2004년도 추계 학술발표대회 발표논문, 2004년 11월, 천안

ANALYSIS OF WELD METAL STRUCTURE AND MECHANICAL BEHAVIOUR ENVISAGING PHASE CHANGE LATENT HEAT EFFECT

Rajesh S.R*, Bang Han Sur**, Joo Sung Min*, Bang Hee Sun***

*Ph D Student, Department of Ocean Engineering and Aerospace Engineering, Chosun University, Korea

**Professor, Department of Ocean Engineering and Aerospace Engineering, Chosun University, Korea

***Asst, Professor, Department of Ocean Engineering and Aerospace Engineering, Chosun University, Korea

ABSTRACT In this paper an important class of problems in welding which come under the category of phase change is considered. Solidification and melting are important process in welding field. Phase change problems are accompanied by either absorption or release of thermal energy i.e. heat transfer process. This is complicated by the release or absorption of the latent heat of fusion at the solid-liquid interface. In this study the liberation of latent heat is taken in to account using fixed grid method. The numerical simulation and the finite element codes for the heat transfer analysis including the latent heat term has been developed based on this fixed grid method.

Nomenclature

q	:	Heat flux
$\lambda_x,\lambda_y,\lambda_z$	:	Thermal conductivity along the x, y, and z
λ_s,λ_l	:	Solidous and liquidus thermal conductivity
c_l,c_s,c_f	:	Solidous, liquidus and freezing interval specific heat
ρ_l,ρ_s	:	Solidous and liquidus density
Q	:	Rate of temperature change
x, y, z	:	Cartesian coordinates
T_l, Ts, Ts	:	Liquidus, Solidous, Reference temperature
t	:	Time in sec
Ω_l,Ω_s	:	Liquidus and Solidous region
[N]	:	Shape function
$\{\}^e$	:	Vector of nodal temperature
S^e,V^e	:	Surface and volume of element
L	:	Latent heat
n	:	time step number
H	:	Enthalpy

1. Introduction

In welding, complicated phenomenon such as temperature dependency of material properties, phase transition (i.e. melting and evaporation) occurs. So numerical stimulation of the welding process using Finite Element Method has been a major topic in welding research from the past few years. The stimulation becomes complicated when considering the interaction of thermal mechanical and metallurgical phenomena. In this study the liberation of latent heat is taken in to account using fixed grid method.

In the process of melting, the solid and liquid phase of a pure substances are in equilibrium with each other. The amount of heat required to convert one unit amount of substance from the solid phase to liquid phase- leaving the temperature of the system unaltered is known as latent heat of fusion [1,2]. The material in the solidous and the liquidus temperatures 'mushy zone' is partly solid and partly liquid and its morphology depends on factors such as the composition, cooling rate and temperature gradient [3].

In this present study the Finite element code of heat transfer analysis including this phase transformation effect has been developed and the microstructure in the weld zone is post processed.

2. Modeling of Phase change

The phenomenon of heat transfer analysis is complicated by the release or absorption of the latent heat of fusion at the solid-liquid interface. The methods used to take into account the latent heat effects are generally

classified into fixed mesh method and moving mesh method i.e. the solution of a continuous system with an implicit representation of phase change and explicit representation as a moving boundary respectively. In this study fixed mesh method is taken into account.
Assuming the thermal conductivity is constant in all direction.

$$\rho_l c_l \frac{\partial T}{\partial t} = \lambda_l \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} \right) in\ \Omega_l \quad (1.0)$$

$$\rho_s c_s \frac{\partial T}{\partial t} = \lambda_s \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} \right) in\ \Omega_s \quad (2.0)$$

In fixed mesh method enthalpy formulation is used and for phase change over an interval of temperatures T_s to T_l as shown in fig.1.

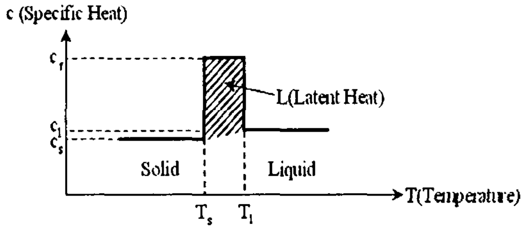

Fig.1 Typical variation of the effective heat capacity

For phase change over an interval of temperatures T_s to T_l

$$H(T) = \int_{T_r}^{T_s} \rho c_s(T) dT + \int_{T_s}^{T} \left[\rho \left(\frac{dL}{dT} \right) + \rho c_f(T) \right] dT \quad (3.0)$$

for $(T_s < T \leq T_l)$ and

$$H(T) = \int_{T_r}^{T_s} \rho c_s(T) dT + \rho L + \int_{T_s}^{T_l} \rho c_f(T) dt + \int_{T_l}^{T} \rho c_l(T) dT \quad (4.0)$$

for $(T \geq T_l)$

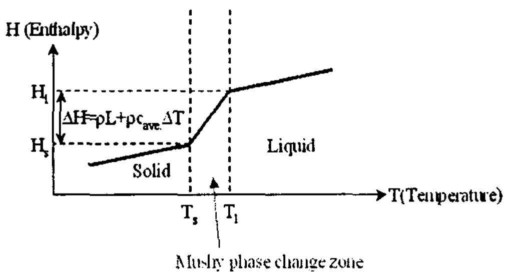

Fig.2 Typical variation of the enthalpy

Applying the error distribution principal known as Galerkin method in the governing equation of heat conduction and setting the n-integral form to zero and then applying Green-Gauss theorem the elemental formulation can be finally written as

$$[k]\{\phi\} + [c]\left\{ \frac{\partial \phi}{\partial t} \right\} = \{f\} \quad (5.0)$$

where Conductance matrix

$$[k]: -\int_{V^e} \lambda \left(\frac{\partial [N]^T}{\partial x} \frac{\partial [N]}{\partial x} + \frac{\partial [N]^T}{\partial y} \frac{\partial [N]}{\partial y} + \frac{\partial [N]^T}{\partial z} \frac{\partial [N]}{\partial z} \right) dV \quad (6.0)$$

Heat capacity matrix

$$[c]: -\int_{V^e} \rho c [N]^T [N]\, dV \quad (7.0)$$

Load vector

$$\{f\}: -\int_{S^e} q [N]^T dS + \int_{V^e} Q [N]^T dV \quad (8.0)$$

In this heat capacity matrix the value ρc for the various temperature limit for $(T_s < T \leq T_l)$ and $(T \geq T_l)$ is

$$\rho c = \left(\frac{H_n - H_{n-1}}{T_n - T_{n-1}} \right) \quad (9.0)$$

The evaluation of the integral of heat capacity matrix is based on the interpolation of enthalpy, since enthalpy is a smooth function of temperature in the phase change region. So enthalpy can be written as

$$H = [N(x,y)]\{H(t)\} \quad (10.0)$$

Based on this formulation the finite element code has been developed.
The phase transformation of steels (austenitic, ferritic-perlitic and bainitic transformations) depends on the cooling rate. Slow cooling rate austenitic phase transform to ferritic-perlitic phase, intermediate cooling rate austenitic transforms to bainitic and fast cooling rate to martensitic phase. The parameters of the Johnson- Mehl- Avrami model were extracted from continuous cooling transformation diagram according to the cooling speed and were inserted in the Finite element code in a tabular form. [4,5]

3. Results and discussion

A plate model with a graded meshing near the weld zone as shown in fig.3 has been used for the verification of the developed code.

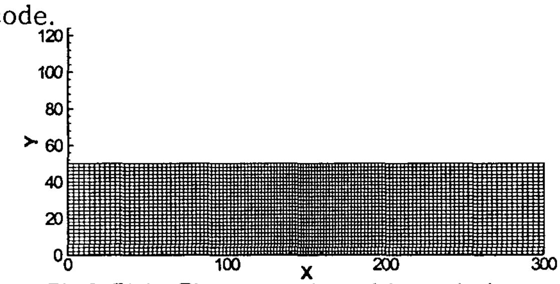

Fig.3 Finite Element mesh used for analysis

The heat transfer analysis is done using the latent heat term using the FE code developed. The temperature contour in the weld zone is as shown in the fig.4

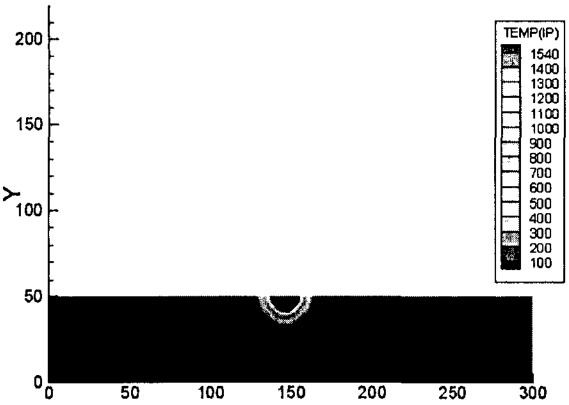

Fig.4 Temperature contour of weld zone

In order to study the variation of temperature near the weld zone certain check points have been chosen as shown in the fig.5

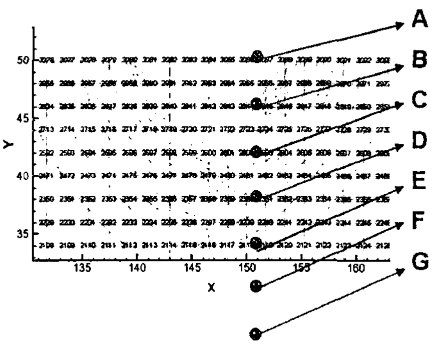

Fig.5 checkpoints in weld zone

The temperature variations with respect to time at these checkpoints are obtained shown in the fig.6. The inclusion of the latent heat term can be easily noticed.

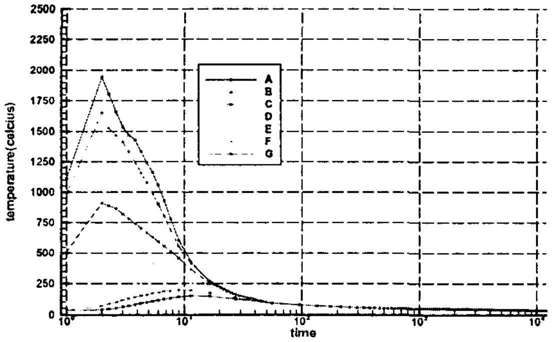

Fig.6 Temperature history at checkpoints

4. Conclusion

Finite element code for the heat transfer analysis including the latent heat term using fixed grid method has been developed. The results have been validated with the analytical solution. Good agreement was obtained between calculated value and analytical solution. The metallurgical transformations using temperature depended material properties and continuous cooling transformation diagram has been obtained but still needs modifications.

References

1. R.W.Lewis., K.Morgan, H.R.Thomas, and Seetharamu K.N., "The Finite Element Method in heat transfer analysis", John Wiley & Sons, New York, 1996.
2. K.N. Seetharamu, R Paragasam, A.Q. Ghulam, Z A Zainal, B Sathya Prasad and T Sundararajan "Finite element modeling of solidification Phenomena", Sadhana, Vol.26 Parts 1 & 2, pp. 103-120, February- April 2001.
3. S. Chakraborty and P. Dutta "A generalized algorithm for modeling phase change problems in materials processing", Current Science, Vol. 78, NO. 7, April 2000.
4. Sameer Phadke, Praveen Pauskar, Rajiv Shivpuri "Computational modeling of phase transformations and mechanical properties during the cooling of hot rolled rod", Journal of Materials Processing Technology, pp.107-115, 2004.
5. Siamak Serajzadeh, "Prediction of temperature distribution and phase transformation on the run-out table in the process of hot strip rolling", Applied Mathematical Modelling, Vol.27, pp.861-875, 2003.