RELIABILITY OF NUMERICAL ANALYSIS OF COOLING CURVES IN THE FUSION ZONE OF SUBMERGED ARC WELDING (SAW) PROCESS

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ABSTRACT

In this work, simulation of fusion welding technique to estimate the cooling curves and temperature distribution in submerged Arc (SA) welded workpiece was assessed. Numerical analysis by using Finite Volume Method (FVM), applied to three-dimensional heat transfer model to determine the cooling curve in weld metal zone. There is no reliable method for calculation such cooling rate as a function of welding current, voltage speed and arc transfer efficiency in metal joint geometry. Cooling rates are determined by affected of weld metal deposition in the fusion zone at different welding speeds (22, 23 and 25) cm/min, with constant welding current at 500 Amp and 40 voltages. The joint geometry of single-V- butt joint with one pass are used for half plate dimensions (150×150×18) mm, fixed with standard geometry of (ISO-2560). Cooling curves model which is confirming the capability and reliability of weld metal deposition in fusion zone with different welding speeds. The optimization of filling area (weld metal deposition) by FVM is determined in each welding speed having correct welding current to filling cell of weld area.

Keywords; Submerge Arc Welding, Cooling Curves, Control Volume Method.

أعتمادية التحليلات العددية لمنحنيات التبريد في منطقة الانصهار لعملية لحام القوس الكهربائي المغمور

الخلاصـــــــه:-

في هذة الدراسة استخدمت محاكات لتقنية اللحام الانصهاري لتخمين منحنيات التبريد والتوزيع الحراري في قطع ملحومات القوس الكهربائي المغمور او الغاطس. التحليلات العددية بأستخدام طريقة الحجوم المحدودة (FVM)، طبقت لنموذج الانتقال الحراري الثلاثي الابعاد لتحديد منحنى التبريد في منطقة الانصهار(FZ). ليس هناك طريقة أعتمادية في حساب معدل التبريد كدالة لتيار اللحام ، الفولتية ، سرعة اللحام وكفاءة القوس الكهربائي في هندسة ربط المعادن. معدلات التبريد حددت بواسطة تأثير ترسيب معدن اللحام في منطقة الانصهار عند سرع مختلفة (22، 23 و25)سم/دقيقة مع ثبات تياراللحام بمقدار (500) أمبير وبفولتية (40)فولت. استخدمت هندسة الربط لوصلات تناكبية مفردة (Single –V) وبتمريرة واحدة لنصف صفيحة بابعاد (طول ،عرض ،سمك) (150*150*18) ملم،ثبتت بموجب المواصفة العالمية (2560- ISO). نماذج منحنيات التبريد التي تؤكد كفاءة وأعتمادية ترسيب معدن اللحام في منطقة الانصهار بأختلاف سرع اللحام. أن تحسين ترسيب معدن اللحام في منطقة الأملاء بواسطة طريقة الحجم المحدود حددت عند كل سرعة لحام التى تمتلك تيار لحام مناسب لاملاء خلية بمنطقة اللحام.

1- INTRODUCTION

Fusion welding process is carried out by manual metal arc welding (MMAW), using filler metal as a consumable electrode through the center of the weldement**.** In this case, when the electrode comes close to the workpiece, an arc is struck between the filler metal and the workpiece, and the filler metal melts and joints two plates by filling metal droplet simultaneously in V-groove of plates**.** In the present work three - dimensional model will be used the application of control volume method (CVM) in the modeling of rapid solidification processes such as welding. This method is a suitable for problems where the phase change occurs and moving the interface at a high temperature. **Gareth et al (1999)** studied the numerical framework computational modeling of welding phenomena. The numerical framework consists of both cell-centered and vertex- based FV methods, which are employed to model problems in computational fluid dynamic (CFD) and computational solid mechanics (CSM). **Moneer et al (2006)** they study Finite Difference Simulation of Low Carbon Steel Manual Arc Welding with plates material type (A-283-Gr-C), using shielded metal arc welding (SMAW). They found the angular distortion increase with increase current and angular distortion decrease with the increase number of passes. **Roy et al (2003)** studied the numerical heat transfer and fluid flow model to develop to determine the temperature profiles and the metal droplets was modeled considering a volumetric heat source. They applied governing equation to be solved in a two- dimensional (2D) system in gas tungsten arc (GTA) welding process. The aim of this work is to;

1- Enable cooling rate model which is confirming the capability and reliability of weld metal deposition in fusion zone with different welding speed by using Finite Volume Method (FVM).

2- Capability and reliability of temperature distribution in (GTAW) of weld joint by using Finite Volume Method (FVM).

3- Optimization of weld parameters relation with filling area (weld metal deposition) by using Finite Volume Method (FVM), and determined for each welding speed have correct welding current.

2- MATHEMATICAL FORMULATION

In this work transient heat distribution is solved by using FVM. Numerical methods appear to be the only practical method for handling the general melting and freezing problems where the phase change occurs over a temperature range. The numerical method is Finite Volume Method (FVM) which employed heat transfer and predict of phase change with moving interface. This method is base on the cell-centered finite volume (FV) and conservation principle i.e. energy balance is expressed for the control volume method. However, the calculations presented here for SA welds are carried out in a three-dimensional (3D) coordinate system, since temperature distribution, cooling rates and weld metal droplet deposition formulation.

2-1 Governing equations

For most of rapid solidification, there is no clear boundary between the liquid and solid; for this case the enthalpy is more appropriate **Yiding Cao and Amir Faghri (1989).** A three-dimensional volumetric heat source model is the conservation of energy equation in the enthalpy

(E) method is considered in term of enthalpy instead of temperature. The governing equations are based directly on the model **Hattel.J.H and N.H.Pryds (2001):-**

$$\frac{\partial(\rho E)}{\partial t}=\frac{\partial^2(\Gamma E)}{\partial X^2}+\frac{\partial^2(\Gamma E)}{\partial Y^2}+\frac{\partial^2(\Gamma E)}{\partial Z^2}+P \tag{1}$$

Where:

$$P=\frac{\partial^2 S}{\partial X^2}+\frac{\partial^2 S}{\partial Y^2}+\frac{\partial^2 S}{\partial Z^2} \qquad \text{And} \qquad \Gamma=\Gamma(E), S=S(E)$$

Equation (1) is nonlinearity of phase- change problems is due to the existence of a moving interface **Cristiene V.Goncalves and Gilmar Guimarae (2002)**. The energy equation has been transformed into a non-linear equation with a single dependent variable E. In the liquid region, equation (1) reduces to the normal linear energy equation**.**

$$\frac{\partial(\rho_L E)}{\partial t}=\frac{\partial}{\partial X}\left(k_L\frac{\partial T}{\partial X}\right)+\frac{\partial}{\partial Y}\left(k_L\frac{\partial T}{\partial Y}\right)+\frac{\partial}{\partial Z}\left(k_L\frac{\partial T}{\partial Z}\right) \tag{2}$$

Also, in the solid region equation (1) reduces to

$$\frac{\partial(\rho_S E)}{\partial t}=\frac{\partial}{\partial X}\left(k_S\frac{\partial T}{\partial X}\right)+\frac{\partial}{\partial Y}\left(k_S\frac{\partial T}{\partial Y}\right)+\frac{\partial}{\partial Z}\left(k_S\frac{\partial T}{\partial Z}\right) \tag{3}$$

Γ(E) and S(E) given by equation(1), has expression phase change occur over a temperature range of the phase change occurring at a single Temperature:

$$\Gamma(E)=\begin{Bmatrix} K_s/C_{ps}............E\le 0 \\ o..................0<E<H \\ K_L/C_{p_L}.........E\ge O \end{Bmatrix} \tag{4}$$

And

$$S(E)=\begin{Bmatrix} O............................E\le 0 \\ O......................0<E<H \\ -K_L H/C_{p_L}...........E\ge H \end{Bmatrix} \tag{5}$$

2-2 Calculations of metal filling cells

Calculation of weld metal deposition (droplet) to filling cell of area is affected by the welding conditions such as welding speed, voltage, preheat temperatures and current. A three -dimensional numerical heat transfer from the arc welding, additional heat conduction from the weld metal droplets. The weld metal is moving along V-joint with the electrode when melt it, and deposits these droplets spontaneously along the cell of weld joint. The expressed of this case is a sensible heat (h) and latent heat content (ΔH), i.e., $H=h+\Delta H$ **Roy et al (2003)**. The sensible heat h is expressed as $h=\int C_p dT$, where C_p is the specific heat and T is the temperature **Kumar, and T.Debroy (2004).** Latent heat content ΔH is given as $\Delta H= f_L L$, where L is the latent heat of fusion. The liquid fraction f_L is assumed to vary linearity with temperature:

$$fl = \begin{Bmatrix} 1, T > Tl \\ T - Ts, Ts \leq \mathrm{T} \leq \mathrm{T}l \\ Tl - Ts, T < Ts \end{Bmatrix} \tag{6}$$

Where;

T_L and T_S are the liquidus and solidus temperature, respectively. The filling rates of cells its mean weld metal deposits per second (volume) is calculated by the following equation **Abbas et al (2010);**

$$\mathbf{V}^{\circ}=I\times V\times\eta / \rho[C_p(T_L-T_S)+h]\,mm^3/s \tag{7}$$

Where;

$\mathbf{V}^{\circ}$ is the metal volume deposit per second, I is weld current (Amp), **V** is voltage (volt), η is submerge - arc welding efficiency = 0.60, ρ is density = (7860 kg/m^3), C_p is the specific heat = (450J/kg.$^{\circ}$C), ΔT is temperature difference = (T_L- T_S) and h is latent heat $=2.7\times10^5$ J/ kg. From equation (7) the cells filling deposition with different welding speeds are calculated by,

$$\text{Deposited Area}= (\mathbf{V}^{\circ}/v)\ mm^{2} \tag{8}$$

Where; S is travel welding speed (cm/min)

2-3 Boundary Conditions

A 3D Coordinate system is used in the calculation, while only half of the workpiece is considered since the weld is symmetrical about the weld center line. Figure (1).

These boundary conditions are further discussed as follows.

1-Top surface; the weld top surface is assumed to be flat and insulated. The welding velocity component along the X, and Y directions equal to zero, while the velocity of welding along Z is varied with welding parameters.

2-Symmetrical surface; the boundary conditions are defined as zero flux across the symmetrical surface.

3- Other surfaces; all other surfaces are insulated.

4- The initial preheat temperatures before welding is 250°C.

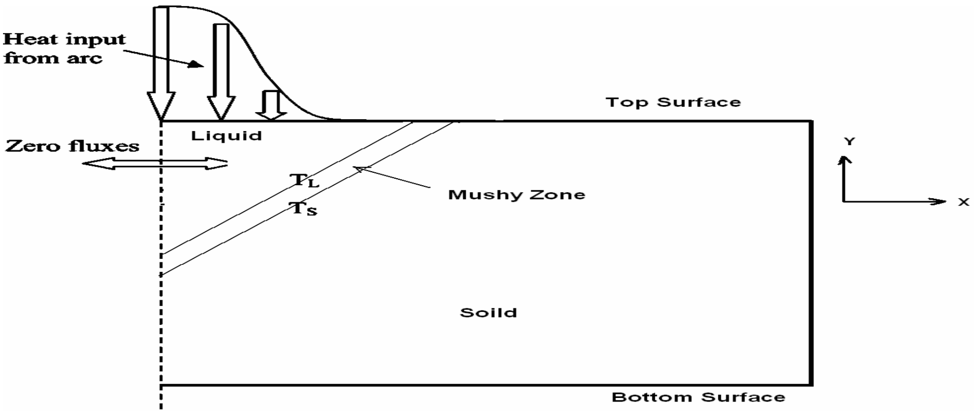


Figure 1:- A schematic the half butt joint shape with the boundary conditions

2-4 Assumptions

A 3-Dmodels for simulation of welding process of the present work used the following assumptions are:-

1- The convection and radiation heat transfer were neglected was assumed.

2- The fluid movement during welding process was neglected.

3- The energy from the arc welding heat source is applied at a uniform rate.

4- All the plate boundaries were assumed to be insulated.

5- The heat transfer from the filler metal droplets is taken into account using time-volumetric heat source and filling it instantaneously.

6- The weld physical properties data in this analysis are summarized in **Table 1, Chol, and J.Mazumder (2002).**

7- Numerical calculations depend on welding parameters which as summarized in **Table 2**.

Table 1: Physical Properties for deposition weld metal of electrode (F60-EM12K) [9].

ρ_L Liquid density = 6980Kg/m

ρ_s Solid density = 7860Kg/m^3

K_L thermal Conductivity of Liquid =31W/m.K

K_S thermal Conductivity of Solid =45W/m.K

Cp_L Liquid specific heat = 450J/Kg.K

Cp_S Solid specific heat = 450J/Kg.K

T_L Liquid temperature = 1537 C°

T_S Solid temperature = 1483 C°

h Latent heat = 2.7×10^5 J/kg

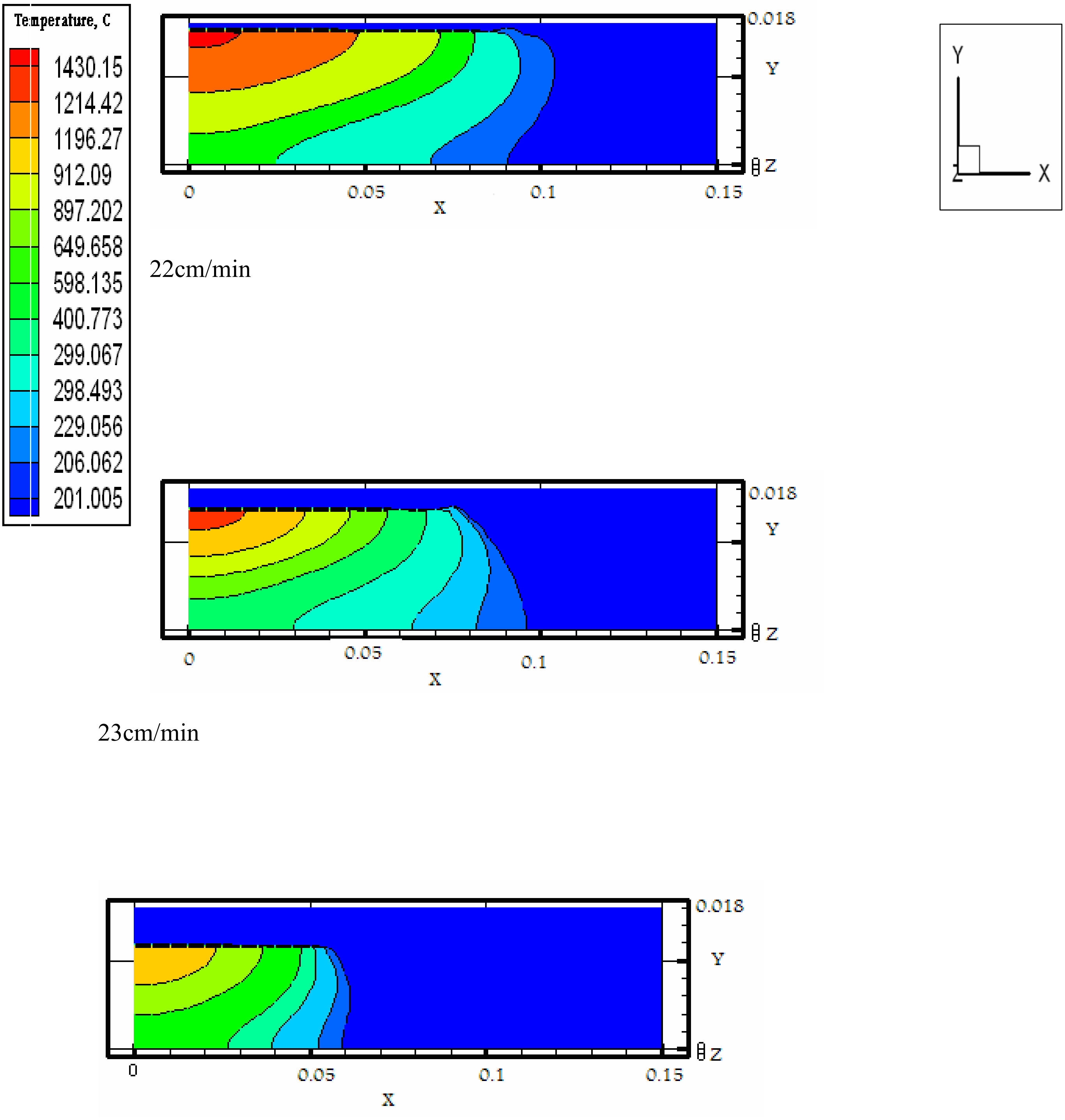
Table 2: Welding parameters of submerged arc welding (SAW), which depend in FVM with single pass, plate thickness (18mm), and preheat temperature 250 ^{O}C.

Welded	Process	Filler Metal		Current		Voltage (V)	Travel Speed (v) (cm/min)
		Class	Diameter	Polarity	Amp.		
1	SAW	EM12K	3.25 mm	DC +	500	40	22
2	SAW	EM12K	3.25 mm	DC +	500	40	23
3	SAW	EM12K	3.25mm	DC +	500	40	25

3- RESULTS AND DISCUSSION

3-1 Temperature distribution

Figure 2, shows the temperature history and determined the cells area of weld metal deposits level by FVM, at x = 0 plane with different welding speed. Cooing rates affected by level cell of weld metal deposition. As increase welding speed effects to decrease weld metal deposits that effects to increased the cooling rates. These results are in agreement with results of **Gareth et al (1999)**.



22cm/min

23cm/min

25cm/min

Figure 2: Program temperature history and weld metal deposition level at x =0 planes (welding current 500Amp, preheat temperature 250°C and time (0.5s) with different welding speeds.

3-2 Cell of filling area

Numerical work provides us predication of cell filling of weld metal deposition with different weld conditions as shown in **Figure (3).** An increasing welding speed leads to decrease the weld metal deposits.

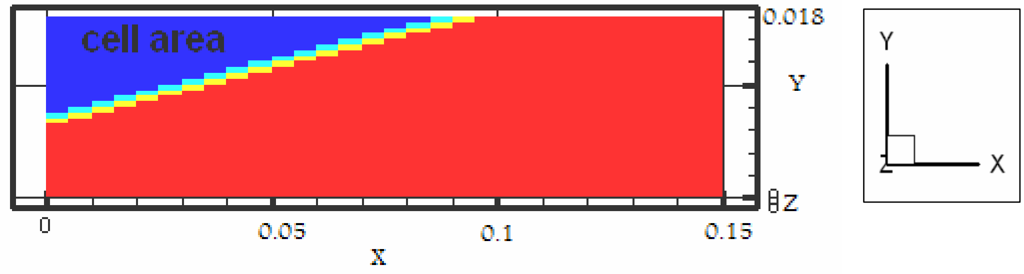


Figure 3: The -V- shape and location of cell area of the welded joint.

3-3 Analysis of Cooling Curves

The assumptions of weld conditions, boundaries are most indicators on cooling curves. An increase welding speed leads to decrease weld metal deposition and increase cooling rates; the data was fitted as shown in **Figure 4.** These results are in agreement with results of **Zhang, et al (2011).**

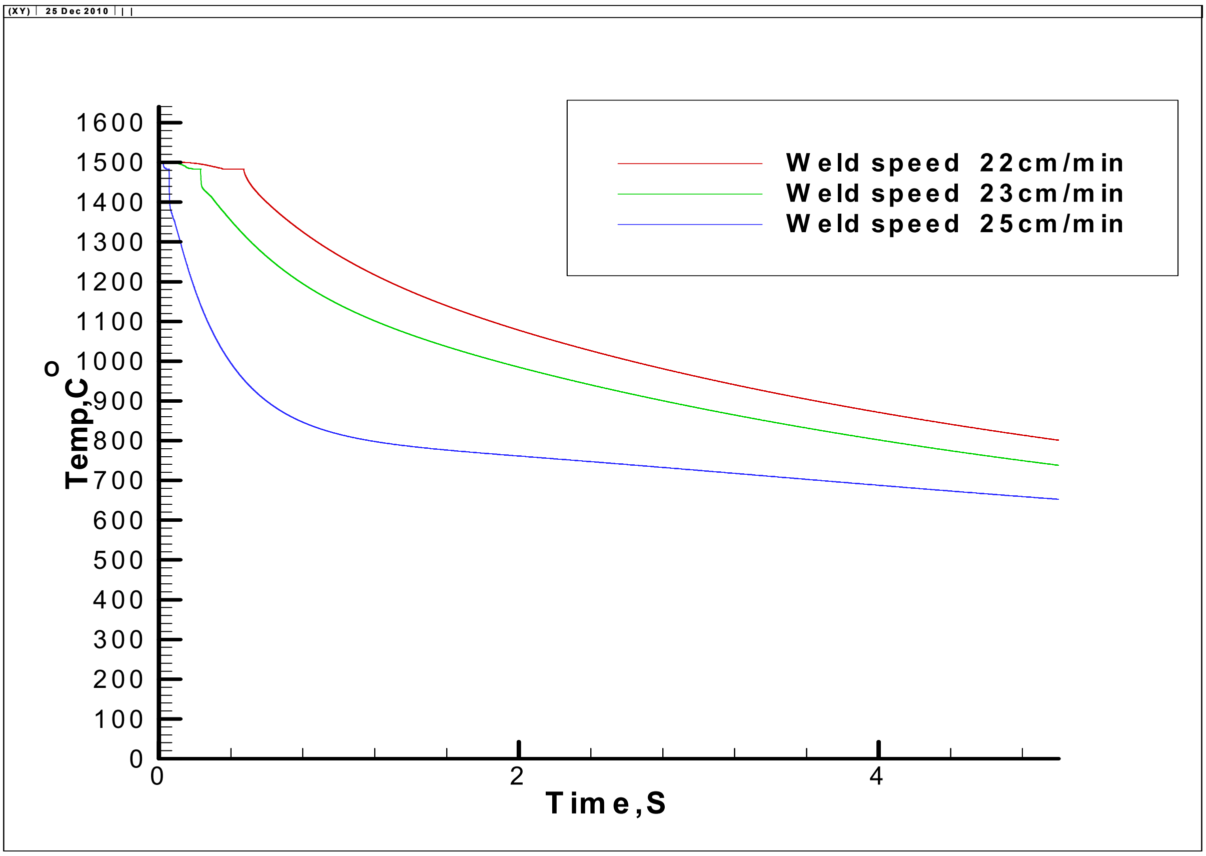


Figure 4: Numerical cooling curves at welding conditions: arc current = 500A, arc voltage= 40V with different welding speeds.

Optimization of welding parameters

Figure 5, shows the cooling curves with best select of welding parameters and those effects on filling cells area of weld metal deposits. FVM has capability reliability of optimization between welding speed and current at filling deposition area. As increase welding current lead to increase welding speed. These results are in good agreement with the results of **Roy et al (2003).**

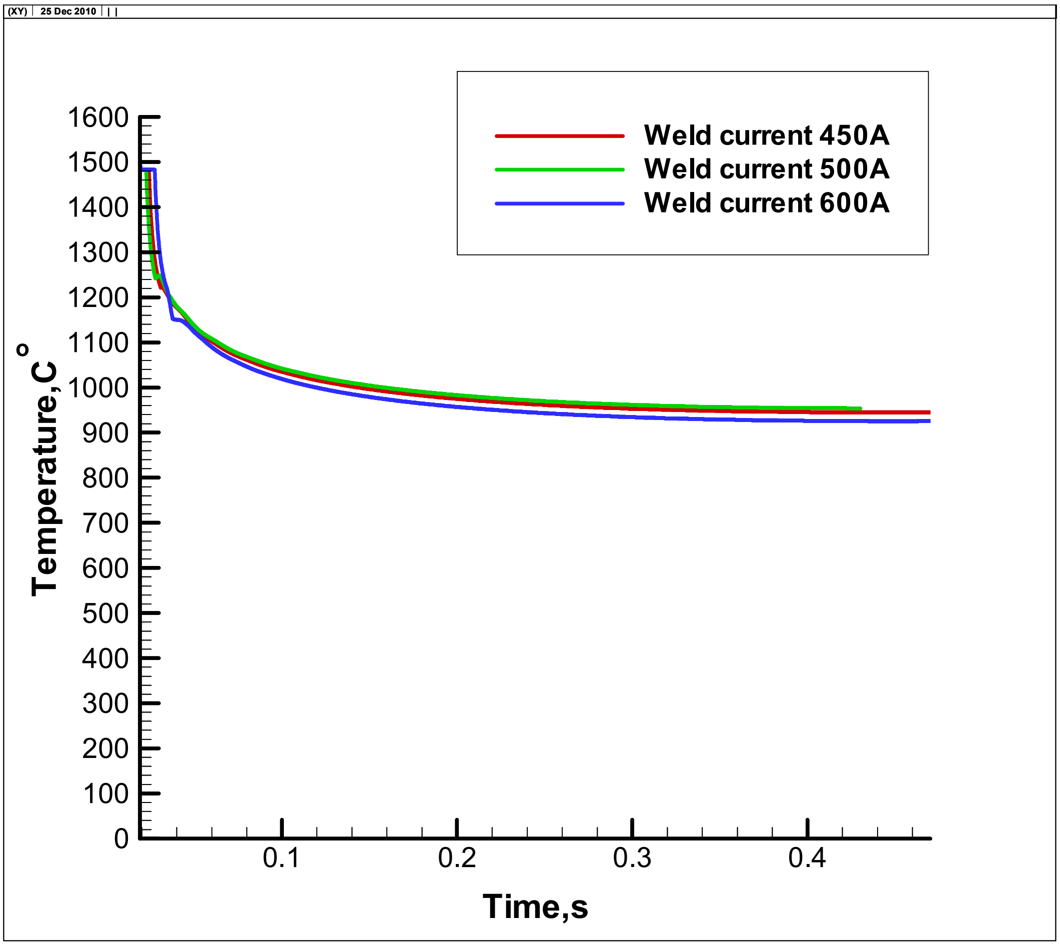


Figure 5:- Optimizations of cooling curves. Welding parameters current-speed (450A-22cm/min, 500-23cm/min and 600A-25cm/min), with preh600A-25cm/min), at time (0.5) Second and preheat temperature 250°C.

CONCLUSIONS

The conclusions of numerical method by finite volume method (FVM) are helping to predicate the:-

* Increasing the welding speed, lead to decrease weld metal deposition rate that effects to increases the cooling rates.

* Helping to determine the location of single -V- weld shape and cell area of weld metal deposition.
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* Optimization of welding parameters, an increase welding current with increase welding speed.

* Temperatures distribution in fusion zone and filling area of weld metal deposition.

REFERENCES

Gareth, A. Taylor, Michael and Koulis Pericleous," *Finite Volume methods Applied to the Computational Modeling of Welding Phenomena*", Second International Conference on CFD in the Mineral and Process Industries, Australia, 6-8 December 1999.

Moneer H.Al-Saady, Mudar A.Abdulsattar and Laith S.Al-Khafagy," *Finite Difference Simulation of Low Carbon Steel Manual Arc Welding, International Conference on Modelling and Simulation*", Turkey, 28-30, Paper No.A125 August, 2006.

Roy G.G, J.W.Elmer, and T.Debroy " *Modeling of heat transfer and Fluid Flow during Gas Tungsten Arc Spot Welding of Low Carbon Steel*", Journal of Applied Physics Vol 93, No.5, pp 3022-3033 March 2003.

Yiding Cao , and Amir Faghri," *A numerical Analysis of Stefan Problem for Generalized Multi-dimensional Phase –Change Structures Using the Enthalpy Transformation Model*", International Journal of Heat and Mass Transfer, Vol. 32, No.7, pp 1289 – 1298, (1989).

Hattel.J.H and N.H.Pryds," *Modeling Rapid Solidification with the Control Volume Method*", Riso National Lab-, Denmark, pp 241-247, (2001).

Cristiene V.Goncalves and Gilmar Guimarae," *Inverse Technique Applied in Welding; A theoretical and Experimental Approach*", 4th International Conference on inverse problems in Engineering, Brazil, 2002.

Kumar, and T.Debroy," *Guaranteed fillet weld geometry from heat transfer model and multivariable optimization*", International Journal of Heat and mass Transfer, pp 5793 – 5806, (2004).

Abbas Sh.Alwan, Muna K.Abbas, and Jalal M.Jalil "Numerical and Experimental Analyses for Effect of Welding Currents on Cooling Rates in (MMAW)Process", Engineering &Technology Science Journal Vol.28, No.12, pp 2276-2293, (2010).

Chol, and J.Mazumder, "*Numerical and Experimental Analysis for Solidification and Residual Stress in the GMAW Process for AISI 304 Stainless Steel*", Journal of Materials Science 37, pp 2143-2158, (2002).

Murugan , Sanjaik K.Rai , P.V.Kumar, and T.Jayakumar," *Temperature Distribution and Residual Stresses due to Multipass Welding in Type 304 Stainless Steel and Low Carbon Steel Weld Pads*", International Journal of Pressure Vessel and Piping78 (2001), pp 307-317.

Zhang, C.H.Kim, and T.Debroy," *Heat and Fluid Flow in Complex Joints During Gas Metal Arc Welding –Part 1: Numerical Model of Fillet Welding*", Journal of Applied Physics,Vol. 95, No.9, pp 5210-5219, February, 2004.

NOMECLATURE

Tm Melting temperature, °C

T1 Liquids temperature, °C

Ts Soldidus temperature, °C

ρl Liquid density, Kg/m^3

ρs Solid density, Kg/m^3

R Cooling rate, °C/S

Cρ Specific heat, J/kg.K

Kl Liquid Thermal conductivity, W/m.°K

h Latent heat, J/kg

E Enthalpy, kJ/kg

H Heat transfer coefficient, $W/m^2.K$

m Mass, Kg

V° Weld metal volume deposit per second, mm^3/s

ν Travel welding speed, mm/s

f_L liquid fraction

ΔT temperature difference, T_L- T_S (K)

t time, s

GREEK SYMBOLS

ρ Density, kg/m^3

η efficiency of arc welding , %

Γ and S Coefficient in equation (1)