International Journal of Science Engineering and Management (IJSEM)
Vol 1, Issue 6, June 2016

Solidification Pattern in V-Groove Submerged Arc Welded Plate

Anirudhha Ghosh
Govt. College of Engineering & Textile Technology, WB, India
agmech74@gmail.com

Abstract: **The study of heat flow in welding is a very important phenomena as quality of weld depends on mainly heat flow through welded plate. Heat input by welding source in a limited zone and it subsequent flow into body of work piece by conduction. A limited amount of heat loss is by a way of convection and radiation. In this paper, an attempt is taken to predict transient temperature distribution through a mathematical model and the associated numerical technique considering the heat transfer and solidification of molten weld pool when it is covered with flux and without flux. The estimated temperature distribution obtained, solidification and melting and those obtained from experimental measurements compared fairly well with variation up to 3% for the peak temperatures.**

Index Terms— **Weld pool; Submerged Arc Welding; Computational fluid dynamics; Melting**

I. INTRODUCTION

More than seventy years ago [1-2], there was the first attempt of investigation heat transfer during welding as heat transfer is a major role of changing of output parameters of arc welding (SAW) process. But due to some unrealistic assumptions, Rosenthal failed to predict the transient temperature distribution near the welding zone. Goldak [3], for the first time accurately modified these lacunae. He assumed double ellipsoidal 3-D heat source model and solved it through FEM method. Nguyen et.al. [4-5] also solved the problem analytically considering double heat source model. But it is very difficult to consider variable thermo-physical properties, weld pool convection, macro-scale mass flow, thermal profiles, convection, meso-scale solid/liquid interface, micro-scale phenomena, heat density distribution, effect of flux, gravity force, the drag force exerted by the flowing gas, electromagnetic force, and the retaining force by the surface tension, Lorentz force due to the divergence of the electric current within the drop accounts for the electromagnetic force etc. in analytical method. But without consideration of these constrains, prediction of accurate transient temperature distribution during welding is quite impossible. For that case numerical platform may give better approximation. Yeh et.al. [6-7] attempted to find out transient temperature distribution using finite difference method but they did not consider all aforesaid constrains, i.e. heat source model, momentum equation, continuity equation, Lorentz force, Marangoni convection etc. Mondal et. al. [8] also solved the problem through FEM, they considered variable thermo-physical properties etc. but still they did not consider all constrains. W. G. Essers and R. Walter [9] studied heat transfer during welding and depth of penetration. In their study they considered momentum of drop, magnetic effects on the direction of movement of the detaching drops etc. but they did not consider other few important influence process parameters. Actually researchers are concentrated on different particular influence parameters but overall effect should be emphasized. For example, H. Waszink and L. H. J. Graat [10] discussed about all possible force during GMA welding. K. C. Tsao and C. S. WU [11] discussed about fluid flow and heat transfer during welding, they solved energy and momentum equation through finite difference method for finding out results. But few more criteria which are important in calculation of heat flow problems in welding i.e. variable thermo-physical properties etc. were not included. S. Liu and T. A. Siewert [12] discussed about the effect of input parameters i.e. current, voltage etc. on metal transfer during welding and shape, rate, size liquid metal droplets. M. C. Tsai and S. Kou [13] studied on weld pool convection and discussed heat transfer and fluid flow during welding based on electromagnetic force distribution. R. T. C. Choo and J. Szekely [14] focused on the effect of gas shear stress on marangoni flows in arc welding and they observed that for below 200 A current operation shear stress exerted by the plasma jet in GTA welding play an important role on free surface deformation of weld pool. S. Rhee and JR. E. Kannatey-Asibu [15] investigated metal transfer during gas metal arc welding. They studied drop frequency, current effect on drop frequency, shielding gas effect on drop frequency, electrode extension effect, stability, fumes and bead formation, drop acceleration in the arc experimentally.

In this paper, effects of heat transfer from weld pool and solidification weld pool was investigated heat transfer through numerical technique using ANSYS Fluent. During solidification of liquid molten droplets, latent heat will also be released from this liquid molten droplet which also helps to melt the work piece at the vicinity of weld pool. The phase change during melting and solidification is modelled using fluent to determine coupling among composition, temperature, and the liquid fraction.

II. BOUNDARY CONDITIONS:

A specified initial temperature covering the entire plate surface is

$$T = T_{\infty} \quad \text{for } t = 0 \quad \text{....(1)}$$

Where T_{∞} is the ambient temperature. During the welding process, heat is dissipated into environment through convection and radiation heat losses on the top surface of the welded plate. Convection and radiation heat losses are also assumed on the bottom surface. The heat loss due to convection and radiation over these surfaces is given by

$$-k(T)\frac{\partial T}{\partial n} = h_c(T-T_{\infty}) + \varepsilon\sigma(T^4-T_{\infty}^4) \quad \text{for } t > 0 \quad \text{......(2)}$$

Only convection heat transfer is considered for the lateral surface of the work piece i.e.

$$-k(T)\frac{\partial T}{\partial n} = h_c(T - T_{\infty}) \quad \text{for } t > 0 \quad \text{....(3)}$$

III. SOLIDIFICATION MODELLING:

The enthalpy of the material is computed as the sum of the sensible enthalpy, h, and the latent heat, ΔH:

$$H = h + \Delta H \quad \text{................. (4)}$$

where,

$$h = h_{ref} + \int_{T_{ref}}^{T} c_p dT \quad \text{................ (5)}$$

The liquid-solid mushy zone is treated as a porous zone with porosity equal to the liquid fraction β, which is defined as

$$\beta = 0 \;\; if \;\; T < T_{solidus}$$

$$\beta = 1 \;\; if \;\; T > T_{liquidus}$$

$$\beta = \frac{T - T_{solidus}}{T_{liquidus} - T_{solidus}} \;\; if \;\; T_{solidus} < T < T_{liquidus}$$

The latent heat content can vary between zero (for a solid) and *L* (for a liquid).

$$\frac{\partial}{\partial t}(\rho H) + \nabla \cdot (\rho \vec{v} H) = \nabla \cdot (k \nabla T) + S_E$$

$$\text{where, } S_E = -\frac{\partial}{\partial t}(\rho \Delta H) - \nabla \cdot (\rho \vec{u} \Delta H)$$

IV. RESULTS AND DISCUSSION

On cooling, liquid metal losses energy in the form of latent heat and so the temperature is lowered which in turn decreases the average inter-atomic distance between mobile & disordered atoms. On further cooling, attractive forces between atoms prevent them moving away from one another and eventually completely liquid to solid transformation takes place. Generally alloys solidify over a range of temperature and formed mussy zone (as shown in fig.2).

The peak temperature is found at the nearer to the centre of the weld and then decreases gradually on approaching towards weld fusion boundary (as shown in fig.1). If flux is used, the temperature is maximum nearer to the center of the weld as well as near the flux zone, but when flux is not used then the maximum temperature zone is transferred to the middle portion of the weld pool as shown in figure 1. If flux is not used, then rate of cooling is high due to convective heat loss from the top portion so solidification also initiated from the top portion of the weld pool. It is also found from figure 1 that mushy zone formation is more for un-fluxed weld pool with respect to weld pool covered with flux) due to convective heat loos from top surface of weld pool.

It was also found that cooling rate of weld pool very high. Temperature is changing exponentially (approximately)with respect time and relative cooling rate is

International Journal of Science Engineering and Management (IJSEM)
Vol 1, Issue 6, June 2016

more of un-fluxed weld pool that is why uncovered weld pool is completely solidified at t= 1.3 s but weld pool which is covered with flux it completely solidifies in 2.3 s.

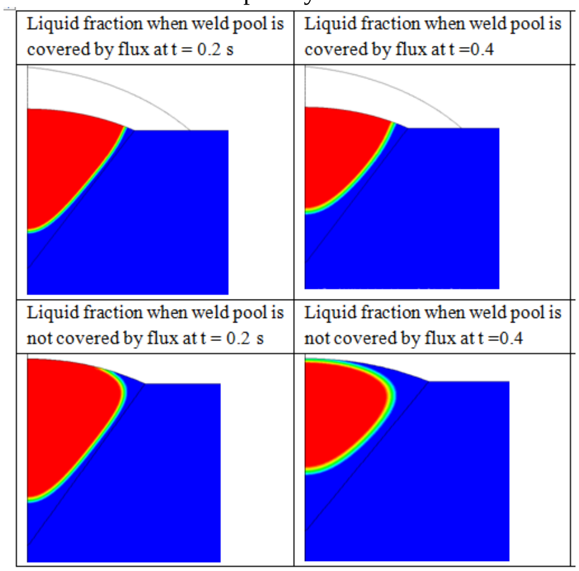

Figure 1: Comparison of solidification pattern when weld pool is covered by flux and without flux at various time

Generally, solidification takes place by nucleation and growth mechanism. However, solidification of weld metal can occur either by nucleation and growth mechanism or directly through growth mechanism depending upon the composition of the filler/electrode metal with respect to base metal composition. In case, when composition of the filler/electrode is completely different from the base metal, solidification occurs by nucleation and growth mechanism e.g. use of nickel electrode for joining steel. And when filler/electrode composition is similar to the base metal, solidification is accompanied by growth mechanism only on partially melted grain of the base metal which is commonly known as epitaxial solidification. The growth of grain on either newly developed nuclei or partially melted grain of the base metal, occurs by consuming liquid metal i.e. transforming the liquid into solid to complete the solidification sequence.

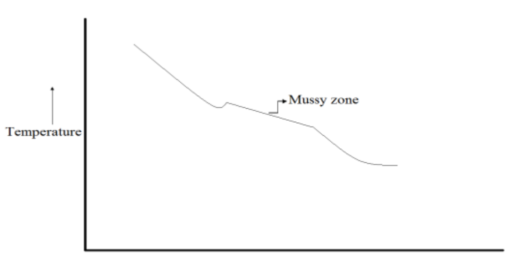

Figure: 2 Schematic of cooling curve for alloy during the solidification

Throughout growth of the solid in the weld pool, the contour of the solid liquid interface controls the development of microstructural features. The nature and the stability of the solid liquid interface is mostly determined by the thermal and constitutional conditions that exist in the immediate vicinity of the interface. Depending on these conditions, the interface growth may occur by planar, cellular, or dendritic growth.

In present paper transient temperature distribution and heat affected zone are also studied. It was found from figure 3 that decent agreement between predicted and measured temperature data on weld line which was very difficult to achieve in analytical model.

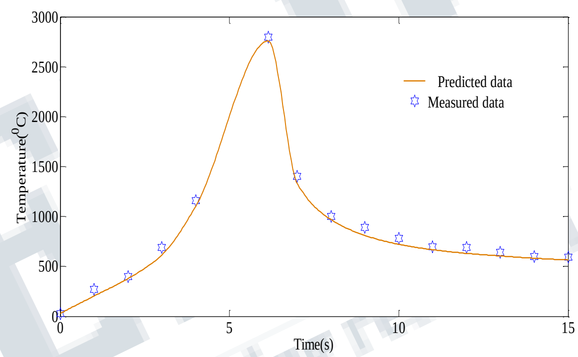

Figure 3: Comparison between predicted and measured temperature distribution at the location (0, 30 mm, 0)

V. CONCLUSION

To estimate the transient temperature distribution on welded plate in semiautomatic arc welding process, Convective and radiative heat losses were also considered. The experimental measurement shows that the peak temperature was higher and the cooling rate was larger for a work piece closer to welding path with respect to other part of welded plate as convection heat loss is proportional to temperature difference between welded plate and atmospheric temperature. The estimated temperature distribution obtained through ANSYS and those obtained from experimental measurements compared fairly well with variation up to 3% for the peak temperatures. Because of high heat input the heat removal rate is insufficient through convection cooling, and as a result temperature near the welded zone remains higher than the recrystallization temperature of welded plate for a sufficient time. It also has been found that flux is functioning as insulation on welded pool so it restricts rapid solidification and mushy zone width.

REFERENCES

[1] Rosenthal, D. 1935. Etude theories du regime thermique pendant la soudre a Tare. Congress national des sciences, 2d, Brussels: 1277-1292.

[2] Rosenthal, D. 1946 (Nov.). The theory of moving sources of heat and its application to metal treatments. Transactions of the American Society of Mechanical Engineers 68:849- 866.

[3] Goldak J, Chakravarti A, Bibby,M.,(1985) A double ellipsoidal finite element model for welding heat source, IIW Doc. No212-603-85.

[4] Nguyen NT, Ohta A, Matsuoka K, et al. Analytical solution for transient temperature of semi-infinite body subjected to3-D moving heat sources. Weld Res 1999; 12: 265–274.

[5] Nguyen NT, Mai YW, Simpson S, et al. Analytical approximate solution for double ellipsoidal heat source in finite thick plate. Weld Res 2004; 83(3): 82–93.

[6] Yeh, R.H., Liaw, S.P., Yu, H.B. (2003),Thermal analysis of welding on aluminum plates, Journal of Marine Science and Technology, Vol. 11, pp.213-220.

[7] Yeh, R.H., Liaw, S.P., Tu, Y.P. (2007), Transient three-dimensional analysis of gas tungsten arc welding plates, Numerical Heat Transfer, Part A,Vol.51, pp.573-592.

[8] Biswas P and Mandal NR. Thermomechanical finite element analysis and experimental investigation of single pass single-sided submerged arc welding of C-Mn steel plates. Proc IMechE, Part B: J Engineering Manufacture2009; 224: 627–639.

[9] W. G. Essers and R. Walter, Heat Transfer and Penetration Mechanisms with GMA and Plasma-GMA Welding, Welding Research Supplement, February 1981, 37-s 42-s.

[10] H. Waszink and L. H. J. Graat, Experimental Investigation of the Forces Acting on a Drop of Weld Metal, APRIL 1983, Welding Research Supplement, 108-s -116-s.

[11] K. C. Tsao and C. S. WU, Fluid Flow and Heat Transfer in GMA Weld Pools, MARCH 1988, Welding Research Supplement ,71-s-75-s.

[12] S. Liu and T. A. Siewert, Metal Transfer in Gas Metal Arc Welding: Droplet Rate, February 1989, Welding Research Supplement, 52-s - 58-s.

[13] M. C. Tsai and S. Kou, Electromagnetic-Force-Induced Convection in Weld Pools with a Free Surface, Welding Research Supplement, June 1990,241-s- 246-s.

[14] R. T. C. Choo and J. Szekely, The Effect of Gas Shear Stress on Marangoni Flows in Arc Welding, Welding Research Supplement, SEPTEMBER 1991, 223-s - 233-s.

[15] S. Rhee and JR. E. Kannatey-Asibu, Observation of Metal Transfer during Gas Metal Arc Welding, Welding Research Supplement, October 1992,381-s - 386-s.