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Thermal Modelling of Electric Arc Welding

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***Abstract*—This study focused on the modelling and thermal distribution of a heat source applied with electric arc welding. The heat source was modelled from the standard inputs. The heat source intensity is calculated with the effect of the natural convection and treated as boundary conditions. The model was implemented in the Ansys Thermal module. The complete solver was tested against experimental measurements for Electric Arc welding with a symmetric configuration of the work piece. The symmetric approach indeed reduces the computational effort. Various boundary conditions were set on the analysis. The flow of the heat on the specimen is calculated and physical experimentation details are included in the forthcoming developments.**

***Index Terms*— thermal modelling, electric arc welding**

I. INTRODUCTION

Electric Arc welding as a method of assembling metal parts through fusion is an old technology. This manufacturing process is however still under proper development, in order to study different parameters such as productivity, weld control, and weld quality. Such improvements are useful for both from economic and environmental point of view.

The electric arc welding process is interdisciplinary in nature, and complex to master as it involves very large temperature changes. Its investigation was long based on experimental studies. Today, thanks to recent and significant progress done in the field of welding simulation, experiments can be complemented with numerical modelling to reach a deeper process understanding. The numerical calculation for boundary conditions and heat input, to investigate heat flux transferred from the electric arc. Electric arcs used in welding are generally formed coupling an electric discharge between anode and cathode with a gas flow.

II. LITERATURE SURVEY

A. Geometry specifications

For the calculation of the thermal distribution considering the metal plates, equal in size with a dimension of 300 x 150 x 8 mm are butt welded with weld geometry between them. The base metal plates are of 1020 mild steel material. The welding geometry is shown in the Fig. 1.

The welding simulation has been done firstly by studying the welding temperature field followed by incrementally applying the temperature results to simulate the weld. After the welding process is over the thermal distribution is evaluated on the plate.

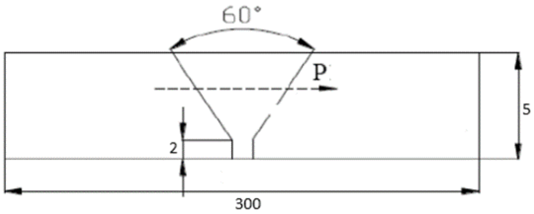


Fig. 1. Weld specimen geometry dimensions

1) Geometry

The present research work concentrates on the how the heat transfer is taking place when an arc welding torch is being moved on the weld area of the plates. For the current analysis two plates of dimensions 200*150*5 mm AISI 1020 plates are taken and simulated for the thermal distribution.

TABLE I
MATERIAL PROPERTIES

Property	Value
Density	8000 g/cc
Young's modulus	190 GPa
Poisson's ratio	0.29
Tensile strength	320 Mpa
Thermal conductivity	46 W/m-k

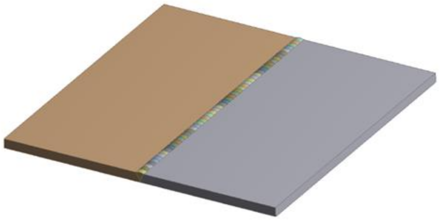


Fig. 2. Model geometry

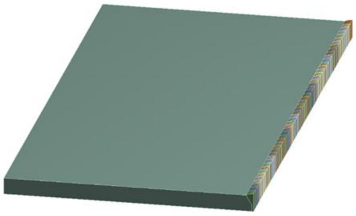


Fig. 3. Symmetry model

For the convenience of the simulation symmetry model is considered for the analysis.

Fig. 4. Weld bead geometry

Standard weld bead geometry and gap between the two weld plates is maintained as per the ASME welding standards.

2) *Meshing*

The model has been meshed with the required element size and the mesh method.

TABLE II
MESH SETTINGS

Sizing		Quality	
Size Function	Adaptive	Target Quality	Default (0.050000)
Relevance Center	Coarse	Smoothing	Medium
Element Size	Default	Mesh Metric	None
Transition	Fast	Number of CPUs for Parallel Part Meshing	6
Span Angle Center	Coarse	Statistics	
Automatic Mesh Based Defeaturing	On	Nodes	308571
Defeature Size	Default	Elements	70500
Minimum Edge Length	0.50 mm		

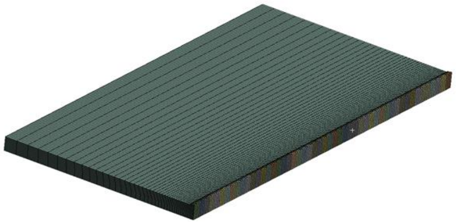
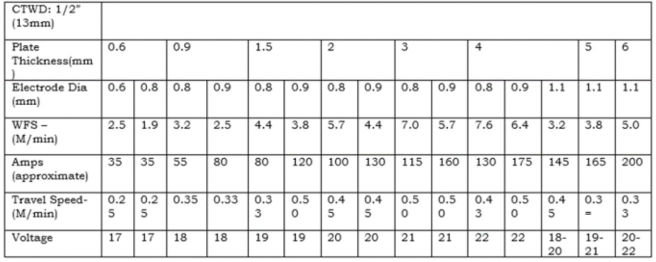


Fig. 5. Half symmetry mesh model of the weld bead along with plate

TABLE III
ARC WELDING PARAMETERS (DEPARTMENT OF CHEMICAL AND MATERIALS ENGINEERING UNIVERSITY OF ALBERTA)



CTWD: 1/2" (13mm)															
Plate Thickness(mm)	0.6		0.9		1.5		2		3		4			5	6
Electrode Dia (mm)	0.6	0.8	0.8	0.9	0.8	0.9	0.8	0.9	0.8	0.9	0.8	0.9	1.1	1.1	1.1
WFS – (M/min)	2.5	1.9	3.2	2.5	4.4	3.8	5.7	4.4	7.0	5.7	7.6	6.4	3.2	3.8	5.0
Amps (approximate)	35	35	55	80	80	120	100	130	115	160	130	175	145	165	200
Travel Speed- (M/min)	0.25	0.25	0.35	0.33	0.33	0.50	0.45	0.45	0.50	0.50	0.43	0.50	0.45	0.3=	0.33
Voltage	17	17	18	18	19	19	20	20	21	21	22	22	18-20	19-21	20-22

Boundary Conditions:

The boundary conditions are calculated for the present model using some set of relations.

Boundary conditions needed:

- Heat source calculation.
- Convection parameters.

Heat source calculations:

Heat input = $\frac{V\ X\ I}{T}$

$$Nu = \frac{Convective\ heat\ transfer}{Conductive\ heat\ transfer} = (h_c * L)/k$$

Where,
V – Voltage = 21V
I – Amperes = 165A.

Heat input = $\frac{V\ X\ I}{T} = \frac{165\ X\ 21}{0.38\ X \frac{1}{60}}$ = 0.54 kJ/mm

Arc travel time = 0.38 m/min
= $\frac{380}{60}$
= 6.3 mm/sec

Wattage = Heat input * T mm/sec
= 0.54 * 6.3
= 3.402 kJ/sec
= 3.402 kW
= 3402 W

Internal generation per unit volume = $\frac{Wattage}{Volume\ of\ weld\ bead}$
= $\frac{3402}{17.668}$
= 192.5 W/mm^3

Transient time step:

The complete weld run is divided into 50 domains throughout the weld run with a domain size of 3mm.

The analysis is carried out for every 0.5sec and het input is given as per the time step.

Time travel = 0.38 m/min
= 6.3 mm/sec

Total time for welding 150mm is 23.08sec and it is rounded to 25 sec

For each bead the heat is made to generate for 0.5sec and rest the heat is allowed to conduct to the plate.

Convection:

For convection we use the convection heat transfer coefficient hc, W/(m^2 K). A different approach is to define h through the Nusselt number Nu, which is the ratio between the convective and the conductive heat transfer:

Where:
- Nu = Nusselt number
- h_c = convective heat transfer coefficient
- k = thermal conductivity, W/mK
- L = characteristic length, m

The convection heat transfer coefficient is then defined as following:

The Nusselt number depends on the geometrical shape of the heat sink and on the air flow. For natural convection on flat isothermal plate the formula of Na is given in Table-3.

TABLE III
NUSSELT NUMBER FORMULA

	Vertical fins		Horizontal fins
Laminar flow	$Nu = 0.59 * Ra^{0.25}$	Upward laminar flow	$Nu = 0.54 * Ra^{0.25}$
Turbulent flow	$Nu = 0.14 * Ra^{0.33}$	Downward laminar flow	$Nu = 0.27 * Ra^{0.25}$
		Turbulent flow	$Nu = 0.14 * Ra^{0.33}$

$$Ra = Gr * Pr$$

Where:

Ra is the Rayleigh number defined in terms of Prandtl number (Pr) and Grash of number (Gr). If Ra < 106 the heat flow is laminar, while if Ra > 106 the flow is turbulent.
The Grash of number, Gr is defined as following:

$$Gr = \frac{g*L^3*\beta*(T_p-T_a)}{\eta^2}$$

Where:
- g = acceleration of gravity = 9.81, m/s^2
- L = 0.130, longer side of the fin, m
- β = air thermal expansion coefficient. For gases, is the reciprocal of the temperature in Kelvin:

β = 0.033

$$\beta = \frac{1}{T_a}, 1/\mathrm{K}$$

- Tp = 75^{o}C, Plate temperature, °C.
- Ta = 30^{o}C, Air temperature, °C
- η = air kinematic viscosity, 1.6^{-5} at 30 °C.

Gr = $\frac{9.81*0.130*0.130*0.130*0.033*(75-30)}{1.6^{-5^2}}$

Gr = 7.2*10^{-7}

For plate temperature, Tp, set a expected value. Finally, the Prandtl number, Pr is defined as:

$$Pr = \frac{\mu*cp}{k}$$

Where:
- μ = air dynamic viscosity, is 1.86^5 at 30 °C.
- c_p = air specific heat = 1005 J/(Kg*K) for dry air
- k = air thermal conductivity = 0.026 W/(m*K) at 30 °C

Pr = $\frac{1.86^{-5}\ X\ 1005}{0.026}$

Pr = 0.7189

Convective heat transfer coefficient:

$$h_c = \frac{Nu*k}{L}$$

$$h_c = \frac{57.59 * 0.026}{0.130}$$

h_c = 11.874 (For vertical walls)

h_c = 10.864 (For horizontal walls)

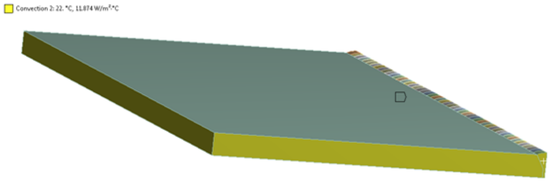


Fig. 6. Convection for vertical walls

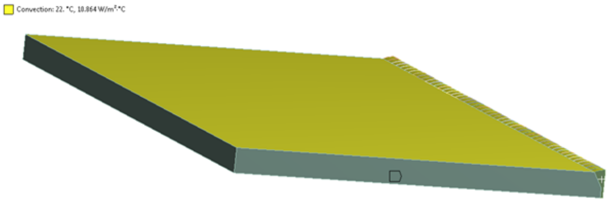


Fig. 7. Convection for horizontal walls

III. SIMULATION RESULTS

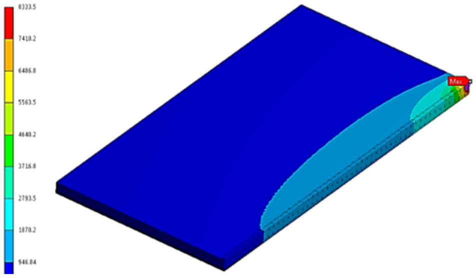


Fig. 8. Temperature contour of the welding simulation

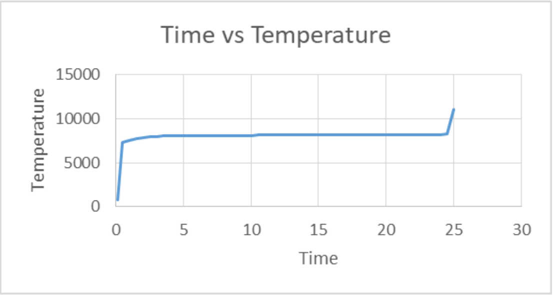


Fig. 9. Time vs. Temperature

The above graph depicts the temperature distribution with respect to the time, the temperature of 11000oC is achieved for the fraction of time at 25 sec, whereas a maximum temperature of 8000oC is observed at every weldment of the specimen between 3 to 24 seconds.

IV. CONCLUSION

In the present analysis the primary investigation is done to determine the thermal distribution due to the heat source on the material and it is simulated by using the Ansys Transient Thermal package. The heat source energy is calculated using the correlations of the input voltage, current and weld transverse speed. The maximum temperature attained is in the order of 8333^{o}C and minimum temperature is 946.84^{o}C.

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