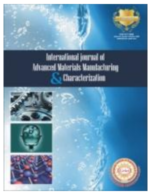

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Review on Finite Element Analysis of Temperature Distribution in Heat Affected Zone by Different Welding Process

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ABSTRACT

This work has reviewed models and techniques for predicting the temperature distributions. The metal adjacent to a weld is exposed to severe thermal events. As a result, complex changes in metallurgical structure occur in heat affected zone region.When creating a numerical model, the aim is to implement the physical behaviour of the process into the model. However, it may be necessary to compromise between accuracy of the model and the required computational time. Different types of simplifications of the problem and more efficient computation methods are discussed

Introduction

Welding is one of the most important and versatile means of fabrication available to Industry. Its' widespread use includes the' assembly of most large metal structures such as pipelines, cars, bridges and ships. The finite element method (FEM) is a computational technique used to obtainapproximate solutions of boundary value problems in engineering. The finiteelement method is a way of getting a numerical answer to a specific problem. Asimple description of FEM is the cutting of a structure into several elements,describing the behaviour of each element in a simple way, reconnecting theelements at "nodes" as if it were pins or drops of glue that held the elementstogether.Welding has been employed at an increasing rate for its advantages in designflexibility,costsavings,reducedoverallweightandenhanced structuralperformance.

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Finite Element Analysis of Welding

The numerical modeling of welding can be used as design tool or manufacturing analysis tool. As a design tool, FEM can be used to evaluate the feasibility of designs as early as the concept phase. As a manufacturing analysis tool, for fixed designs, different welding processes and sequences can be evaluated to minimize welding distortion . Despite the success that had been demonstrated by researchers over the pastfew decades of conduction heat flow models in predicting fusion weld sizes, base metal temperatures and processing requirements, FEA application in the weldingmanufacturing world is still uncommon.

Three-dimensional Modeling

A full three-dimensional model with a sufficiently fine mesh can model the heat flow as accurately as the errors in the material properties, geometry, heat input, convectionandradiationparameterspermit(Goldak,Bibby,Moore,House, Patel, 1986) [18]. The reason that three-dimensional analysis has not been standard procedure for the thermal analysis of welds is that it is time consuming and resource intensive. Residualstresspredictions in 2D modelling provided accurate estimations comparable to 3Danalyses, since the stress field exhibits a uniform distribution through the length oftheworkpiece.

Thermal and Structural Analysis

The definition of coupled systems includes the multiple domains and independent or dependent variables describing different physical systems. In the situation with multiple domains, the solution for both domainsis obtained simultaneously. In a couple dwelling analysis the temperature distribution and the thermal strains cause dbythe in tense heat source are calculated simultaneously

Heat Transfer

Once the overall heat input is known, two other things must be known before the thermal cycle can be determined: The distribution of the heat input as it is applied, and how the heat energy is dispersed after it enters the weld. The heat is dispersed from the weld zone, primarily through conduction into the surrounding material of the work piece. The conduction depends on the thermal properties of the metal (namely the specific heat and the thermal conductivity), the geometry of the weld joint, and the ambient temperature (preheat) of the metal surrounding the weld joint. The temperature field, *T(x, y, z, t),* is a function of spatial coordinates, *(x, y, z),* and time, *t.* It satisfies the following parabolic differential equation, the *heat equation,* at every point ill the domain [4]:

$$(\partial k \cdot (\partial T/\partial x))/\partial x + (\partial k \cdot (\partial T/\partial y))/\partial y + (\partial k \cdot (\partial T/\partial z))/\partial z + Q = \rho c_P \cdot (\partial T/\partial t) \qquad (1)$$

The essential boundary condition can be defined as:

$$T(x, y, z, t) = T1(x, y, z, t) (2)$$

(x, y, z)are points on the boundary for times after t = 0.

The natural boundary condition can be defined as:

$$k_n \cdot (\partial T/\partial n) + q + \alpha \cdot (T(x,y,z,t) - Ta) + \sigma\epsilon (T(x,y,z,t)^4 - Ta^4 (3)$$

(x, y, z)are points on the boundary for times after *t* = 0.

If radiation is included, or if the convective heat transfer coefficient is temperature dependent, this boundary condition is non-linear. In addition, the initial condition must be specified for *(x, y,* z) points ill the domain:

$$T(x,y,z,0) = T_0(x,y,z) \qquad (4)$$

If the partial differential Equation.1, a boundary condition 2 or 3, and the initial condition 4 are specified, the problem is well posed and a unique solution exists. Transient temperature gradient which itself is a function of the total heat input and heat distribution patterns within the weldments This leads to the critical requirement for the determination of realistic temperature gradients in the weldments. A very careful and accurate modeling of moving heat source is mandatory in order to capture exact temperature distributions. Heat source model is related to simulation approach .To give input Heat source Model has been used in upgraded form. Heat source model is discussed in literature review.

Affected Zone

When metals are joined by fusion welding, the material is heated to above its melting point and then cooled again rapidly. As a result of the severe thermal cycle, the original microstructure and properties of the metal in a region close to the weld can be drastically altered. This volume of metal, or zone, is called the heat affected zone (HAZ)

Fig.1 The Sub-zones of the Heat Affected Zone (Easterling (1983))[20]

The HAZ displays a range of microstructures and (hence) properties due to the varying thermal cycles experienced at different distances from the heat source. Figure 1 shows the various sub-zones of the HAZ and the corresponding region of the Fe-Fe3C equilibrium diagram

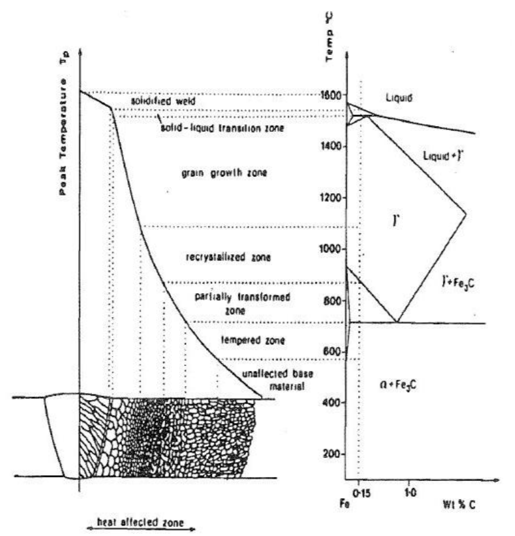

Fig.1 The Sub-zones of the Heat Affected Zone (Easterling (1983))[20]

Literature review

The weldability of steel has attracted a great deal of interest from researchers over the last 50 years. Their studies have used physical metallurgy, experimental results, models of the arc physics and other theoretical models to help predict weldability. My search of available literature was aimed at answering the following questions. How does one model welding to get accurate predictions of the temperature distribution?, How detailed does the model need to be? and How does one use the temperature distribution predictions to determine the weldability?

M.J. Attarha I. Sattari-Far [1] studied 3D finite element simulation of GTAW welding for three joints (two similar and one dissimilar) comprised of AISI type 304 stainless steel and St37 carbon steel thin plates and the temperature distributions and histories were compared with experimental measurements. Prediction of the cooling slope with distance can be used in the prediction of the HAZ microstructure.

E Ranjbarnodeh, S Serajzadeh1, A H Kokabi, and A Fischer [2] worked a three-dimensional model was used to predict the temperature field during and after dissimilar welding between CK4 and AISI 409 using automatic TIG welding. In addition, experimental measurements employing EBSD were conducted to assess the effect of welding parameters on grain growth in the HAZ of welded samples. the grain size and its distribution were strongly dependent on the welding heat input and the sample with the highest welding heat input (i.e. 583 J/mm) showed a larger grain size of about 250 mm, as well as a more homogenous grain size distribution in the HAZ of AISI 409.

K S Booand H S Cho [3] derived an analytical solution to predict the transient temperature distribution in a finite thickness weldment subjected to a travelling Gaussian distributed heat source. The transient temperature distribution was obtained by adopting Green's function to represent the temperature distribution due to an instantaneous point heat source with convection boundary conditions at the surfaces of a finite thickness plate.

S-J Na and S-Y Lee [4] analyzed the transient temperature distribution in the GTA welding process by employing a three-dimensional finite element model. The solution domain moving with the heat source was introduced to minimize the number of elements and, accordingly, the computation time. Since the moving solution domain was smaller than the real weldment, the combination of the convection and conduction boundary was varied with the progress of the simulation.

M. Afzaal Malik *et al* FEMS(2007)[5] implemented a Gaussian distributed moving heatheat source model based on Goldak's heat source model through author written APDL subroutines and MATLAB scripts and experimentally validated for the 3D finite element simulations of arc welding process. The important conclusions are Welding speed, heat source parameters and the total heat input to the plates can significantly affects the peak temperatures in the FZ and HAZ. Also the shape and boundaries of FZ and HAZ are sensitive to the changes in the input parameters. GOLDAK's heat source parameters distribution directly has direct affects on the boundaries and shape of the FZ and HAZ. The heat source parameters also significantly affect the peak temperature in FZ and HAZ. The change in temperature is approximately directly proportional to the heat input. Similarly the increase in welding speed results in decrease of the peak temperature in the FZ and HAZ.

P Biswas, M M Mahapatra, and N R Mandal [6] developed a 3D finite element model for the double-sided fillet SAW process and successfully compared with the experimental results. The temperature distributions obtained through analysis and those obtained from experimental measurements compared fairly well with a variation of only 8 per cent for the peak temperatures.

Ogwuagwu, O. Vincent et al [7] obtained the temperature profile from the simulation is in close agreement with those obtained by Goldak et al (1984). the stress distribution shows that the effect of plastic strain is greater close to the source of heat, which is the point of application of the electrode.

Y Satoshi , Y Takuya , K Tomoaki , N Toru and Y Hikaru [8] investigate the dynamic behavior of the displacement due to the welding distortion by designed the numerical model In spite of the difference between the numerical simulations and the experiments about the temperature behavior on the back side of the base metal,

Aniruddha Ghosh, Somnath Chattopadhyaya [9] studied analytical solutions for the transient temperature field of a semi infinite body subjected to 3-D power density moving heat source (such as double conical heat sources) were found and experimentally validated.. Prediction of temperature on different points on welding pates after welding has been made through numerical method .It is also newly found solution which will be very helpful to predict rate of cooling of metal so hardness, heat affected zone.

Huang Pengfei, Li Yan, Lu Yangyang and Lu Zhenyang [10] investigate A three-dimensional computational model is built in this by the software ANSYS to simulate the transient process of heat transfer in the fix-point welding pool with the same heat input. From the simulation results, it can be gotten that the distribution of temperature gradient and the change of depth-to-width ratio in the welding pool have corresponding relationship with the generation of undercut.. The experiment results are consistent with the numerical simulation results and ensure the correctness of numerical simulation.

M.O.H. Amuda and S. Mridha analyzed [11] the sensitization profile in medium chromium FSS welds produced under different welding conditions has been investigated. The findings apparent from the study are the width of the sensitization zone increases with increasing the heat input. The depth of the sensitization zone in the thickness direction is insignificant and it is generally within one-half of a millimeter. The use of heat input greater than 432J/mm increases the development of sensitized regions. This level of heat input correspond to heat fluxes in the range 1008-1296W and welding speeds between 3mm/s and 3.5mm/s. Under this condition the average cooling time is about 10s.

Ali. Moarrefzadeh [12] formulated a 3D mathematical model for the metal transfer process in MMAW. A case of an axis symmetric arc was studied first using this 3D model for the verification purpose. 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 work piece surface did not represent of the real situation. The calculated distributions for the moving arc were non-axis symmetric and the peaks shifted to the arc moving direction.

Shanmugam NS et al. [13] employs the finite element code SYSWELD to determine the thermal field and bead shape during the laser welding of T-joint welds. The conclusions are Proper fusion of base material (horizontal and vertical sheets) and tie between the bead profiles is achieved when the laser system is operated with 60° beam incident angle, irrespective of beam power and welding speed. A non-penetration defect is established in the macro-graph, when the beam angle is maintained at 30°. Comparison of experimental and simulation results reveals a very good correlation for depth of penetration and bead width values with a standard error of 2.78% and 1.9%, respectively.

Balasubramanian, K.R.; Siva Shanmugam, N.; Buvanashekaran, G.&Sankaranarayanasamy, K.[14] studied a three-dimensional Conical Gaussian heat source profile is used for the analysis.Characteristics of laser beam welding of butt-joint configuration have been combined withfunction extended SYSWELD to develop a finite-element model which is capable ofsimulation this process numerically.

Hu Seyi˙N Yapici, Gu Ls¸Ah O Zis¸ Ik And M Serdar Genc [15] investigated a hollow steel sphere (workpiece) heated partly-circumferentially by a moving uniform heat source applied on its outer surface under stagnant ambient conditions is considered to analyze numerically the transienttemperature and thermal stress distributions. The numerical analyses were performed in various thermal conductivities and in the different heated segment areas.The conclusions derived from this study can be listed briefly as follows: The temperature gradients and the thermal stress ratios peak at the heated segments because of the motion of the heat source, and however, after four-five cycles, the low peaks are noticed.

Ali Moarrefzadeh [16] studied the Shielded metal arc welding (SMAW) and Stainless steel temperature field is gained in this process. An integrated comprehensive 3D model has been developed to study the transport phenomena in SMAW. This paper presents a short analysis of the the basics of finite element simulation of the metal welding process.

S.C. Saha et al [17] developed a simple numerical heat transfer model by using a basic concept of heat transfer, numerical integration, distributed heat source and reducing the problem of three dimensions in one dimension SAW process. To account for greater realistic approach a volumetric heat source term is introduced. The heat distribution parameter (ƒ) is calculated from empirical relation developed by the investigation. This concept is successfully validated with experimental results obtained from submerged Arc welding process.

N. T. Nguyen, Y.-W. Mai, S. Simpson, And A. Ohta [18] described the detailed derivation of the analytical approximate solution for a double ellipsoidal density heat source in finite thick plate. This has shown that the solution of the heat source can be effectively used to predict the thermal history of the thick welded plate as well as weld pool shape geometry and various welding simulation purposes once the parameters of the heat source have been calibrated.

X.K. Zhu, Y.J. Chao [19] based on the experimental data of transient temperaturehistory at several specific locations during the FSW for304L stainless steel, an inverse analysis method for thermalnumerical simulation is developed. Results showthat due to unknown heat energy input from the process,this inverse analysis method is unique and effective forthe calculation of temperature field in the FSW. The maximum temperature determined from the simulation is between 900 and 1000 ◦C, which is significantly less than the melting temperature of 304L stainless steel at 1450 ◦C.

M. Iranmanesh ,A.R.Darvazi [21] analyzed that concerning the result of 3-dimmensional model. We can find the motion of heat source has stable state an d residual stress also take congenial state, of course, except the area close to beginning point.

Michael Schnick, Uwe Füssel, Jörg Zschetzsche [22] the commercial CFD Software Ansys CFX has been used for the numerical simulation of electric arcs of plasma torches as they are used for welding, cutting and coating of metals. The process simulation of plasma arc welding can be used to improve the welding process. The validation of the numerical results is indispensable.

D. Dean, K. Shoichi, S. Hisashi M. Hidekazu and H. Yukihiko [23] a thermal elastic plastic FEM was developed to predict welding residual stresses in 2.25Cr-1Mo steel pipes. In the developed FEM, the effects of solid-state phase transformation on welding residual stress were considered.

The Thao Doan and Thien Phuc Tran [24] the sequentially coupled 2-D FEM models for sequence and simultaneous weld are developed to simulate the temperature, distortion and residual stress fields in multi-pass T-joint fillet welded, and the following conclusions have been drawn: FEM is an efficient technique for optimizing welding procedure by analysis the welding residual stress and deformation distribution.The increases in heat input result in decrease in residual stresses. The simultaneous welding has the welding residual stresses smaller than sequence one but it has a larger deflections.

D. B. Darmadi, J. Norrish, Anh Kiet Tieu [25] the temperature profiles observed on longitudinal and transversal lines using both analytic and FEM method are in a good agreement. Comparing to the solution proposed by Rosenthal for point heat source model, the proposed analytic solution is closer to temperature profiles provided by FEM method. It is found especially at remote position behind the heat source center.

J. Sorina-Müller et al.[26] the developed simulation calculates the temperature evolution at any point in time during the whole process of the linear welding . Considered the variation with time of the surface contact area, material’s properties and the frictional parameters, with material’s properties and friction coefficient changing with temperature

C. K. Takemori, D. T. Müller, M. A. De Oliveira [27] the comparison between the numerical simulations results and the experimental data obtained demonstrates that the method to determinate housing and internal components temperatures of the compressor during the sealing weld is effective. It’s possible to reduce the development time of the welding process for new products.

M. Abid, M. J. Qarni [28]following conclusions are drawn from the study: The temperature distribution in the developed 3D FE models of single pass welding was reasonably steady around the heat source during the welding process of the pipe flange joint of low carbon and stainless steel. Using this FE model, a parametric study can be performed for the process variables, such as the welding current, voltage, and efficiency, preheating temperature of the work piece, welding velocity, and the path sequence of the welding procedure. Extension of this work is in progress to couple with a mechanical model to simulate the thermal stress developed during the process and dimensional accuracy of the welded pipes.

A. H. Yaghi, D. W. J. Tanner, T. H. Hyde, A. A. Becker, and W. Sun [29] presentedthe FE thermal analysis of the arc welding of a typical P92 pipe. The thermal analysis is simulated by applying a distributed heat flux to the model, the accuracy of which is judged by considering the fusion zones in both the parent pipe as well as the deposited weld metal

Conclusion

- Finite element analysis to simulate the transient thermal conditions of the weld would prove to be the most accurate and flexible method of modelling.
- The use of temperature dependent material properties had been proved to becrucial in the estimation of the temperature distribution of the plates.
- The prediction of residual stresses, distortion and microstructural changes of material can be determined by thermal profile obtained through temperature distribution.
- More work is needed to accurately evaluate the effects of welding parameters on thermal and mechanical responses of the weld, as well as the metallurgical events in the HAZ during dissimilar welding of ferritic stainless steels.

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