviour of the metal microstructure, thus gave a significant role in the welding deformation. Distribution of the temperature on the weld metal significantly based on welding parameters such as welding speed, thickness of the metal plate and size of the coated electrode since, it will initiate the residual stresses and distortion on the weld metal [3]. Figure 2.1 shows the type of welding deformation in welding process [4].

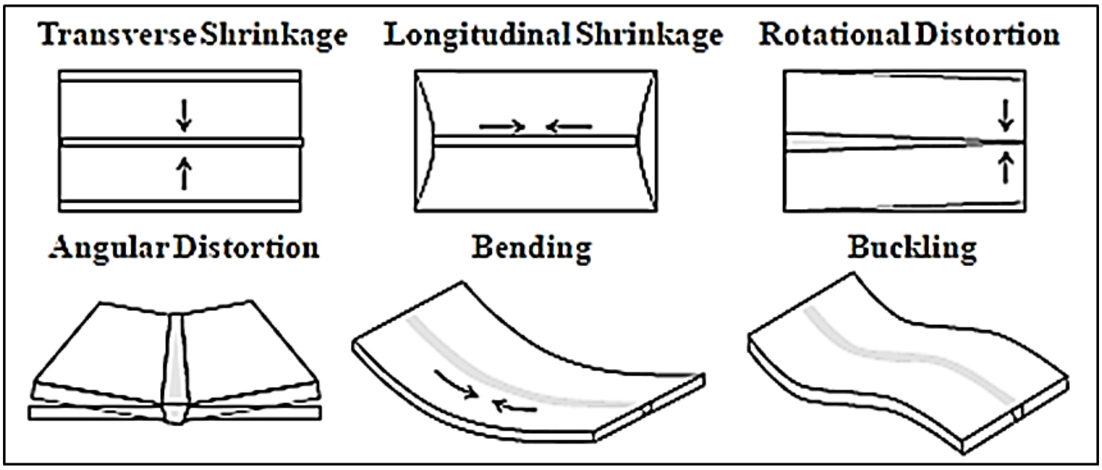

FIGURE 2.1. Type of Welding Deformation in Welding Process [4]

2.2 Welding Simulation Using APDL

In modern engineering practice, study of various welding processes were established with the help of advance computational and simulation tool method similar to FEM. Figure 2.2 shows the temperature distribution on welded plate on APDL [5]. Design and data assumption can be used in simulation to calculate welding distortions and residual stresses. Nonetheless, simulation and calculation of welding distortions and residual stresses are quiet challenging. This is due to intricate geometry of the weld components and the complexity of the welding process parameters. Therefore, it is important to have a deep understanding on the influence on the welding parameters so that effective simulation can be develop with sufficient thermal and mechanical analysis accuracy of the welding process [5].

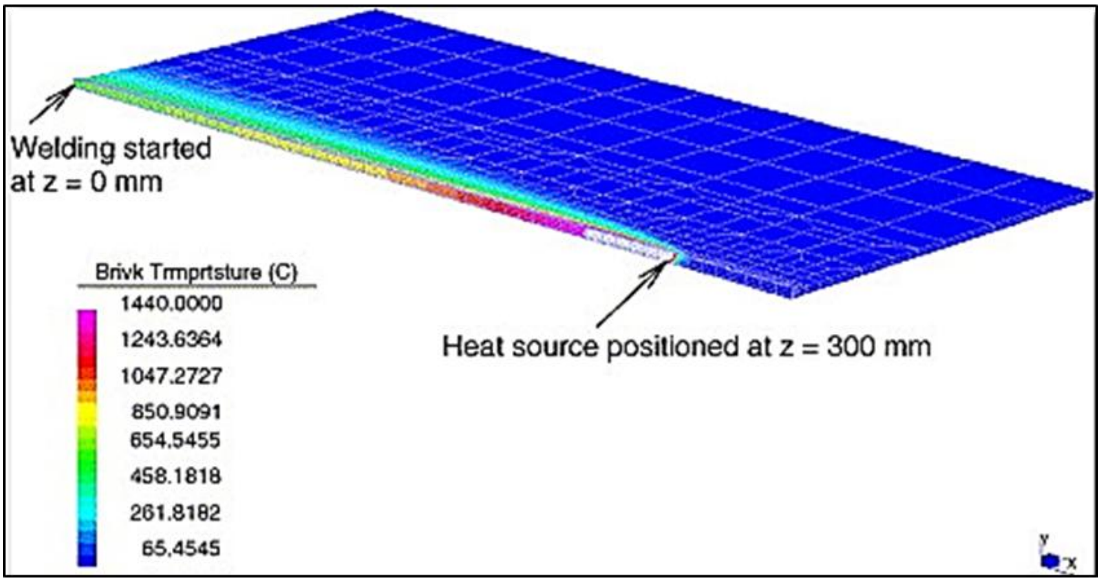

FIGURE 2.2. Temperature Distribution on Welded Plate on APDL [5].

2.3 Effect of Welding Speed on Weld Metal

Previous study has shown that welding speed is one of the main factor that influence the heat distribution along the weld metal. Figure 2.3 shows the effect of travel speed on the residual stress on the welded plate [6]. According to [6], similar weld size with different travel speed produce dissimilar heat distribution pattern. Residual stresses not only reduces but it is also lessens the volume of metal affected by the heat input form the arc when higher welding speed was applied. This effect can be explained by the narrower isotherm that produced during higher welding speed that effect transverse shrinkage of butt welds.

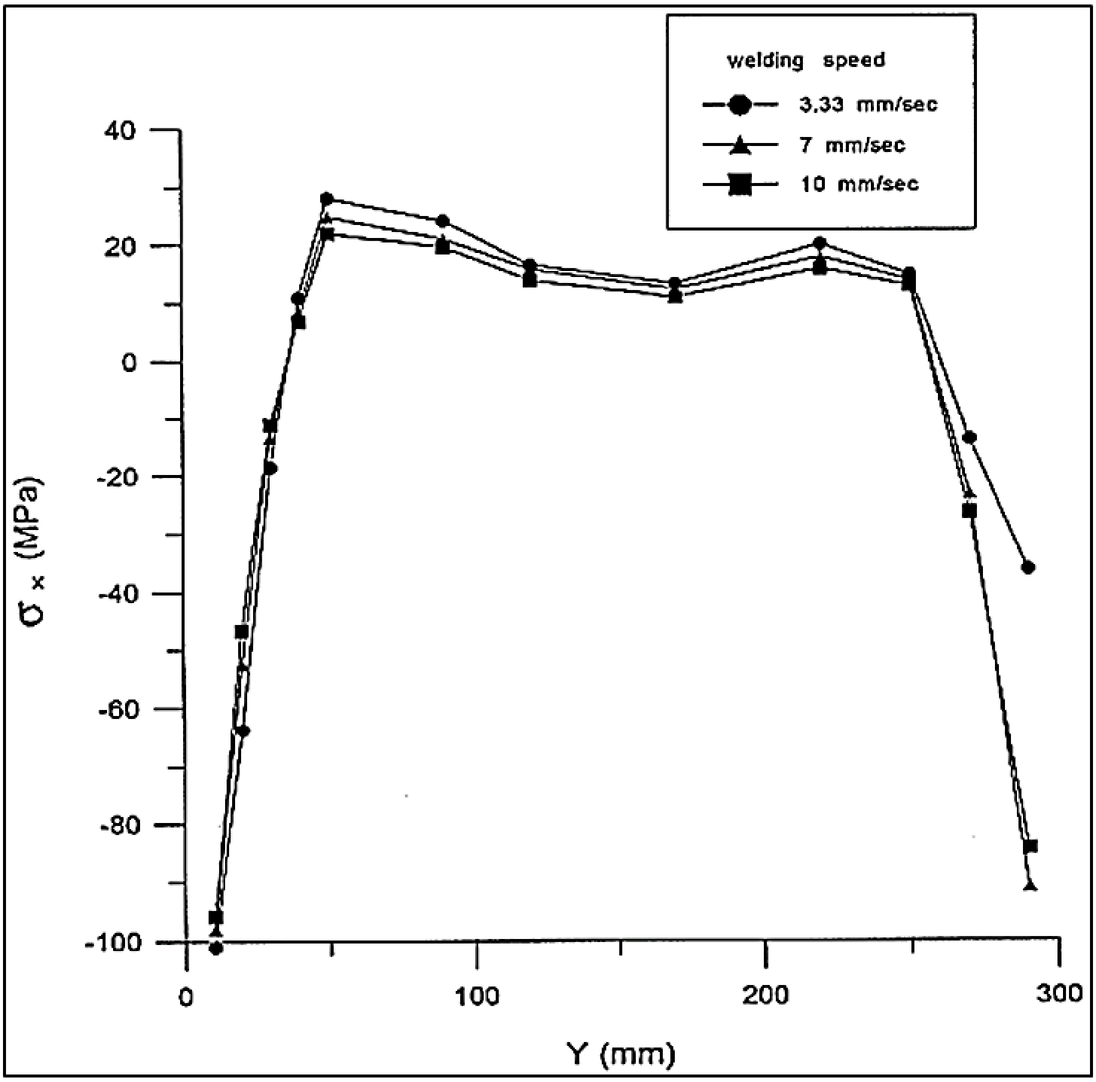

FIGURE 2.3. Effect of Travel Speed on the Residual Stress on the Welded Plate [6]

Optimum welding parameters particularly welding speed have to be attain to yield a decent welding quality. According to previous study [7], a lesser amount of heat input will be distributed along the Butt-joint when higher welding speed had been applied causing less volume of metal melts on the weld area. Furthermore, higher welding speed delivered a shallow penetration on the joints resulting narrower fusion zone and heat affected zone on the weld specimen. Simultaneously, this effect will influence the welding strength on the Butt-joint.

2.4 Residual Stresses on Different Plate Thickness

Furthermore, residual stresses in the weld specimen can be reduce if SMAW were applied to thicker metal specimen. Previous study [3] has been conducted on different weld specimen thickness to clarify the hypothesis. It has been proven that weld specimen with thicker dimension is able to absorb more energy per unit volume. Whereby in this case, the distribution of tensile stress always acting from the top layer of butt joint welding and decreasing as it travel to the bottom part of the weld specimen, resulting the reduction in residual stresses with thicker specimen thickness. Figure 2.4 shows the peak temperature of heat distribution on different metal plate thickness [3].

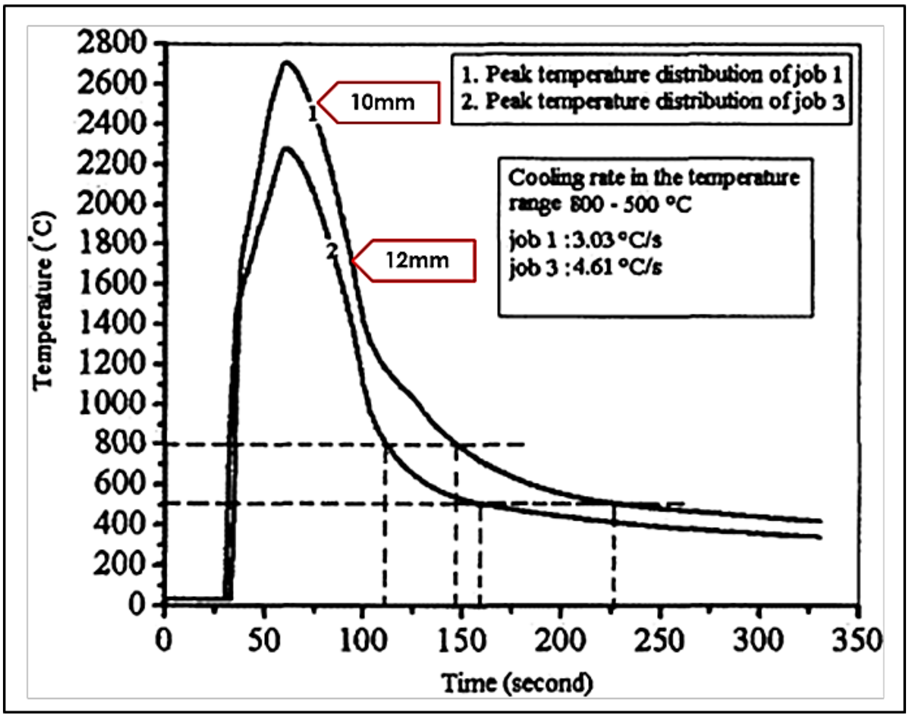

FIGURE 2.4. Peak Temperature of Heat Distribution on Different Metal Plate Thickness [3]

CHAPTER 3
METHODOLOGY

3.1 Project Flowchart

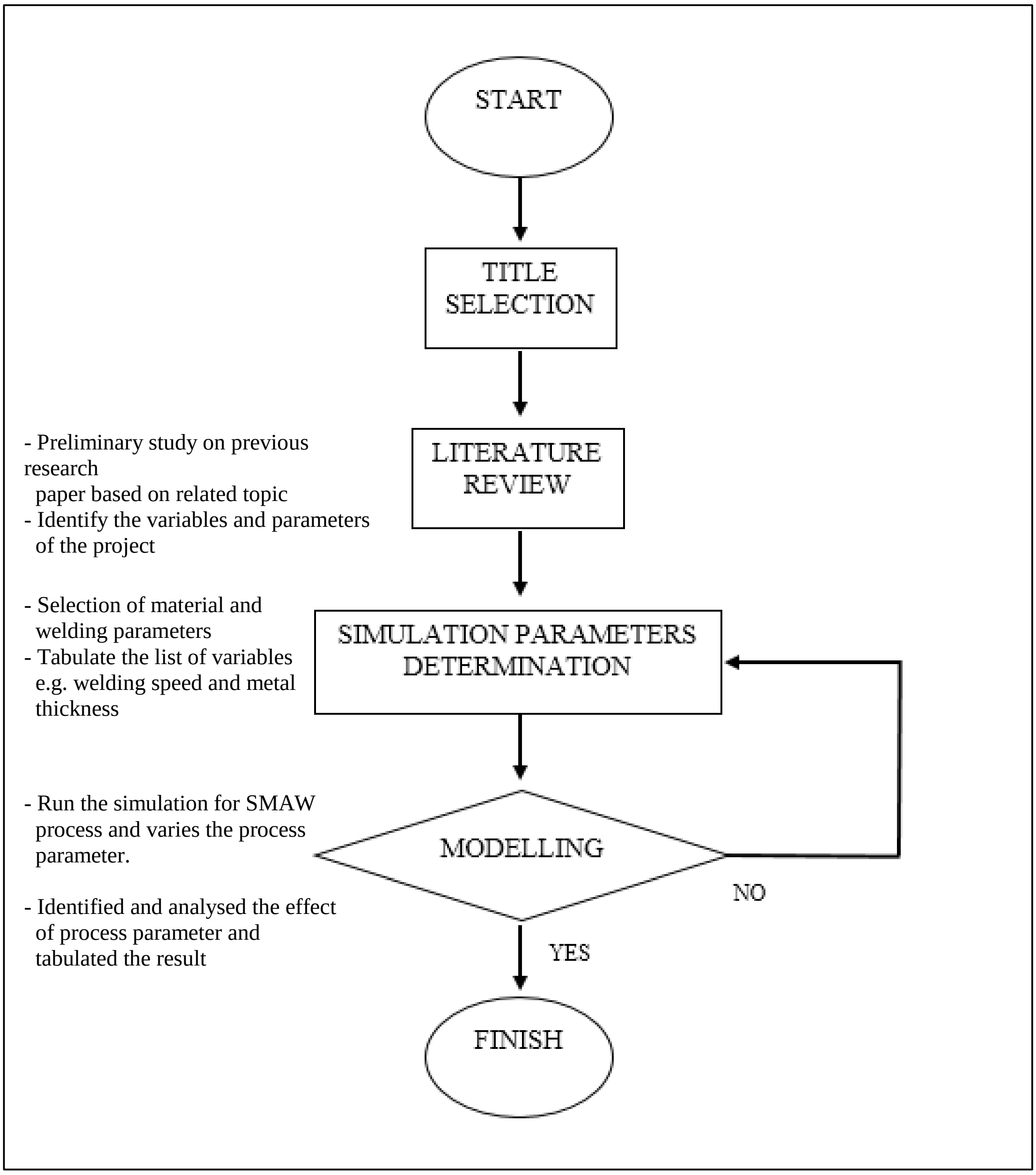

FIGURE 3.1. Flowchart of the Project

3.2 Project Gantt chart

TABLE 3.1. Final Year Project 1 Gantt chart

NO	FINAL YEAR PROJCT 1	WEEK													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Title selection & allocation		●												
2	First meeting with project supervisor		●												
3	Extended proposal preparation														
3.1	Background of study														
3.2	Literature review														
3.3	Problem statement														
3.4	Objectives														
3.5	Methodology														
3.6	Project milestone														
4	Submission of extended proposal						●								
5	Proposal defence									●					
6	Interim Report preparation														
6.1	Abstract														
6.2	Introduction														
6.3	Literature review														
6.4	Methodology														
6.5	Key project milestone														
6.6	Gantt Chart														
6.7	Summary of future work														
7	Submission of Interim Draft Report													●	
8	Submission of Interim Final Report														●

TABLE 3.2. Final Year Project 2 Gantt chart

NO	FINAL YEAR PROJECT 2	WEEK													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
9	Project work continues														
10	Submission of progress report							●							
11	Project work continues														
12	Pre - SEDEX														
13	Submission of final draft report														
13.1	Submission of desertation (soft bound)														
13.2	Submission of technical paper												●		
14	Project Viva													●	
15	Submission of project desertation														●

Key Milestones of the project ●

Process

3.1 Simulation Tools and Materials

3.3.1 Software Selection

Thermal simulation of SMAW process on butt joint for this project will be done by using APDL to simulate the actual welding process based on the welding parameters that have been selected. By using APDL, virtual 3D model of the Butt-joint SMAW process can be created to demonstrate the interaction of all disciplines of physics, structural, heat transfer, mechanical and thermal effect on the metal plate.

Furthermore, APDL is capable to compute advance engineering simulation based on FEM effectively by its variation of algorithms, time based loading features and nonlinear material models. Detailed dimension of the metal plate in butt joint welding will be generated by using AutoCAD and will be transferred in APDL followed by applying selected welding parameters on the thermal model of Butt-joint SMAW.

Furthermore, APDL will further on with the thermal analysis and provide results in form of graph, arithmetical and graphical. Welding simulation can be simplify to by performing thermal and mechanical analysis independently. Thermal and mechanical analysis will be done based on the assumption that only thermal load will cause mechanical change on weld metal plate while mechanical load does not affecting any change on the thermal state [8].

3.3.2 Weld Specimen

In this simulation, carbon steel ASTM A36 have been selected as a weld specimen for butt joint SMAW process. This selection of material based on the actual welding industries that used carbon steel as a common weld specimen. It is well known that ASTM A36 delivers excellent welding properties and fit with a various machining process. It is significant to do a simulation of SMAW process for this type of metal based on the objective of the project. Table 3.3 shows the temperature dependant material properties of ASTM A36 [8].

TABLE 3.3 Temperature Dependent Material Properties of ASTM A36 [8]

Temperature (°C)	Specific heat (J/kg°C)	Conductivity (W/m°C)	Yield stress (Mpa)	Young's Modulus (Gpa)	thermal expansion coefficient $\times 10^{-5}/°C$
0	480	60	380	210	1.1
200	520	45	315	200	1.2
400	650	38	230	170	1.3
600	750	30	110	80	1.42
800	1000	25	30	35	1.45
1000	1200	26	25	20	1.45
1200	1400	28	20	15	1.45
1400	1600	37	18	10	1.45

3.3.3 Electrode Selection

To simulate general SMAW welding process, selection of parameters were made based on type of electrode and usage specification. Type of the electrode selected will determine the amperage range for the welding simulation process. Table 3.4 shows the type of electrode with respective usage specification [9]. Thus, electrode E6013 was selected because of it general usage and low penetration level since metal thickness for this simulation varies from 2mm to 6mm.

TABLE 3.4. Electrode Usage Specification [9]

Electrode	DC	AC	Penetration	Usage
6010	EP		Deep	Rough, high spatter
6011	EP	√	Deep	
6013	EP,EN	√	Low	General
7014	EP,EN	√	Medium	Smooth, easy, fast
7018	EP	√	Medium	Low hydrogen, strong
7024	EP,EN	√	Low	Smooth, easy, faster
NI-CL	EP	√	Low	Cast Iron
3D8L	EP	√	Low	Stainless

3.4 Thermal Model

3.4.1 Geometry of Butt-joint SMAW model

For this project, thermal simulation on Butt-joint SMAW welding process are done by finite element method by ANSYS software to illustrate the thermal effect during welding procedure. Figure 3.2 shows the geometry of the weld plate for this simulation. Considering the symmetrical geometry of the weld plate, only half of the weld plate will be modelled in APDL to simplify the simulation process.

To accomplish the objective of this thermal simulation which is to study the effect of welding speed and metal thickness variation in Butt-joint SMAW using APDL, three variables for plate thickness 2mm, 4mm and 6mm will be modelled. Constant heat source from the welding process will be applied along the weld line with variable welding speed selected for this thermal simulation speed.

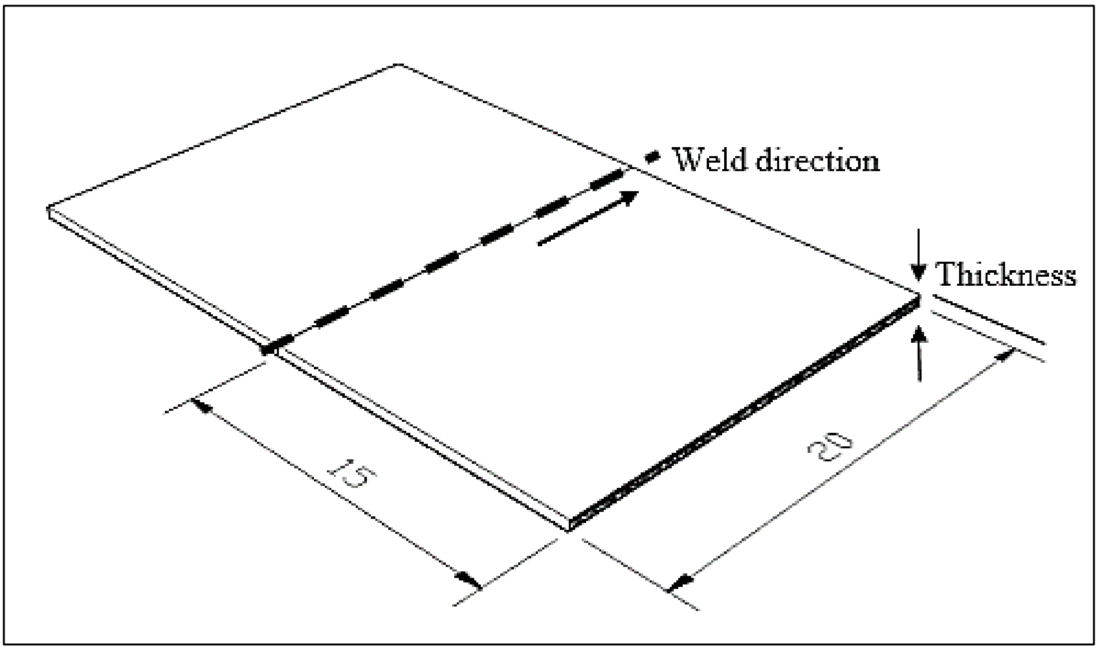

FIGURE 3.2. Geometry of the Weld Plate Model

3.4.2 Simulation Parameters and Assumption

Based on the selected electrode type which is E6013, modelling of welding process for this thermal simulation was conducted on the operating amperage according to the electrode size as shown in Table 3.5 [9]. Therefore, to maximize the effect of heat distribution during the joining process, maximum amperage range which is 300A for 0.25 inch electrode diameter will be used to simulate the welding process. Thus, effects to the metal plate from the heat distribution from the welding process will be more apparent for result analysis and interpretation.

TABLE 3.5. Amperage Range for SMAW According to Electrode Size [9]

Electrode	Diameter (inch)	Amperage Range							
		50	100	150	200	250	300	350	400
6013	1/16								
	5/64								
	3/32								
	1/8								
	5/32								
	3/16								
	7/32								
	1/4								

In actual SMAW process, current or amperage is set by the operator while the voltage is designed into the unit. This type of machine is often called 'Drooper'. Figure 3.3 displays the constant current voltage ampere curve for welding process [1]. From the working amperage range of 300A, voltage supply for the process will be regulate by the Drooper based on the graph that plots the volt-ampere curve that indicate approximately 32V of voltage supply for working amperage at 350A had been selected to simulate the welding condition in the thermal analysis.

Value of welding arc voltage and welding arc current were selected at maximum range to make the effect on the temperature distribution on the metal plate more visible. Therefore, result from the thermal analysis can be easily analysed. However, in industries, SMAW for metal plate thickness 2mm to 6mm usually were being done with 240A and voltages from 15 to 45 V. Selection of the proper power supply for welding process depends on the type of metals being welded, electrode type and length, and depth of weld penetration required.

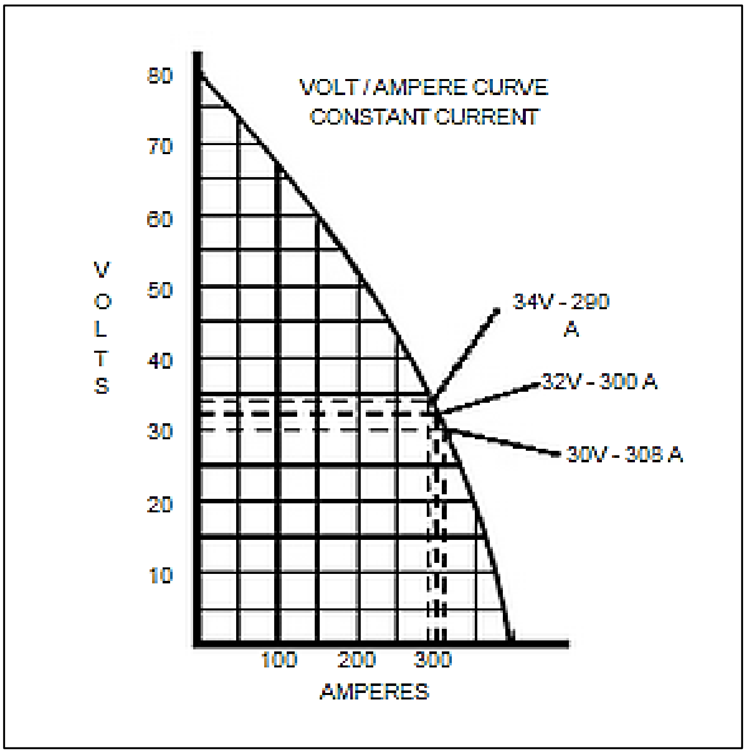

FIGURE 3.3. Graph of Constant Current Voltage Ampere Curve [1]

In the meantime, thermal analysis of the Butt-joint SMAW process will be done to study the effects of the heat input from the welding arc on the metal plate during joining process. Based on the welding parameters that have been selected for this simulation, different effects on the weld metal will varies according to different welding speed and metal thickness. Table 3.6 shows the welding variable parameters for the thermal simulation.

TABLE 3.6. Welding Variable Parameters for Thermal Simulation

Plate Thickness (mm)	Welding Speed (mm/s)									
2	10	12.5	15	17.5	20	22.5	25	27.5	30	32.5
4										
6										

In the other hand, heat input during welding process was assumed to be supplied at constant volume when passing through the weld area. Furthermore, velocity of the welding arc applied on the weld metal was assumed to be constant throughout the process according to the selected welding speed. Distance from the welding arc from the metal plate also assumed to be constant to simplify the thermal model of Butt-joint SMAW for this simulation.

3.4.3 Modelling of heat source

Basically, heat input from SMAW will be governed by the welding parameters and equipment set up by the operators. Therefore, assumption to model a heat source from SMAW for this simulation will be determined by referring to previous study that have been accomplished to study the effect of welding parameters on joining quality in welding process.

Therefore, heat source for the thermal simulation of Butt-joint SMAW will be modelled by assuming heat flux as the input transferred from welding arc to the metal plate during SMAW process. Generally, amount of heat flux acting on the metal plate will depend on the welding parameters that have been set up for the joining process. According to [10] Gaussian heat flux distribution on the surface of the metal plate will be given as (3.1). Figure 3.4 shows the schematic diagram of the Gaussian heat source [4].

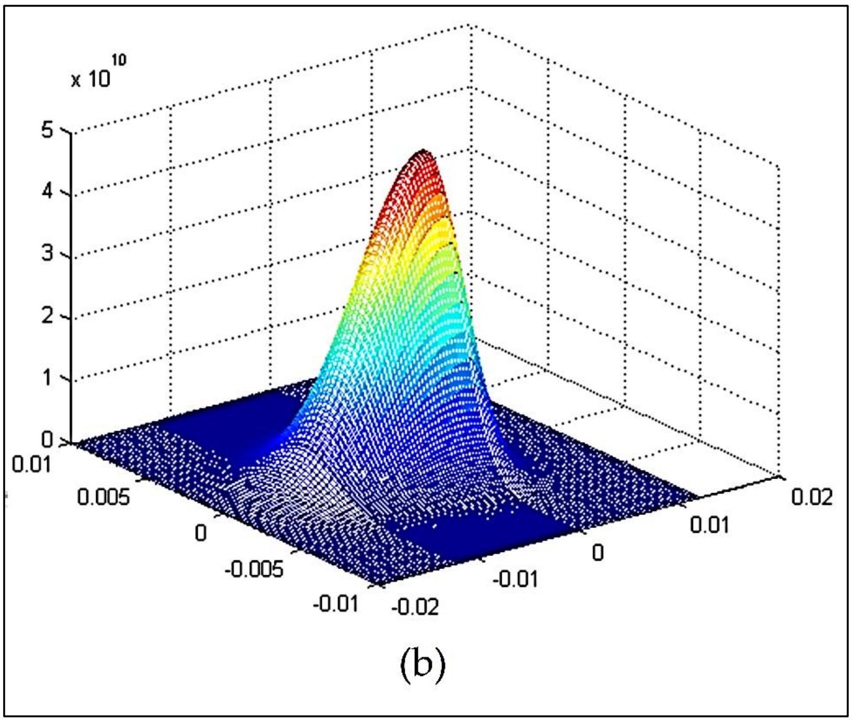

FIGURE 3.4. Gaussian Distribution Heat Source Model [4]

$$q(x,z,t)= \frac{3Q}{\pi r^2} \exp\left[-3\left(\frac{x}{r}\right)^2\right] \exp\left[-3\left(\frac{x+v\left(\left(\frac{r}{v}\right)-t\right)}{r^2}\right)^2\right] \qquad (3.1)$$

Where,

x is the distance perpendicular to weld line

z is the distance along the direction of weld line

v is the speed rate of the electrode

r is the region in which 95% of the heat flux is deposited

Heat input, Q can be denoted as amount of electrical energy supplied through the welding arc during the welding process. Therefore heat input must be consider as one of the most important welding parameters during the joining process. In addition, referring to (3.2), heat input can almost written off as the ratio of power supplied to the welding [11].

$$Q = \left(\frac{V \times I}{S}\right) \times \text{efficiency SMAW} \qquad (3.2)$$

Q is the heat input (kJ/mm)

V is the welding arc voltage (V)

I is the welding arc current (A)

S is the welding travel speed (mm/min)

In this Butt-joint SMAW simulation, influence of the heat input will be varies with the value of welding speed that have been set up for this experiment. The value of welding voltage (V) and welding current (I) will be kept constant throughout this simulation parameters to show the effect of different welding speed on different plate thickness.

To study the effect of welding speed on weld specimen, the value of heat input are kept constant throughout the welding process. Therefore the amount energy transferred from the welding arc to the weld specimen are denoted as heat flux, q calculated using (3.3). Thus, thermal analysis on the heat distribution during the welding process will be carried out using this equation to acquire temperature distribution on the metal plate.

$$\mathbf{q} = \left(\frac{\mathbf{V \times I}}{\mathbf{A}}\right) \times \textbf{Efficiency of SMAW} \tag{3.3}$$

q is the heat flux (Watts)

V is the welding arc voltage (V)

I is the welding arc current (A)

A is the surface area tip of the electrode (m^2)

Thermal analysis on heat distribution during the welding process will be carried out to acquire temperature distribution on the metal plate. Heat flux acting on the metal plate were determined from the amount of welding current and welding voltage based on previous that have been made by author according to the variable parameters in this simulation. For this thermal simulation, Area of heat flux acting on the metal plate will be assumed based on the surface area of the electrode. Figure 3.5 shows the schematic diagram for heat source model for the thermal simulation.

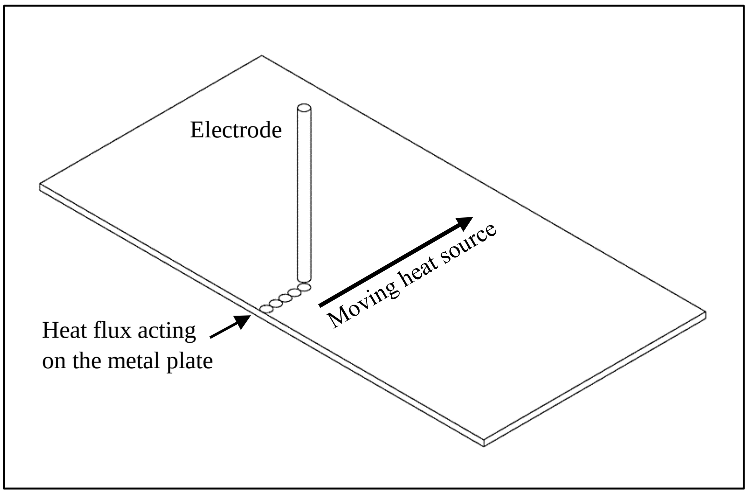

FIGURE 3.5. Heat Source Model

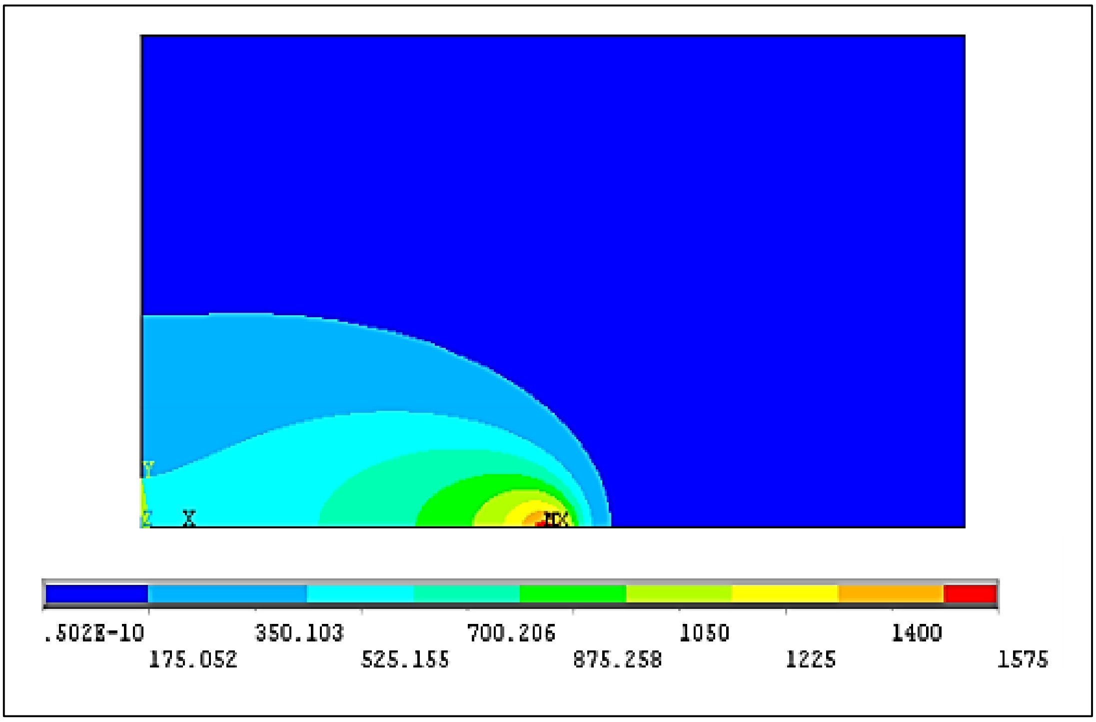

FIGURE 3.6. Contour Plot of Heat Distribution on Metal Plate *[12]*

SMAW process efficiency was assumed to be 0.75 and thermal analysis on the heat distribution during the welding process will be carried out to acquire temperature distribution on the metal plate. Figure 3.6 shows the contour plot of heat distribution on metal plate during welding [12], circular pattern of heat source can be seen on the metal plate in previous analysis to validate the assumption of area of heat flux for this simulation.

3.4.5 Heat Transfer on Metal Plate

Throughout SMAW process, temperature distribution on the metal plate will be varies due local heating from the welding process. Heat transfer during SMAW both on the metal plate and surrounding can be categorize to three different heat transfer method which is heat conduction, heat convection and heat radiation [13]. Heat from the welding arc in SMAW are mostly transferred to the metal plate through heat conduction whereas region with higher temperature will pass their thermal energy to region with lower temperature. In this thermal simulation, heat conduction is denoted as the amount of heat flux form the welding arc in (2).

Besides, heat transfer between the welding arc and the surrounding is categorized as heat convection which is calculated using (3.4). According to Ideal Gas Law, heat convection occurs when heat are transferred by the movement of fluid whereby in SMAW process, heat from the metal plate are transferred to the surrounding by air and calculated as (4). To simplify the thermal model of Butt-joint SMAW, heat transfer through radiation usually can be neglected since the effect of heat radiation on the thermal model in welding process is relatively small.

$$\mathbf{q_{conv} = h_f\left(T^4 - T_\infty{}^4\right)} \tag{3.4}$$

q_{conv} is the heat convection

h_f is the convection heat transfer coefficient

T is the body temperature

T_∞ is the surrounding temperature

3.5 Thermal Simulation Procedure

Thermal simulation procedure for Butt-joint SMAW process were conducted using APDL Graphical User Interface method and can be divided to three major process which is Preprocessing, Solution and Postprocessing. Thermal simulation of the Butt-joint SMAW will be initiated in Preprocessing stage where the type of the simulation procedure will be determined. Besides, type of element to model the geometry of the metal plate also will be selected. Meshing on the geometry of the metal plate will be done and the size of each element in the model will be defined so that properties of the material of the metal plate can be inputted into the thermal model.

After completing the Preprocessing stage, all the parameters, assumptions and thermal loads will be applied to the geometry of the metal plate. Boundary condition which is heat transfer through conduction and convection will be specified in this stage. Moreover, modelling of moving heat source by using Time Step and Load Step will be done in this stage to simulate a moving welding arc on the heat affected zone along the welding line. After all load data have been inputted into the Butt-joint SMAW model, APDL will solve the simulation and Temperature distribution on the metal plate can be obtained.

Lastly, after completing both of Preprocessing and Solution stage, result from the thermal analysis can be obtain in Postprocessing stage. Temperature distribution on metal plate will be displayed as a heat contour. Moreover, temperature at each node of the metal plate will be obtained. Temperature at selected nodes along the welding line will be analyse and interpret to study the effect of heat input form the welding process on the metal plate. Later in this report, every stage of the Butt-joint SMAW which is Preprocessing, Solution and Postprocessing will be further discussed to give a clear understanding on the methodology of the thermal simulation.

3.5.1 Preprocessing

Element type of SOLID70 in Figure 3.7 will be used for the thermal model in the simulation according to it special characteristic which has eight nodes and single degree of freedom. SOLID70 is able to compensate for mass transport heat flow from a constant velocity field on the thermal model of the metal plate [14]. Type and size of the element selected for this simulation is significant in attaining accurate result and minimizing the time required to solve the Finite Element Analysis.

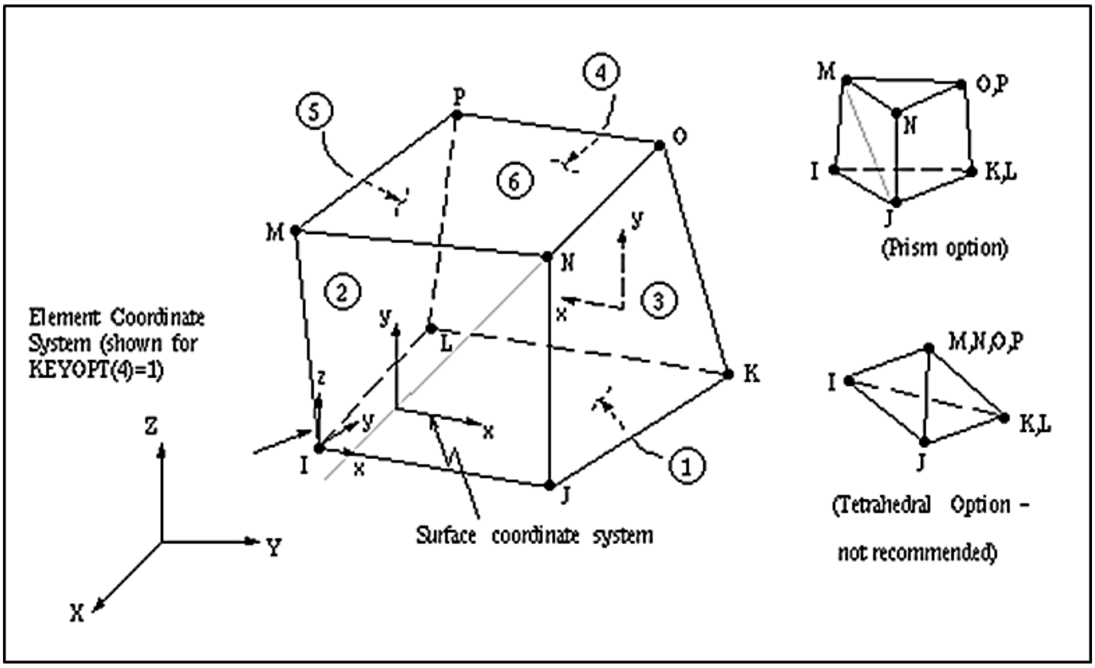

FIGURE 3.7. SOLID70 3D Structural Solid [14]

Thermal temperature dependent properties of carbon steel ASTM A36 such as thermal conductivity, specific heat capacity and density in Table 3.3 will be employed into the material properties of the element type SOLID70 for the thermal simulation. Therefore, the thermal model of Butt-joint SMAW will possess a characteristic similar to ASTM A36 so that effect of the heat input from the welding process can be simulate.

Modelling of the thermal model of Butt-joint SMAW will be generated by using direct generation technique since the geometry of the metal plate is not complex. Considering the location of the welding line is at centre of the metal plate, only half of the metal plate will be modelled to simplify the thermal simulation. Geometry of the Butt-joint SMAW will be modelled with three different metal plate thickness according to Table 3.6.

To analyse the heat distribution from welding process on the metal plate, heat affected zone near the welding line will be modelled with finer mesh size as shown in Figure 3.8. When finer mesh is applied along the weld line, number of elements and nodes on the metal plate geometry will increase and higher data accuracy of heat distribution along the weld line can be attained.

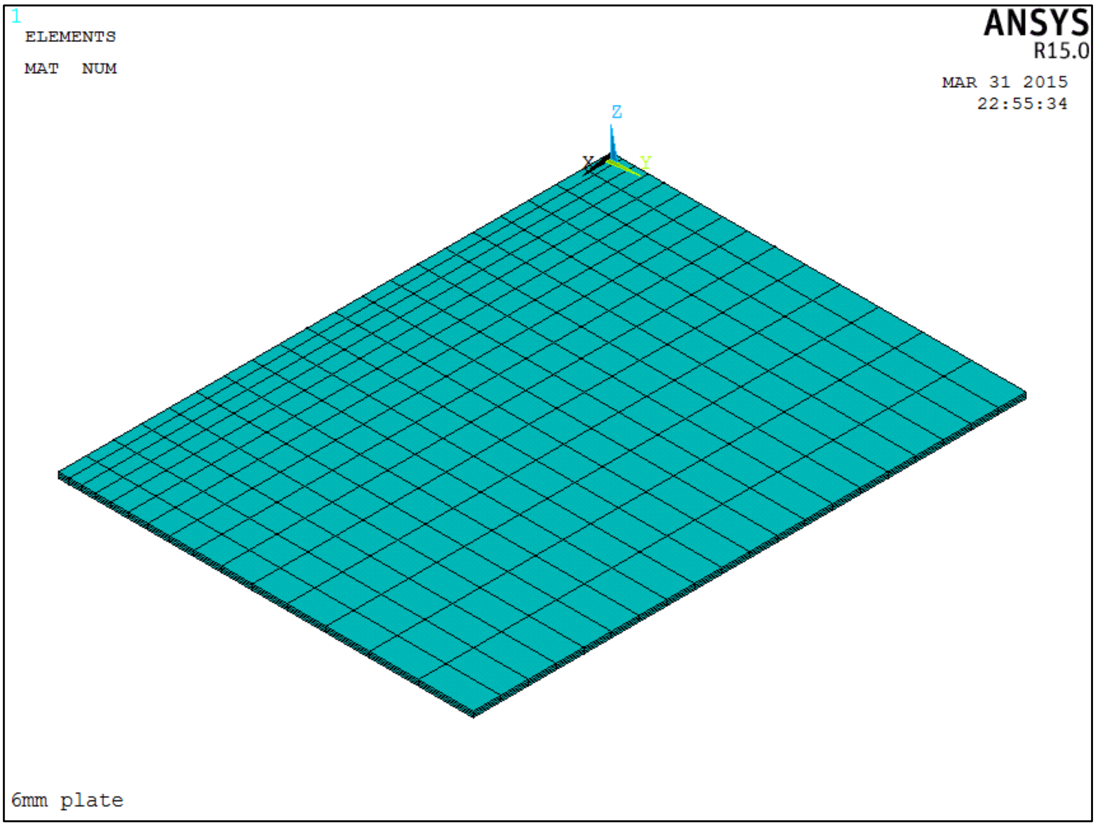

FIGURE 3.8. Meshed Model of the Weld Plate Geometry

3.5.2 Solution

Thermal simulation of Butt-joint SMAW are done by using Transient thermal analysis Heat transfer analysis especially welding simulation usually conducted by using transient thermal analysis since the temperature distribution on the metal plate will be varies according to time. Different from steady state thermal analysis, thermal loads in transient analysis will be applied in the function of time or load steps as shown in Figure 3.9 [15].

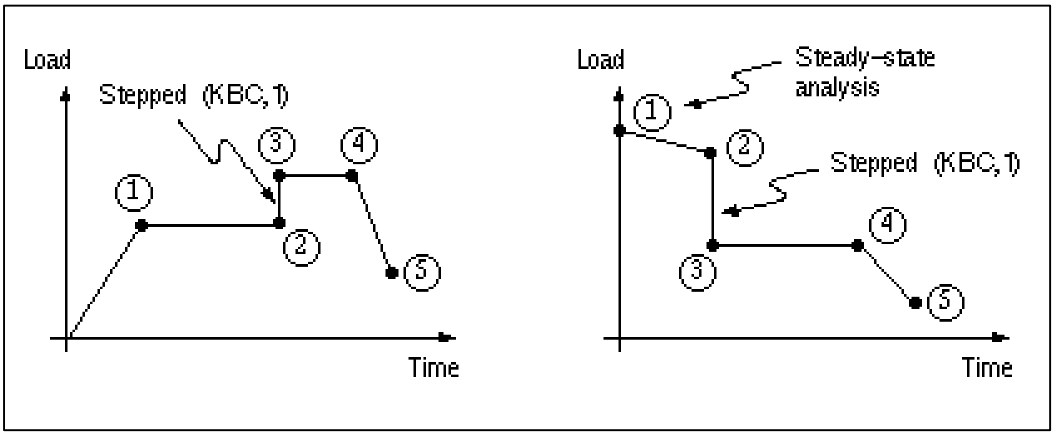

FIGURE 3.9 Loads versus Time Curve [15]

In the meantime, moving heat source from welding process is simplified by assuming the welding arc was maintained at constant volume of heat generation. To model a moving heat source, the location of the heat source will change with time. Generally, present time step will be set as the initial condition for the next time step. Time step for this simulation were calculated by dividing length of the weld line with welding speed as shown in (3.5).

$$\textbf{Time step (t)} = \frac{\textbf{length of welding line}}{\textbf{welding speed}} \qquad \textbf{(3.5)}$$

After calculating the value of time step, time for each load step have to be determine so the time of heat source acting on each element on the geometry of weld model can be acquired. Time for each load step can be calculate by dividing the value of time step with no of element along the weld line as shown in (3.6). Time for each load step will be varies according to the welding speed thus, it is important to calculate the value of each load step accurately since it will affect the result of the simulation.

$$\textbf{Load step (t)} = \frac{\textbf{time step}}{\textbf{no of element}} \qquad \textbf{(3.6)}$$

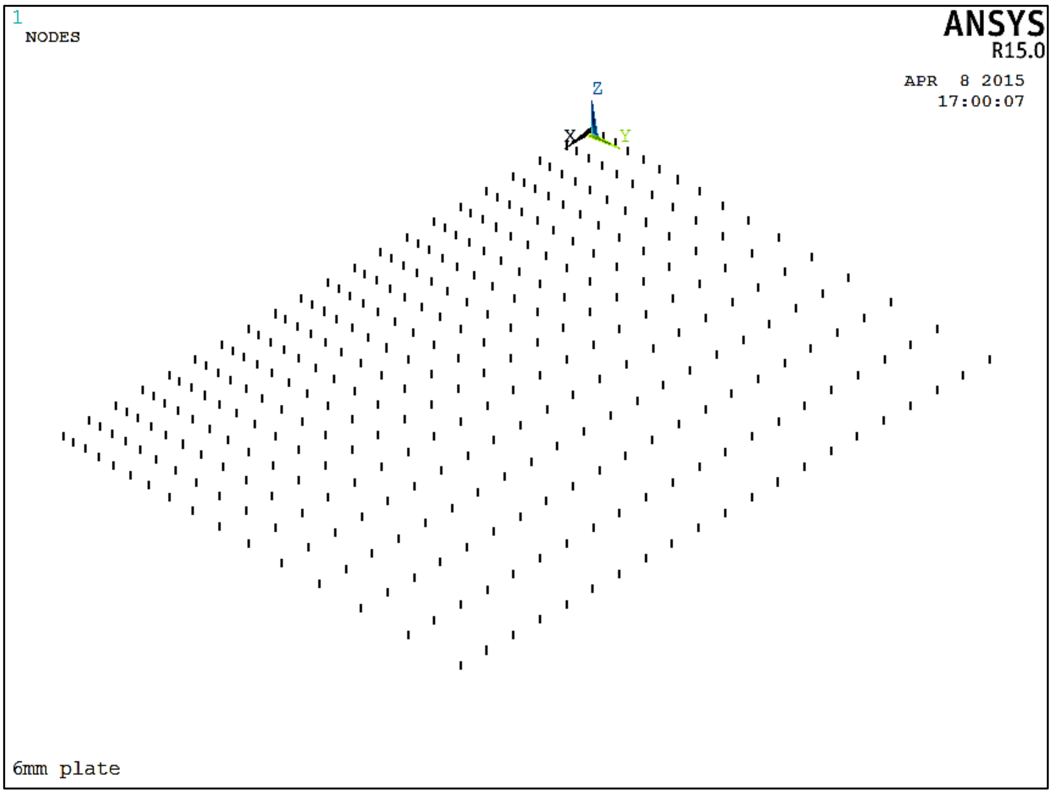

FIGURE 3.10. Nodes on the Weld Plate Geometry

Since the heat input from the welding process is denoted as a heat flux acting on the top surface along the welding line, value of the heat flux will be applied as a load step at the nodes on the top surface of the weld plate geometry as shown in Figure 3.10. As the heat flux moves from one node to another, time of each load step calculated in (3.6) will be inputted to simulate a moving heat source and will be varies according to the welding speed.

3.5.3 Postprocessing

Results from the thermal simulation of Butt-joint SMAW will be observed and analysed during this final stage. Changes in temperature on the metal plate will be displayed in the form of heat contour to visualize the heat distribution on the metal during welding process. Therefore, pattern of the contour plot and the temperature distribution at desired nodes on the metal plate will be obtained by using result viewer.

Since the heat flux from the welding process is acting on top surface of the metal plate, nodal temperature along the welding line at the bottom surface of the metal plate will be analysed to study the rate of heat dissipation and the effect of the heat flux on the weld metal plate during welding process. The value of maximum temperature at desired nodes will be tabulated in Microsoft Excel to study the pattern of maximum nodal temperature curve along the welding line.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Heat Input of SMAW

Referring to assumption that have been made for the thermal simulation, heat input from the welding process will be calculated in form of heat flux, **q** in units of Watts as mentioned in (3.3). Where, welding arc voltage = 32V, welding arc current = 300A, area of the tip of the electrode = $4.868\times10^{-3}\text{m}^2$. Therefore a constant amount of heat flux of 96.7×10^6 W/m^2 from the welding arc will be applied along the welding line in thermal simulation of Butt-joint SMAW.

$$q = \left(\frac{V\times I}{A}\right) \times 0.75$$

$$= \left(\frac{32\times300}{4.868\times10^{-3}}\right) \times 0.75$$

$$= \mathbf{96.7\times10^6\ Watts/m^2}$$

4.2 Heat Convection

Referring to (3.4), heat convection, q_{conv} during SMAW process will be calculated in the thermal simulation with ambient temperature of 27°C and heat transfer coefficient of 15 W/m^2.°C. In the meantime, welding process will be assumed to undergo natural convection and heat transfer through radiation will be neglected in this thermal simulation since the effect on the temperature distribution on the metal plate is insignificant.

4.3 Effect of Welding Speed

Thermal simulations of SMAW were conducted by varying the parameters welding speed and metal thickness with constant heat energy supply on the metal plate according to Table 3.6. Temperature distribution on the metal plate were analysed based on the nodal temperature at bottom of the metal plate along the welding line. Based on the graph of nodal temperature against load step for 4mm metal plate thickness as shown in Figure 4.1, nodal temperature distribution curve for 10mm/s to 30mm/s were plotted.

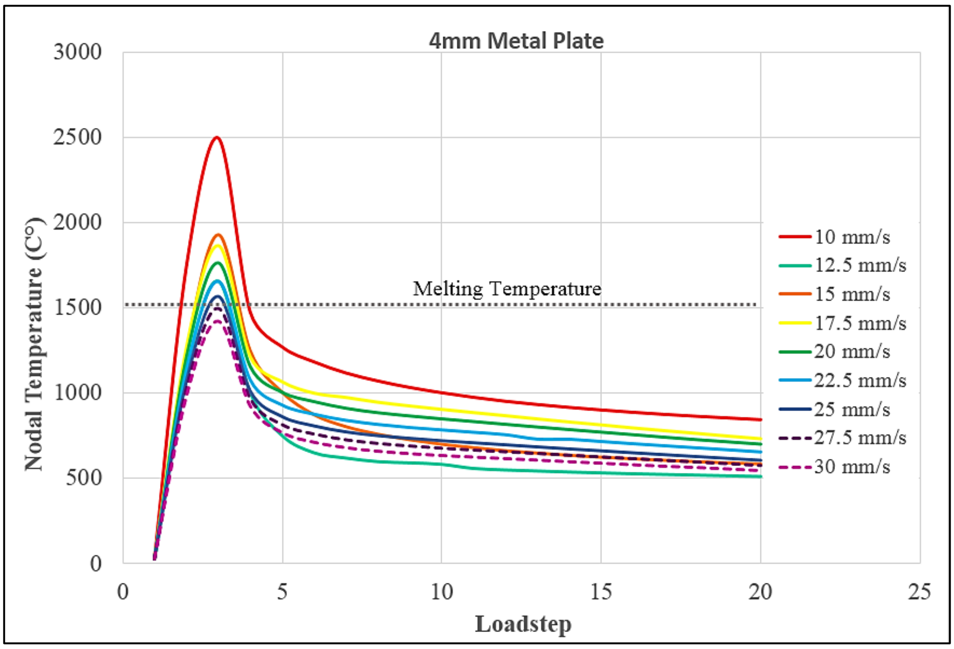

FIGURE 4.1. Graph of Nodal Temperature against Load Step for 4mm Metal Plate

Pattern of the graph indicates heat flux from the welding process will increase the temperature of the metal plate until it exceed the plate melting point at 1538°C. Increase in temperature will continue until it reach the peak temperature and start to cool down as the heat flux moves away to another nodes along the welding line. As the welding speed increase, the nodal peak temperature will decrease as a result from lesser amount of heat input transferred on the metal plate.

Optimum welding speed can be obtain by observing the nodal peak temperature from Fig. 4.1. Since ASTM A36 will melts at 1538°C, nodal peak temperature for respected welding speed at the bottom of the plate that exceed the melting temperature will indicates complete welding process because all metal on the heat affected zone were fully melts. 25mm/s welding speed was selected as the optimum welding speed for 4mm metal plate because of the nodal peak temperature is slightly higher than the melting temperature of metal plate.

Referring to the temperature at load step 3 for each welding speed, the temperature value will indicate whether the peak nodal temperature will exceed the melting temperature of the metal plate. Even though nodal peak temperature of welding speed of 10mm/s to 22.5mm/s exceed the melting temperature of the metal plate, excessive heat from the welding arc may lead to structural deformation of the weld metal plate. Table 4.1 shows the temperature distribution at each load step for 4mm metal plate along the welding line according to the welding speed.

TABLE 4.1. Temperature Distribution along the Welding Line According to Welding Speed

Load step	10.0 mm/s	12.5 mm/s	15.0 mm/s	17.5 mm/s	20.0 mm/s	22.5 mm/s	25.0 mm/s	27.5 mm/s	30.0 mm/s
1	27	27	27	27	27	27	27	27	27
2	1740	1127	1237	1263	1205	1133	1068	1023	979
3	2496	1657	1926	1864	1762	1653	1568	1493	1420
4	1476	1003	1246	1213	1155	1076	1013	965	924
5	1271	751	1004	1066	1004	929	863	813	768
6	1183	650	872	999	949	875	808	758	711
7	1118	619	802	974	910	839	773	724	679
8	1071	598	758	946	884	815	751	703	658
9	1033	598	725	924	865	797	735	688	644
10	1002	582	699	904	848	783	721	675	633
11	975	558	679	885	832	769	709	664	624
12	952	549	661	867	816	755	697	654	615
13	933	543	647	848	800	729	685	644	606
14	916	537	634	830	785	728	673	634	597
15	901	532	623	813	770	715	662	624	588
16	887	527	614	795	755	702	650	614	579
17	875	523	605	779	740	690	639	604	570
18	864	519	597	763	726	678	628	594	563
19	854	515	590	747	713	666	617	584	554
20	844	511	584	732	700	654	606	574	545

4.4 Effect of Metal Plate Thickness

Different metal plate thickness will have different rate of heat dissipation. Nodal temperature along the welding line for different metal plate thickness 2mm, 4mm and 6mm also have been analysed to study the heat distribution on the metal plate. Figure 4.2 shows the graph of nodal temperature against load step for different metal thickness. From the graph plotted, it can be seen that the peak nodal temperature of 2mm metal plate is the highest compared to 4mm and 6mm metal plate. As the thickness of the plate increase, the value of peak nodal temperature will decrease. Table 4.2 shows temperature distribution at each load step for 10.0 mm/s welding speed along the welding line according to the metal thickness.

Thicker metal plate is able to absorb more heat energy since it has bigger volume compare to thinner metal plate thus, rate of heat dissipation in thicker metal plate is higher. Moreover, when applying 10mm/s welding speed on three different metal plate, nodal temperature curve for 2 mm metal plate exceed the melting temperature throughout the welding process. This pattern indicates excessive heat acting on the metal plate during welding process and higher welding speed should be applied on thinner metal plate. Therefore, optimum welding speed will be varies according to different metal thickness since it possessed different rate of heat dissipation.

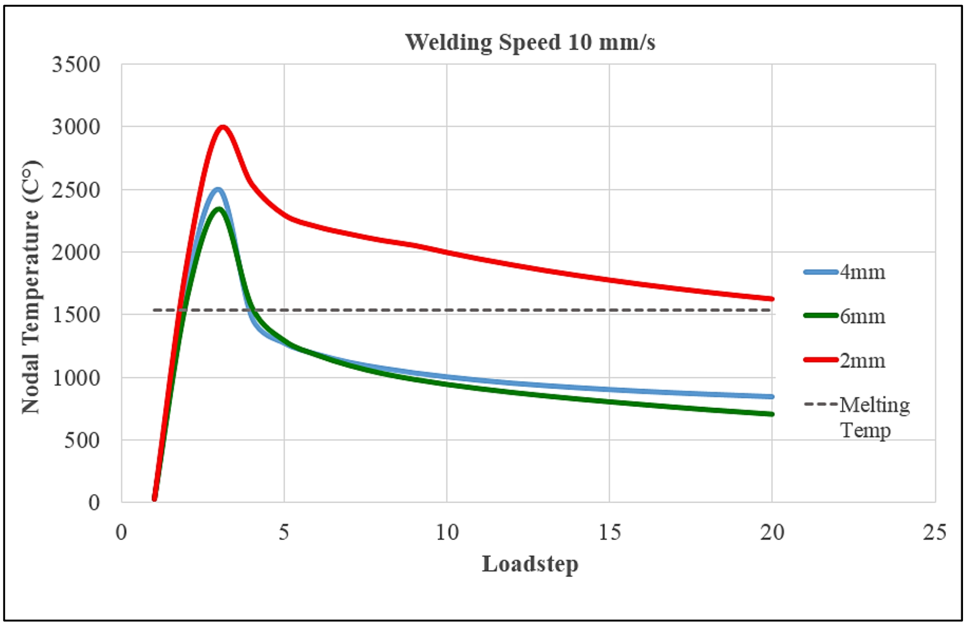

FIGURE 4.2. The Graph of Nodal Temperature against Load Step for Different Metal Thickness

TABLE 4.2. Temperature Distribution along the Welding Line According to the Metal Thickness

load step	2mm	4mm	6mm
1	27	27	27
2	1907	1740	1630
3	2979	2496	2347
4	2537	1476	1562
5	2293	1271	1294
6	2200	1183	1179
7	2141	1118	1096
8	2090	1071	1032
9	2050	1033	984
10	1994	1002	944
11	1942	975	910
12	1895	952	880
13	1851	933	853
14	1811	916	828
15	1774	901	805
16	1739	887	783
17	1707	875	762
18	1677	864	742
19	1649	854	724
20	1623	844	706

After the welding process have been completed, the metal plate will undergo cooling process by natural heat convection until it reach steady state at room temperature. Figure 4.3 shows the contour plot of temperature distribution on weld plate metal for time 10s to 20s. From the contour plot it, can be seen that the heat source from the welding arc during welding process will dissipate throughout the weld metal plate. Heat from the welding arc will concentrate along the welding line and will be distribute throughout the metal plate as the time increase until it reach a steady state at room temperature.

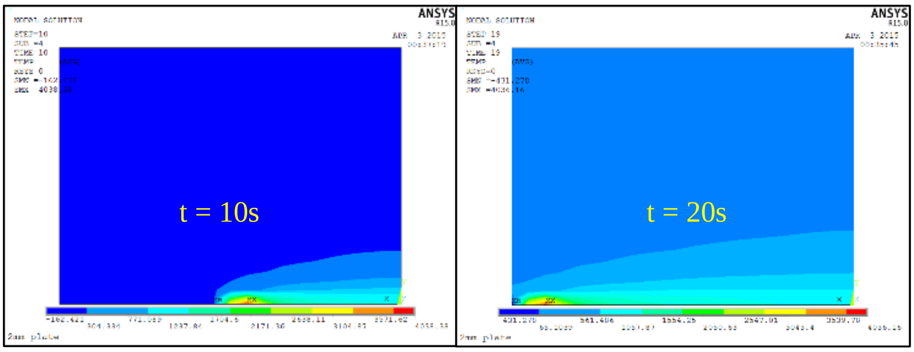

FIGURE 4.3. Contour Plot of Temperature Distribution on Weld Plate Metal for Time 10s to 20s

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Thermal simulation of SMAW butt joint welding by using ANSYS software will demonstrate the effect of different welding parameters on the metal plate during the joining process. Several conclusions were arrived after analysing the result from the thermal analysis of the welding process. Optimum welding speed according to different metal thickness have been obtain in the simulation. Besides, results from the simulation also proved the rate of heat dissipation on thinner metal is lower than thicker metal plate, thus higher welding speed need to be applied on thinner plate to get a decent welding quality. Therefore, both objective of this this project which is to simulate the effect of welding speed and metal thickness variation in SMAW on the butt joint welding using ANSYS and to get optimum welding speed in SMAW according to metal thickness have been accomplished.

5.2 Recommendation

Result from the thermal analysis of Butt-joint SMAW will significantly reduce the experimental effort to find the optimum parameters and can be utilized in nowadays industries especially in fabrication process. In details, methodology of this simulation can be used to visualize the effect of welding parameters on real application during fabrication. Welders can input the parameters of the SMAW and get the optimum welding speed as a guide to complete the welding process. Therefore, deformations in welding that caused by unsuitable applied welding speed from the welders can be minimize thus, enhance the joining quality of the weld product.

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