Finite-Element Modeling of Manual Metal Arc Welding (MMAW) Process

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***Abstract*— Manual Metal Arc Welding is a process where an arc is struck between a flux-coated consumables electrode and the work piece. The arc and the weld pool are both shielded by gases generated by the flux coating of the electrode. In this paper, the Manual Metal Arc Welding is studied and Carbon Steel temperature field is gained in this process. The thermal effect of Manual Metal Arc that specially depends on the electrical arc, electrode type and temperature field of it in workpiece, is the main key of analysis and optimization of this process, from which the main goal of this paper has been defined. Numerical simulation of welding process in SIMPELC method and by ANSYS software for gaining the temperature field of carbon steel, the effect of parameter variation on temperature field and process optimization for different cases of electrode done.**

***Keywords*—** Finite-Element, MMAW, FSI, SIMPLEC, ANSYS Temperature Field and Carbon Steel

I. INTRODUCTION

Manual Metal Arc Welding is a process where an arc is struck between a flux-coated consumables electrode and the work piece. The arc and the weld pool are both shielded by gases generated by the flux coating of the electrode. Be certain that you are wearing suitable protective clothing, gloves etc. and that you are working in a non-hazardous area. If necessary, refer again to the SAFE PRACTICES section of this manual. Manual Metal Arc Welding (MMAW) Process shows in Fig.1.

Connect the Work Clamp to the work piece. Place the desired electrode in the Electrode Holder.

Turn on the power switch located on the rear panel. Wait approx 5 seconds as the unit goes through its initiation sequence.

Press the Weld Mode button until the Stick Mode LED is lit. The Induro 145 keeps the last mode used in memory, so this step is only necessary when using a different mode to that used last.

Select an appropriate welding current for the electrode diameter by setting the knob on the machine front panel. WIA AUSTARC electrodes will give the best results. To strike the arc, drag the end of the electrode along the work piece as if striking a match. As the arc initiates, lift the electrode slightly away, aiming to establish an arc length of approximately 3mm.

As the electrode end is consumed, feed the electrode into the arc in order to maintain arc length. As a general rule, the arc should be held as short as possible while still giving stable burn off and good weld appearance. An arc which is too long cause an unwieldy flow of metal with a rough weld appearance and reduced penetration. An arc too short leads to a narrow weld deposit and "stuttery" arc characteristics, and the electrode is liable to freeze onto the work piece.

As the solidified weld deposit forms, move the end of the electrode s lowly along the weld path, aiming to maintain a pool of molten weld metal behind the arc. Decreasing this rate of travel will result in a wider weld deposit, and similarly increasing it will narrow the weld deposit.

Always fill the crater which tends to form at the end of a weld deposit, by pausing momentarily before withdrawing the electrode to break the arc. Unfilled craters are a point of weakness, and can lead to weld cracking.

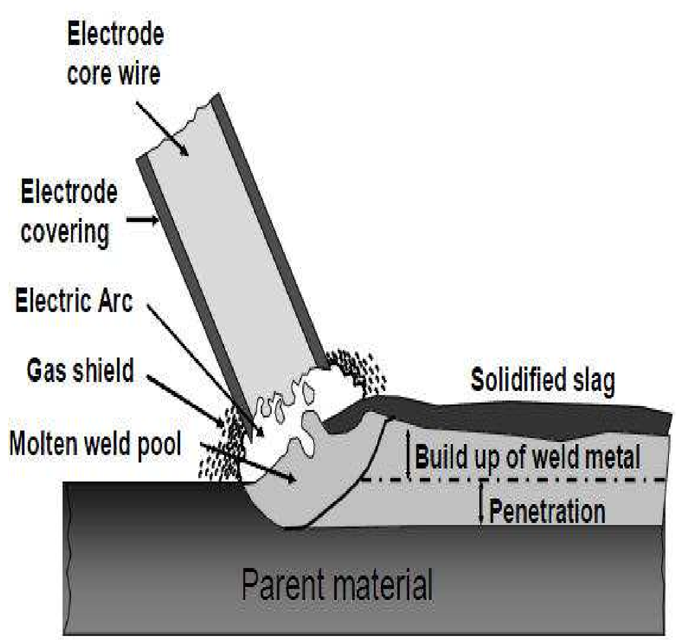

Fig. 1 (a). Manual Metal Arc Welding (MMAW) Process

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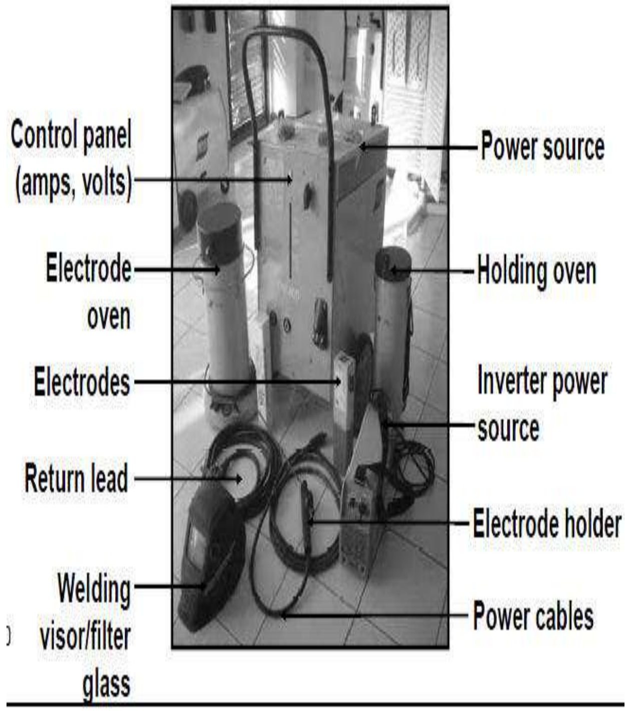


Fig.1 (b). Manual Metal Arc Welding Basic Equipment

II. GOVERNING EQUATIONS

In the common direct current electrode positive (DCEP) connection, the electrode is the anode and the workpiece is the cathode. A Manual Metal arc is struck between the electrode and the workpiece. The electrode is continuously fed downward and melts at the tip by the high temperature arc. Droplets are then detached from the electrode and transferred to the workpiece. The computational domain includes an anode zone (electrode), an arc zone, and a cathode zone (workpiece). The anode and cathode sheaths have been omitted and treated as special boundary conditions for computational simplifications. Assuming the arc is in local thermal equilibrium (LTE) and the plasma flow is laminar and incompressible, the differential equations governing the arc, the electrode, detached droplet, and the workpiece can be put into a single set.

The differential equations governing the conservations of mass, momentum, and energy based on continuum formulation given by Chiang and Tsai are modified and employed in this study. The derivation of the equations can be found in The idea of continuum formulation is to eliminate the need of explicitly tracking the solidifying or melting interface, and therefore the established conversation equations is valid for both solid and liquid phases[2].

The differential Equations (1) – (4) are solved iteratively by the SIMPLEC numerical procedure:

Mass continuity equation:

$$\frac{1}{r}\frac{\partial}{\partial r}(r\rho\upsilon_r)+\frac{\partial}{\partial z}(\rho\upsilon_z)=0 \qquad (1)$$

Radial momentum conservation equation:

$$\begin{aligned}&\frac{1}{r}\frac{\partial}{\partial r}(r\rho\upsilon_r^2)+\frac{\partial}{\partial z}(\rho\upsilon_r\upsilon_z)=\\&-\frac{\partial\rho}{\partial r}-j_zB_\theta+\frac{1}{r}\frac{\partial}{\partial r}(2r\eta\frac{\partial\upsilon_r}{\partial r})+\\&\frac{\partial}{\partial z}(\eta\frac{\partial\upsilon_r}{\partial z}+\eta\frac{\partial\upsilon_z}{\partial r})-2\eta\frac{\upsilon_r}{r^2}\end{aligned} \qquad (2)$$

Axial momentum conservation equation:

$$\begin{aligned}&\frac{1}{r}\frac{\partial}{\partial r}(r\rho\upsilon_r\upsilon_z)+\frac{\partial}{\partial z}(\rho\upsilon_z^2)=\\&-\frac{\partial\rho}{\partial z}+j_rB_\theta+\frac{\partial}{\partial z}(2\eta\frac{\partial\upsilon_z}{\partial z})+\\&\frac{1}{r}\frac{\partial}{\partial r}(r\eta\frac{\partial\upsilon_r}{\partial z}+r\eta\frac{\partial\upsilon_z}{\partial r}).\end{aligned} \qquad (3)$$

Energy conservation equation:

$$\begin{aligned}&\frac{1}{r}\frac{\partial}{\partial r}(r\rho\upsilon_r h)+\frac{\partial}{\partial z}(\rho\upsilon_z h)=\\&\frac{1}{r}\frac{\partial}{\partial r}(\frac{rk}{c_p}\frac{\partial h}{\partial r})+\frac{\partial}{\partial z}(\frac{k}{c_p}\frac{\partial h}{\partial z})+\\&j_rE_r+j_zE_z-R,\end{aligned} \qquad (4)$$

In the solution of Equation (1) – (4), special attention needs to be put on the energy effects on the electrode surface. At the cathode surface, additional energy flux terms should be included in Eq. (4) because of thermionic cooling due to the mission of electrons, ion heating, and radiation cooling [2].

III. NUMERICAL SIMULATION

Finite-Element techniques:

1-Finite elements modeling, types and properties for model different parts.

2- The definition of material properties

3- parameter definition

4- Loading

5- Boundary and initial value definition

IV. ARC-ELECTRODE MODEL

The tungsten cathode, arc plasma and anode are described in a frame of cylindrical coordinate with axial symmetry around the arc axis. The calculation domain is shown in Fig. 2. The diameter of the tungsten cathode is 3.2mm with a 60° conical tip. The anode is a water-cooled stainless steel. The arc current is set to be 150 A. Ar, He or mixture of them is introduced from the upper boundary of the calculation domain. The flow is assumed to be laminar, and the arc plasma is assumed to be under local thermodynamic equilibrium (LTE).

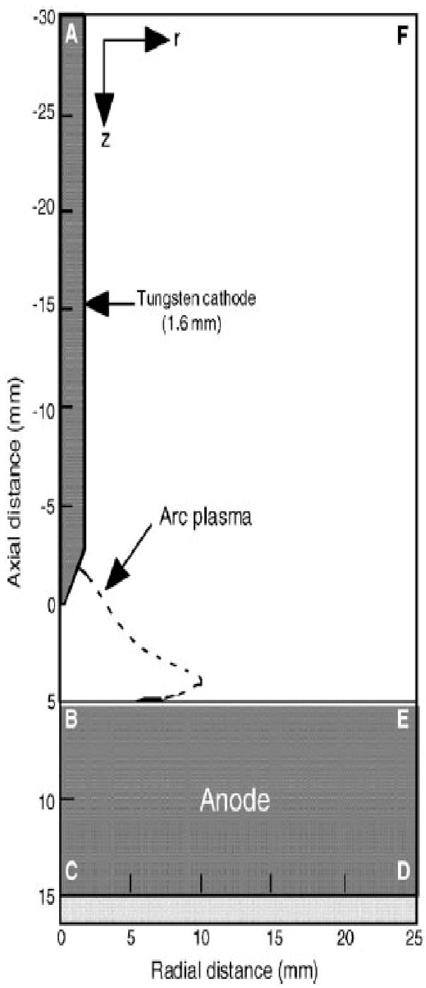


Fig. 2. Arc-electrode model [8]

V. NUMERICAL CONSIDERATIONS

For the metal domain, the method developed by Torrey et al. was used to solve p, u, v, and T. This method is Eulerian and allows for an arbitrary number of segments of free surface with any reasonable shape. The basic procedure for advancing the solution through one time step, Dt, consists of three steps. First, explicit approximations to the momentum Equations (2) – (4) are used to find provisional values of the new time velocities at the beginning of the time step. Second, an iterative procedure is used to solve for the advanced time pressure and velocity fields that satisfy Eq. (1) to within a convergence criterion at the new time. Third, the energy equation Eq. (4) is solved. Fig.2. shows A typical sequences of temperature, electrical potential, and pressure distributions on the symmetric plane for an axisymmetric stationary arc.

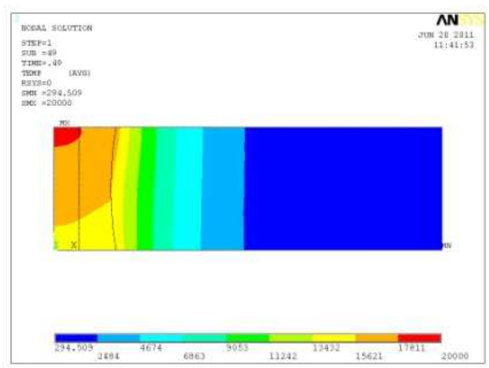
For the arc domain, a fully implicit formulation is used for the time-dependent terms, and the combined convection diffusion coefficients are evaluated using an upwind scheme. The SIMPLEC algorithm is applied to solve the momentum and continuity Equations (1) – (4) to obtain the velocity field. At each time step, the current continuity equation Eq. (4) is solved first, based on the updated parameters.

The new distributions of current density and electromagnetic force are then calculated for the momentum and energy equations. The momentum equations and the mass continuity equation are then solved in the iteration process to obtain pressure and velocity. The energy equation is solved to get the new temperature distribution. Next, the temperature-dependent parameters are updated, and the program goes back to the first step to calculate the current continuity equation. This process is repeated for each time step until the convergence criteria are satisfied [2].

VI. RESULTS AND DISCUSSION

Conclusions for fluid temperature field carbon steel temperature field, completely shown in Fig.3.

a)



b)

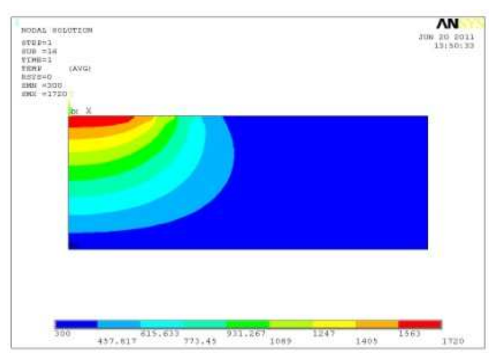


Fig.3. Conclusions for temperature field: a) temperature field, b) Carbon steel temperature field

A person acting as Fire Watcher must be standing by with suitable fire extinguishing equipment during and for some time after welding or cutting if Combustibles (including building construction) are within 10 metres. Combustibles are further than 10 metres but can be ignited by sparks. Openings (concealed or visible) in floors or walls within 10 metres may expose combustibles to sparks. Combustibles adjacent to walls, ceilings, roofs, or metal partitions can be ignited b radiant or conducted heat.

After work is done, check that area is free of sparks, glowing embers, and flames. Any tank or drum which has contained combustibles can produce flammable vapours when heated. Such a container must never be welded on or cut, unless it has first been cleaned as described in AS.1674-1974, the S.A.A. Cutting and Welding Safety Code. This includes a thorough steam or caustic cleaning (or a solvent or water washing, depending on the combustible's solubility), followed by purging and inerting with nitrogen or carbon dioxide, and using protective equipment as recommended in AS.1674-1974. Water-filling just below working level may substitute for inerting. Hollow castings or containers must be vented before welding or cutting. They can explode. Never weld or cut where the air may contain flammable dust, gas, or liquid vapours.

Exposed conductors or other bare metal in the welding circuit, or ungrounded electrically alive equipment can fatally shock a person whose body becomes a conductor. Ensure that the machine is correctly connected and earthed. If unsure have machine installed by a qualified electrician. On mobile or portable equipment, regularly inspect condition of trailing power leads and connecting plugs. Repair or replace damaged leads. Fully insulated electrode holders should be used. Do not use holders with protruding screws. Fully insulated lock-type connectors should be used to join welding cable lengths. Terminals and other exposed parts of electrical units should have insulated knobs or covers secured before operation.

The output fluid temperature field from nozzle showing heat transfer way between electrical arc and electrode and environment, with related temperatures is completely drawn in Fig.4. For study the temperature variations in plasma axis and its heat transfer to electrode according to diagram (Fig.5), the temperature field of electrical arc in its symmetry axis with standoff is drawn.

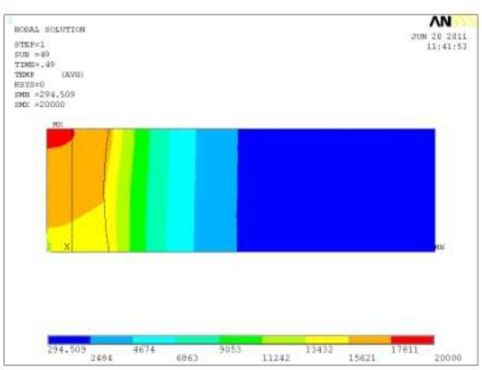


Fig.4. Electrical arc temperature field

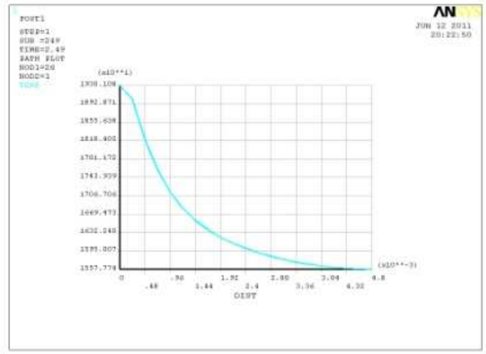


Fig.5. The temperature field of electrical arc in its symmetry axis by standoff.

In this diagram, in each distance from nozzle to workpiece surface, the desired temperature can be derived.

Thermal conductivity variation and thermal specific of carbon steel are shown in Fig. 6 and Fig. 7.

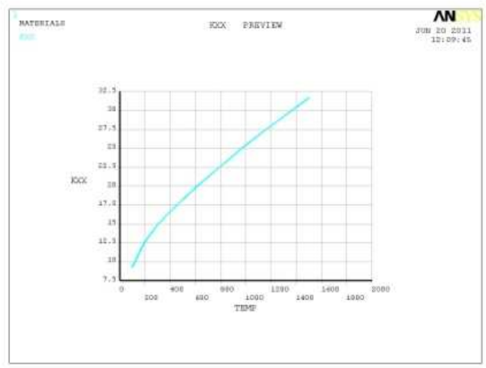


Fig.6. Thermal conductivity of carbon steel

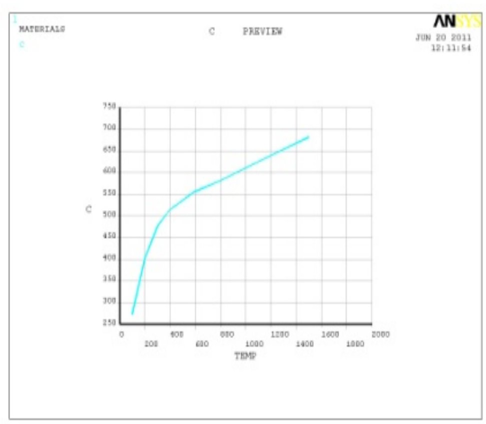


Fig.7. Thermal specific of carbon steel

VII. CONCLUSIONS

Exposed conductors or other bare metal in the welding circuit, or ungrounded electrically alive equipment can fatally shock a person whose body becomes a conductor. Ensure that the machine is correctly connected and earthed. If unsure have machine installed by a qualified electrician. On mobile or portable equipment, regularly inspect condition of trailing power leads and connecting plugs. Repair or replace damaged leads. Fully insulated electrode holders should be used. Do not use holders with protruding screws. Fully insulated lock-type connectors should be used to join welding cable lengths. Terminals and other exposed parts of electrical units should have insulated knobs or covers secured before operation.

A 3D mathematical model for the metal transfer process in MMAW was formulated in this article. A complete model describing the MMAW welding process is developed, however, the computation of the transient solution of the complete model was prohibitively time-consuming and beyond the capability of the current PCs. In order to study the plasma arc interaction with metal during the metal transfer process, some simplifications have been made. A case of an axisymmetric arc was studied first using this 3D model for the verification purpose. The numerical results agreed well with the previous two-dimensional studies. A case of a moving arc was then computed to demonstrate the 3D capability of the model. The results revealed that the time-invariant Gaussian assumption for the distributions of the arc pressure, heat flux, and current density on the workpiece surface did not represent of the real situation. The calculated distributions for the moving arc were non-axisymmetric and the peaks shifted to the arc moving direction.

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