Journal of Naval Architecture and Marine Engineering
June, 2015
http://dx.doi.org/10.3329/jname.v12i1.22670 *http://www.banglajol.info*

A STUDY OF PARAMETRIC EFFECTS ON THERMAL PROFILE OF SUBMERGED ARC WELDING PROCESS

Abhijit Sarkar[1*], R.N.Rai[2] and S.C.Saha[1]
[1]Department of Mechanical Engineering, National institute of Technology, Agartala, Agartala-799046, India,
*Email: sarkarabhijit2014@gmail.com
[2]Department of Production Engineering, National institute of Technology, Agartala, Agartala-799046, India

Abstract:

In this present investigation, a numerical model is carried out to study the effect of welding parameters on the temperature variations in Submerged Arc Welding process (SAW) with moving heat source model (Gaussian distribution) by using finite difference method (FDM). The obtained results from the simulation methodology are compared with experimental results and a good agreement between the experimental and the numerical results is found, with the associate degree overall proportion of error calculable to be between 6-9%, which is confirming the capability and reliability of the proposed numerical model. The numerical model is also recognized to simulate peak temperature at different locations of weldment. Finally parametric effects on temperature profiles based on numerical results are carried out for different weld parameters including welding speed and heat input. It has been shown that all those parameters are playing an essential role in affecting the temperature distribution.

Keywords: Submerged arc welding, temperature profile, finite difference method, moving heat source, peak temperature

1. Introduction

The Submerged Arc Welding (SAW) process is a versatile process, as it gives better quality, saves time, reduces cost, improves the repair procedure, process control, increases efficiency and productivity, which is widely used in many industries such as nuclear plant, shipbuilding, aerospace, transportation, automobile, and offshore. Studies of heat distributions as well as temperature histories become very important in welding. Because, it has a significant affect on the microstructure and mechanical properties of weldments. In other hand, many process parameters of welding like welding current, welding voltage, wire feed rate, stick out, welding speed, electrode diameter and thickness of the weldments are significantly affecting the thermal profile and temperature history. Analysis of the thermal profile of welding process in low carbon steel was introduced by Boumerzoug et al., 2011). Awang (2002) studied for the effects of welding process parameters on response parameters in welding for mild steel plates. A large number of numerical or mathematical models have been designed to predict temperature distributions in the welded joints (Biswas et al., 2010 and Joseison, 1990). Most of these models which were developed to predict the temperature distributions outcomes began in the 1940s. Firstly, the analytical model to predict the temperature for steady state, two dimensional heat flow problem in welding was derived by Rosenthal (1941) and (1946). But in practice, welding faced many problems involve complicated geometries, thermal history with complex boundary conditions, and cannot be solved analytically. Therefore, it is necessary to develop practical or numerical models to predicting the thermal history, for which temperature distribution can be calculated within acceptable tolerance. In such cases, sufficiently accurate approximate solutions can be obtained from computers using numerical methods, because a sophisticated numerical program and methods can generate accurate and reliable results (Takemori et al., 2010). In many branches of thermal and mechanical calculations, numerical model like Finite difference method (FDM) is used, because of its simplicity and speed especially in case of simple geometry. It is always possible to reduce enormous computer times of the 3-D case. Many researchers have pointed out that the FDM can overcome the difficulties arising in the calculation of some numerical methods, such as, Finite element analysis (FEA), Finite volume method (FVM) etc.(Mazumder and Steen, 1980 and Pilipenko, 2001). In 1980, Sharir et al. (1980) introduced the finite difference method as a numerical model to calculate the unsteady heat flow during the fusion welding of thin tantalum sheets. Adedayo and Irehovbude (2013) analyzed the thermal history along the length of a circular section subjected to flash-butt welding by the finite difference method. Al-Sa'ady et al. (2011) suggested the finite difference method to obtain time dependent temperature distributions for shielded metal arc welding of low carbon steel. They are shown that FDM results are better than simple empirical results since it takes into account more thermal and mechanical effects on the formation of the joints. Yeh et al. (2003) investigated the

 Received: March, 2015

steady-state temperature profiles of the welded plate were solved by finite difference method of aluminium plates welded by gas tungsten. There are obtained that the temperature of the welded plate increases with an increase in the heat input, whereas an increase in the welding speed produces the opposite effects. There are also measures that the calculated temperatures of the weldments increase as increases in preheating. Ghadimi et al. (2013) investigated that to obtain temperature profiles, thermal history curves, and cooling times for single-pass underwater wet weldments, three-dimensional finite difference method has been used. They were shown that the convective heat transfer is more effective than radiation in temperature calculations; therefore the radiation can be neglected. Boo and Cho (1990) studied a model to obtain the transient temperature distributions in a finite thickness plate by solving a transient three-dimensional heat conduction equation with convection boundary conditions at the surfaces of the weldment during arc welding. In 1984, the finite difference method has been introduced for stationary and axisymmetric GTAW process with a moving boundary by Oreper and Szekely (1984). Grill (1982) studied the heat flow of welding by the finite difference method during girth welding by the TIG method. He presented a mathematical model for the calculation of the three-dimensional thermal history of a composite cylinder by the implicit finite difference method. Grzesik and Bartoszuk (2009) used the Finite Difference Method for prediction of temperature distribution in cutting zone. Kou et al. (1983) developed a numerical method of three-dimensional heat flow with a finite-difference model for a rectangular moving heat source in a semi-infinite body. In 1997, Dill (1997) studied on calculation of the thermal history for single-pass underwater weldments by using the three-dimensional Crank-Nicholson finite difference method for solving heat transfer equations. During welding, he has applied the Adams approach and Tsai and Masubuchi's semi empirical correlation in his model to obtain the weldment temperature. It is clear from this literature review that the thermal history in a weldment i strongly affected by various welding parameters and their interactions.

In the present investigation, a numerical model has been developed for predicting temperature distributions of submerged arc welding by using a simplified finite difference heat transfer model for a moving distributed heat source. The results show that the numerically computed results compared with experimental results is validated and gives a good agreement with in a range of welding conditions. The numerical model of transient thermal is also recognized to simulate peak temperature in different locations. Also, it has been shown that the input parameters play an essential role in affecting the temperature distribution, so, the effects of welding speed and heat input on temperature distribution were also discussed.

2. Heat Source Model:

2.1 Thermal modelling:

In the thermal analysis, the transient temperature field T of the welded part is a function of time t and the spatial coordinates (x, y, z) and is determined by the non-linear heat transfer Eq. (1)

$$\frac{\partial}{\partial x}(K\frac{\partial T}{\partial x})+\frac{\partial}{\partial y}(K\frac{\partial T}{\partial y})+\frac{\partial}{\partial z}(K\frac{\partial T}{\partial z})+q=\rho c_p\frac{\partial T}{\partial t} \tag{1}$$

Where, K is the thermal conductivity (W/m^{0}c). C_p is the specific heat capacity (J/kg ^{0}C), ρ is the density of the plate material (kg/m^3) and q is the internal heat generation rate (W/m^3), T is the unknown temperature of weld plate (^{0}c) and is the spatial gradient operator. Considering the moving coordinate system ($\xi = x - v_s t$), the governing equation can be rewritten as.

$$\frac{\partial}{\partial \xi}(k\frac{\partial T}{\partial \xi})+\frac{\partial}{\partial y}(k\frac{\partial T}{\partial y})+\frac{\partial}{\partial z}(k\frac{\partial T}{\partial z})+\mathrm{q}=\rho c_p v_s(\frac{\partial T}{\partial \xi}) \tag{2}$$

$$\alpha(\frac{\partial^2 T}{\partial \xi^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2})+\frac{q}{\rho c_p}=v_s(\frac{\partial T}{\partial \xi}) \tag{3}$$

Where α, thermal diffusivity of the work-piece is equal to k/ (ρC_p); V_s is the welding speed and "t" is the time. The carbon steel use for analysis is having the following physical properties shown in Table 1.

2.2. Simulation of the heat source:

The thermal analysis of the weld is the magnitude of the heat transfer which is coming from the welding arc torch. Since the welding arc torch transmits heat over a surface, surface heat source (heat flux) is closer to the real condition than point heat source. Instead of uniform heat distributed, many researchers have used disc type heat source model according to Gauss distribution. For Gaussian distributed heat source, heat at certain distance (r) from center of heat source has value according to Eq. 4.

Table 1: Thermo-physical Properties of parent metal.

Temperature (^{0}C)	Thermal conductivity (W/mK)	Specific heat (J/KgK)	Thermal expansion coefficient ($10^{-6}/^0$C)	Enthalpy (MJ/m^3)
0	51.9	450	10	0
100	51.1	499.2	11	300
200	-	-	-	720
300	46.1	565.5	12	1100
400	-	-	-	1500
450	41.05	630.5	13	-
500	-	-	-	1980
550	37.6	705.5	14	-
600	35.6	773.3	14	2500
700	-	-	-	3000
720	30.64	1080.5	14	-
800	26	931	14	3700
900	-	-	-	4500
1000	-	-	-	5000
1100	-	-	-	-
1450	29.45	437.93	15	-
1510	29.7	400	15	-
1580	29.7	735.5	15	-
>2500	-	-	-	9000

$$q(\mathrm{r}) = q_{\max} \exp^{-c(\frac{r}{\bar{r}})^2} \tag{4}$$

Where, q(r) is the surface heat flux at radius r, q_{max} is the maximum flux at the center of the heat source. C and r is the concentration coefficient and the radial distance from the center of the heat source, respectively and C is closed to 3. $\bar{r}$ is the characteristic radial dimensional distribution parameter that defines the region in which 95 per cent of the heat flux is deposited and Eq. (4) can be represented as in Eq. (5).

$$q(\mathrm{r}) = q_{\max} \exp^{-3(\frac{r}{\bar{r}})^2} \tag{5}$$

The disc type heat distribution is proposed by (Pavelic, Tanbakuchi, Uyehara and Myers, 1969) who assumed that the heat flux be radially symmetrical nature having normal distribution represented as

$$q(\mathrm{r}) = \frac{3Q}{\pi \bar{r}^2} \exp[-3(\frac{r}{\bar{r}})^2] \tag{6}$$

Where $Q = V \times I \times \eta$ and Q is the power of the welding heat source, V is the arc voltage, I is the welding current, η is the arc efficiency. Here, the arc efficiency is assumed to be 0.95 for submerged arc welding process (Grong and Grong, 1997). Krutz and Segerlind (1976) suggested an alternative form for the Pavelic 'disc type' which is expressed in a coordinate system that moves with the heat source and Eq. (6) takes the form:

$$q(\mathrm{r}) = \frac{3Q}{\pi \bar{r}^2} \exp[-3(\frac{r}{\bar{r}})^2] \exp[-3(\frac{\xi}{\bar{r}})^2] \tag{7}$$

(Friedman, 1975) modified the above equation for moving arc at welding speed, considering the moving coordinate system (ξ= X-V_st), Eq. (7) can be written as:

$$q(\mathrm{r}) = \frac{3Q}{\pi \bar{r}^2} \exp[-3(\frac{x - v_s t}{\bar{r}})^2] \exp[-3(\frac{y}{\bar{r}})^2] \tag{8}$$

2.3. Boundary and initial conditions:

Boundary and initial conditions are specified. The finite volume modelling of the thermal behaviour during SAW performed in the present investigation is governed by Eq. (1) and is subjected to the following boundary conditions.

1. The heat flux due to welding arc is used for top surface nodes, which lie on weld line and weld zone, it is defined as

$$-k\frac{\partial T}{\partial n} = -q(\mathrm{r}) - h(\mathrm{T} - \mathrm{T}_a) \tag{9}$$

2. Convection loss only occur at all surface nodes, which lie on edge surface and corner except the bottom surface of the plate and it is defined as

$$-k\frac{\partial T}{\partial n} = -h(T_a - T) \tag{10}$$

3. The bottom surface of the plate is taken with the ambient temperature
4. In initial condition is needed at time t = 0 and the initial condition can be defined as

$$T = T_a, \mathrm{t} = 0; \tag{11}$$

Where, T_0 is the initial temperature or pre-heat or inter-pass temperature. However, in the present work T_0 is the ambient temperature.

2.4 Assumptions made in the thermal model:

As far as possible the actual welding conditions were considered in the model. However, the following assumptions were still required.

1. All the thermal properties were considered to be a function of the temperature.

2. Linear Newtonian convection cooling was considered on all the surfaces.

3. The heat loss due to radiation, conduction through the electrode, and heat consumed by burning of the flux and melting of the electrode were accounted for by the arc energy transfer efficiency parameter η. In the present study a value of 0.95 was taken for η for the SAW process.

4. A constant convection coefficient of 25 W/m^2K was considered.

5. Heat flux was considered as a load.

6. The initial or ambient temperature of the weldments is 30°C.

7. The physical phenomena such as Maragoni effects, convective melt flow, buoyancy force and viscous force are neglected.

8. In order to minimize the computing cost, the analysis is done with a plan (reference section) normal to the welding direction.

3. Numerical Method:

In the present work, a mathematical model has been developed by finite difference method to predict temperature profiles of weldments of submerged arc welding made of carbon steel. Based on the three-point finite differences, the second-order derivative terms of the left side of Eq. (1) at arbitrary node with the position of i, j, k in x, y, z direction and in time step m (Ghadimi et al., 2013), discrete are as follows:

$$\left[\frac{\partial^2 T}{\partial x^2}\right]_{i,j,k}^{m} = \frac{T_{i+1,j,k}^{m} - 2T_{i,j,k}^{m} + T_{i-1,j,k}^{m}}{\left(\Delta x\right)^2} \tag{12}$$

$$\left[\frac{\partial^2 T}{\partial y^2}\right]_{i,j,k}^{m} = \frac{T_{i,j+1,k}^{m} - 2T_{i,j,k}^{m} + T_{i,j-1,k}^{m}}{\left(\Delta y\right)^2} \tag{13}$$

$$\left[\frac{\partial^2 T}{\partial z^2}\right]_{i,j,k}^{m} = \frac{T_{i,j,k+1}^{m} - 2T_{i,j,k}^{m} + T_{i,j,k-1}^{m}}{\left(\Delta z\right)^2} \tag{14}$$

In this equation, the Δx, Δy, and Δz are the distances between the consecutive nodes in x, y, z direction. On the other hand, the first-order derivative term of the right side of Eq. (1) at arbitrary node and time step m, based on the forward difference formula discrete, is as follows:

$$\left[\frac{\partial T}{\partial t}\right]_{i,j,\mathrm{k}}^{m} = \frac{T_{i,j,k}^{m+1} - T_{i,j,k}^{m}}{\Delta t} \tag{15}$$

Where Δt is the time space. By using Eqns. (9-15) in Eq. (1) the temperature for a typical internal weld zone surface node is obtained as

$$h(\mathrm{T}_{i,\mathrm{j,k}}^{m+1} - T_a) + k\left(\frac{T_{i+1,j,k}^{m} - 2T_{i,j,k}^{m} + T_{i-1,j,k}^{m}}{(\Delta x)^2}\right) + k\left(\frac{T_{i,j+1,k}^{m} - 2T_{i,j,k}^{m} + T_{i,j-1,k}^{m}}{(\Delta y)^2}\right)$$
$$+k\left(\frac{T_{i,j,k+1}^{m} - 2T_{i,j,k}^{m} + T_{i,j,k-1}^{m}}{(\Delta z)^2}\right) + q = \rho C_p . \frac{T_{i,j,k}^{m+1} - T_{i,j,k}^{m}}{\Delta t} \tag{16}$$

$$T_{i,j,k}^{m+1} = [(1 - 2[\beta_1 + \beta_2 + \beta_3]).T_{i,j,k}^{m} + \beta_1(T_{i+1,j,k}^{m} + T_{i-1,j,k}^{m}) + \beta_2(T_{i,j+1,k}^{m} + T_{i,j-1,k}^{m})$$
$$+\beta_3(T_{i,j,k+1}^{m} + T_{i,j,k-1}^{m}) + \alpha\Delta t(\frac{q}{k} - h.T_a)].(\frac{1}{1 - h.\alpha.\Delta t}) \tag{17}$$

$$T_{i,j,k}^{m+1} = [\lambda T_{i,j,k}^{m} + \beta_1(T_{i+1,j,k}^{m} + T_{i-1,j,k}^{m}) + \beta_2(T_{i,j+1,k}^{m} + T_{i,j-1,k}^{m}) + \beta_3(T_{i,j,k+1}^{m} + T_{i,j,k-1}^{m})$$
$$+\alpha\Delta t(\frac{q}{k} - h.T_a)].(\frac{1}{1 - h.\alpha.\Delta t}) \tag{18}$$

For convection boundary condition at other surface node:

$$k\left(\frac{T_{i+1,j,k}^{m} - 2T_{i,j,k}^{m} + T_{i-1,j,k}^{m}}{(\Delta x)^2}\right) + k\left(\frac{T_{i,j+1,k}^{m} - 2T_{i,j,k}^{m} + T_{i,j-1,k}^{m}}{(\Delta y)^2}\right) + k\left(\frac{T_{i,j,k+1}^{m} - 2T_{i,j,k}^{m} + T_{i,j,k-1}^{m}}{(\Delta z)^2}\right)$$
$$+h(\mathrm{T}_{i,j,k}^{m+1} - \mathrm{T}_a) = \rho C_p . \frac{T_{i,j,k}^{m+1} - T_{i,j,k}^{m}}{\Delta t} \tag{19}$$

$$T_{i,j,k}^{m+1} = [(1 - 2\{\beta_1 + \beta_2 + \beta_3\}).T_{i,j,k}^{m} + \beta_1(T_{i+1,j,k}^{m} + T_{i-1,j,k}^{m}) + \beta_2(T_{i,j+1,k}^{m} + T_{i,j-1,k}^{m}) +$$
$$\beta_3(T_{i,j,k+1}^{m} + T_{i,j,k-1}^{m}) - h.\mathrm{T}_a].\left(\frac{1}{1 - \alpha h \Delta t}\right) \tag{20}$$

$$T_{i,j,k}^{m+1} = [\lambda.T_{i,j,k}^{m} + \beta_1(T_{i+1,j,k}^{m} + T_{i-1,j,k}^{m}) + \beta_2(T_{i,j+1,k}^{m} + T_{i,j-1,k}^{m}) +$$
$$\beta_3(T_{i,j,k+1}^{m} + T_{i,j,k-1}^{m}) - h.\mathrm{T}_a].\left(\frac{1}{1 - \alpha h \Delta t}\right) \tag{21}$$

Where, $\beta_1 = \frac{\Delta t\alpha}{\Delta x^2}, \beta_2 = \frac{\Delta t\alpha}{\Delta y^2}, \beta_3 = \frac{\Delta t\alpha}{\Delta z^2}$ (22)

$$\lambda = 1 - 2[\beta_1 + \beta_2 + \beta_3] \tag{23}$$

Where α is the thermal diffusivity, defined as $\alpha = \frac{k}{\rho C_p}$ (24)

In the present case, a section is taken at a distance of 10 cm from starting point of welding in weldments as shown in Fig. 1. The first step in mathematical formulation is to demarcate the reference section, i.e. unit slice from the weld plate and reference section shown in Fig. 1. On which the heat transfer aspects of the model are to be employed. Knowledge of relative position of the reference section from the heat source (ζ) at any instant of time t is important. This is arrived by subtracting the position of heat source at that instant of time (ν_s) from the distance of the reference section from the starting point of the plate. The value of ζ may be positive or negative depending on the position of the heat source being before (start of welding) or after the reference section with respect to time. However, it should be mentioned that the heat content of the reference section changes with the changing value of ζ and it is maximum at ζ=0 (which means the source is above the reference section). The governing equations and the boundary conditions are then transformed into a set of explicit finite difference equations and were solved numerically.

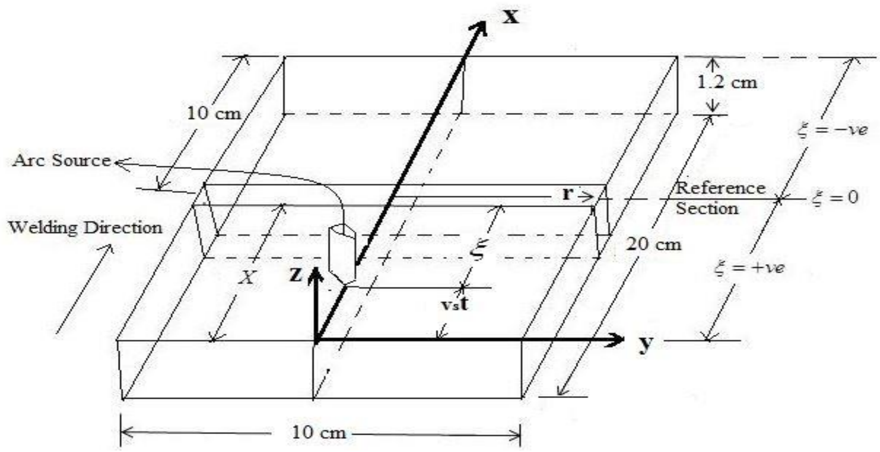


Fig. 1: Dimensions of weld (all dimensions in cm) plate and discretization of plate section.

2. Experiment Procedure:

The experiment is conducted on SAW machine, ADOR WELDING LTD. INDIA, Machine No: MODEL PS-1200(F) shown in Fig. 2. A fused type silicon product with grain size 0.2 to 1.6 mm with basicity index 1.6 flux (AUTOMELT A55) is used for welding which having a chemical composition of, SiO2+TiO2=30%, CaO+ MgO =10%, Al2O3 + MnO= 45%, CaF2= 15. Bead-on-plate welds were deposited using mild steel electrode coated with copper wire diameters of 3.15mm. Table 2 shows the chemical composition of the base material and electrode wire. Total 6 welds were deposited following the welding parameters given in Table 3.

4.1. Experiment preparation:

The specimen used for measurement of temperature was a rectangular piece of carbon steel of size 20×10×1.2 cm. To measure the temperature in the welding process, the K type Chromul-Aumul thermocouple was used. The positions of the thermocouples based on the chosen coordinate system are tabulated in Table 4. The thermocouples 1-3 were attached to a depth of 0.6 cm, through the blind holes which were drilled from the top of the plate and thermocouple 4 attracted to a depth of 0.6 cm from the bottom of the plate and its schematic diagram shown in Fig. 3. A PC-based data acquisition system (NI PCIE-6351, X Series Multifunction DAQ) with a maximum frequency of 100 MHz was used to sample the signal from the thermocouples. They give the flexibility of capturing data at a very high sampling rate. A SHC68-68-EPM Shielded cable was used to minimize the noise. Firstly, Thermocouples is attached to a DAQ system that can sample the temperature data at 60 Hz. Data collection is accomplished with two DAQ systems, one for temperature and other for force, that are attached to a personal computer with a customized program running on Lab-View Software. Thermocouples are connected at junction box and then subsequently coupled to Data acquisition system for recording the thermal histories of different location of the plate, shown in Fig. 4. The data acquisition system of LABVIEW was used to acquire the temperature every second, during welding from these 3 locations as well as the room temperature. A flow chart of the numerical model calculation process is shown in Fig. 5.

Table: 2 Chemical compositions of the base plate and electrode wire.

Element	C	Mn	Si	Cr	P	S	Mo
Base metal	0.15	0.78	0.115	1.74	0.0275	0.003	0.9
Electrode	0.040	0.40	0.050	-	-	-	-

Table 3: Operating welding parameters

Ex. No	Current (A)	Voltage (V)	Welding speed (cm/sec)
1	350	30	0.67
2	400	30	0.67
3	450	30	0.67
4	350	30	1.00
5	400	30	1.00
6	450	30	1.00

Fig. 2: Submerged arc welding machine

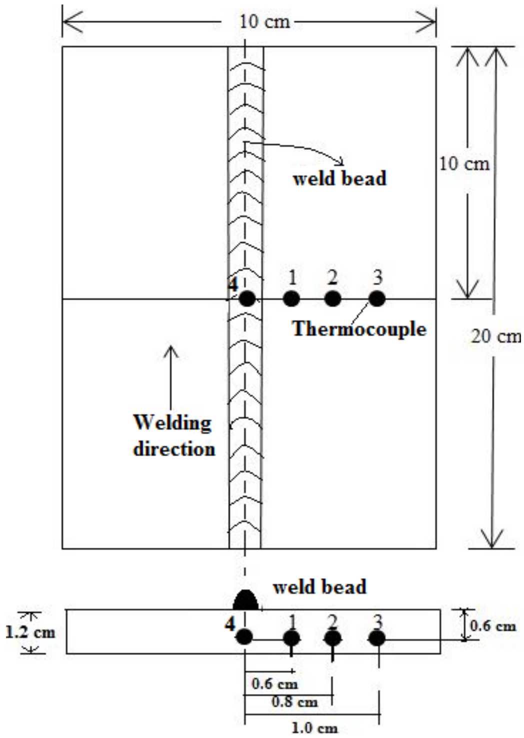
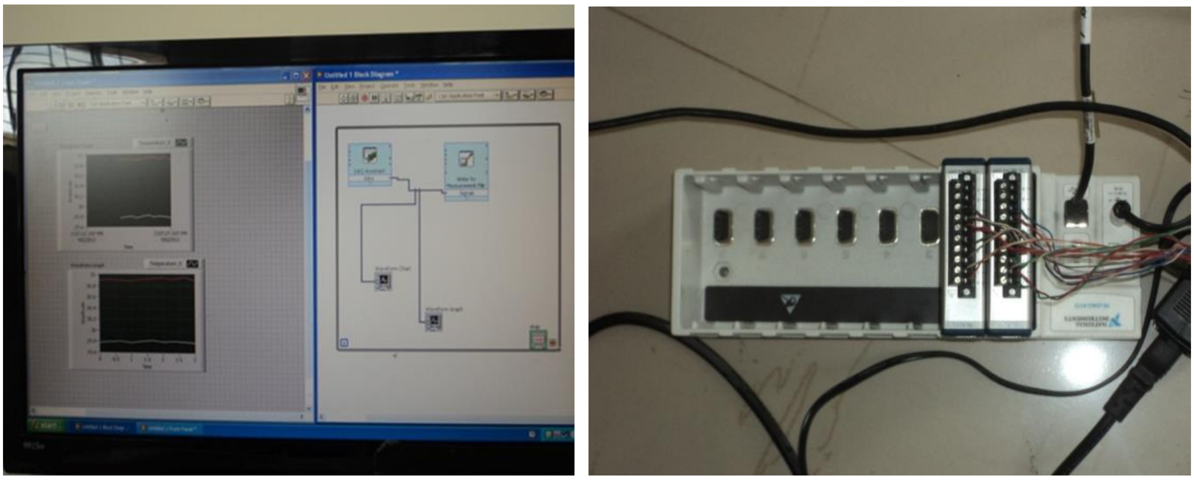


Fig. 3: Schematic diagram of welded plate used in the experiment.

Table 4: Thermocouple mean positions

Thermocouple (k-type) (chromul-Aumul)	Mean position (cm)		
	X	Y	Z
T1	10	0.6	0.6
T2	10	0.8	0.6
T3	10	1.0	0.6
T4	10	0.0	0.6



(a) (b)

Fig. 4: (a) Simulink of Lab view software (b) DAQ system for temperature recording

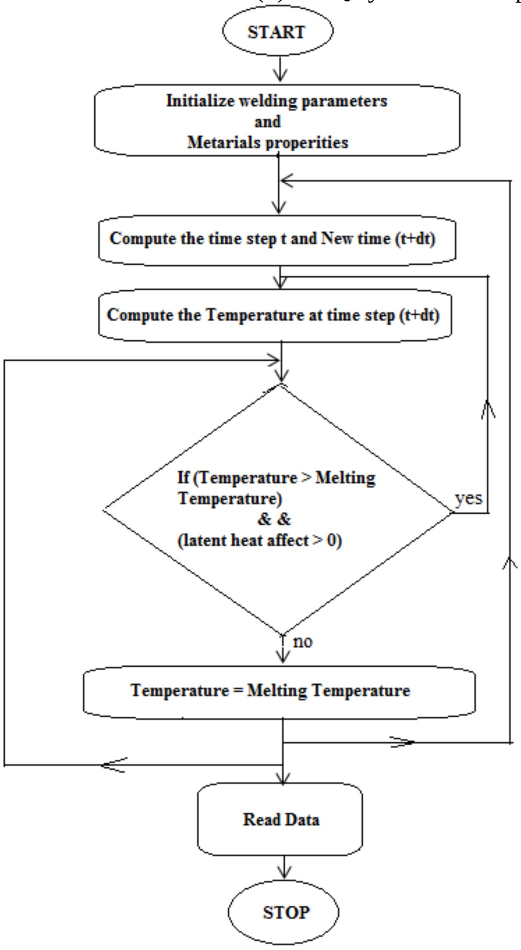


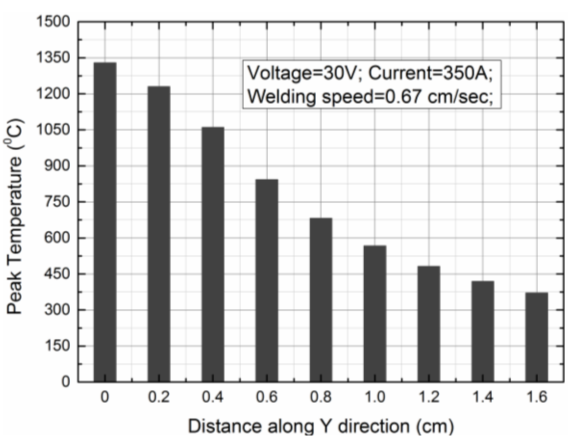
Fig. 5: Flow chart of numerical model calculation.

5. Results and Discussion

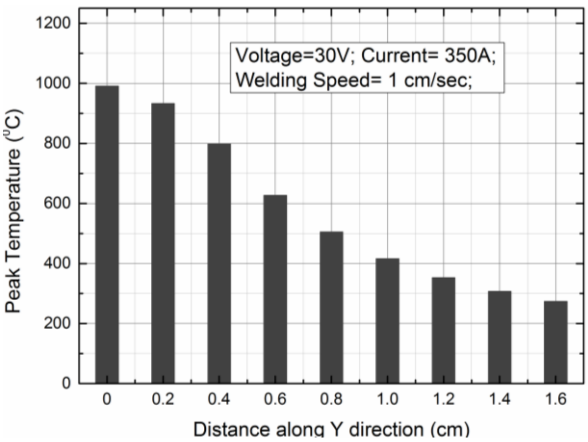
The result obtained from the numerical model at various welding parameters are studied to understand the nature of temperature distribution in the weld plate, the rate of heating, the peak temperature attained, the rate of cooling in different points in the weldments. The variation of peak temperature with respect to welding parameters and distance are also noted. The effects of welding speed and heat input on temperature field distribution were discussed. Finally the validity of the model is checked with the experimental result and has found a good agreement.

5.1. Peak temperature with various welding parameters:

The nature of peak temperature with respect to distance is drawn by taking selective point in the transverse direction of the plate which is shown in Fig. 6 (A)-(F). An important investigation here is that the peak temperature directly depends upon the total heat input to the plate from the welding line. Peak temperature decreased with distance as a move away from the weld center line. The high heat input in case of shows significantly higher peak temperature as compared to lower one. Fig. 6 shows the peak temperature achieved transverse to weld direction (a section at z=0. 6 cm) when the heat source is applied at different welding current and speed to the plates. From Fig. 6 (A) and (B), it is shown that the increase in welding speed will result in lower temperatures. The same part is indicated from Figs. 6 (C) and (D) and Figs. 6 (E) and (F). So it is definite that welding current and speed is a significant effect on the peak temperature. This study may be used to find the dimension of weld zone and heat affected zone by projecting the fusion temperature (1500^0C) and the lowest temperature where microstructural changes take place i.e. 723^0C.



(A)



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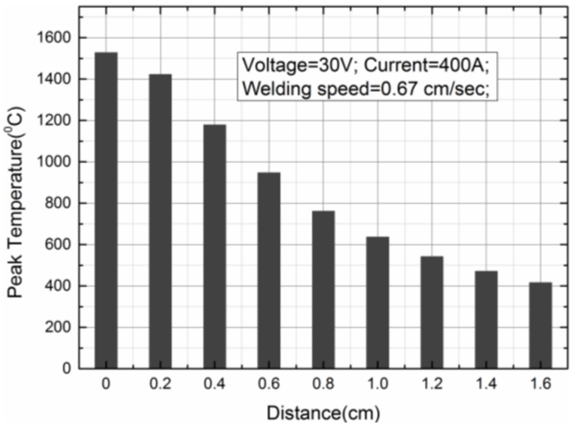
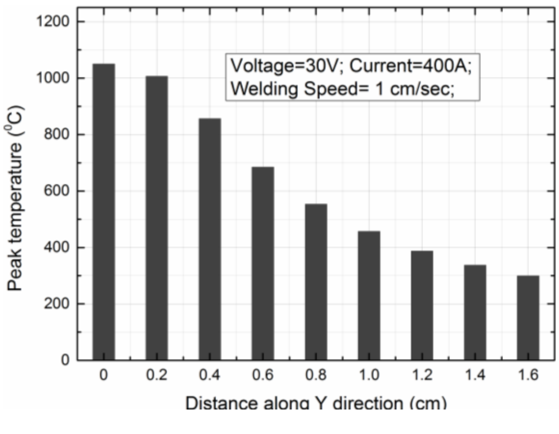
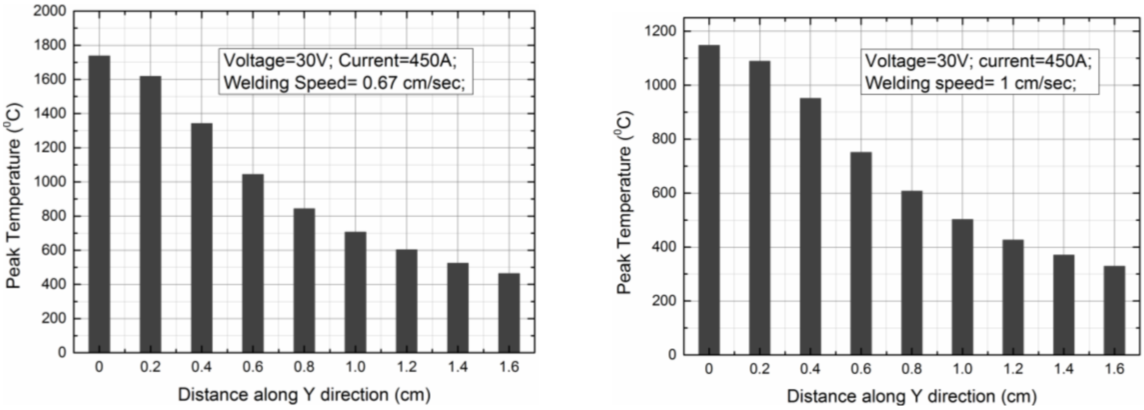


(C)



(D)



(E) **(F)**

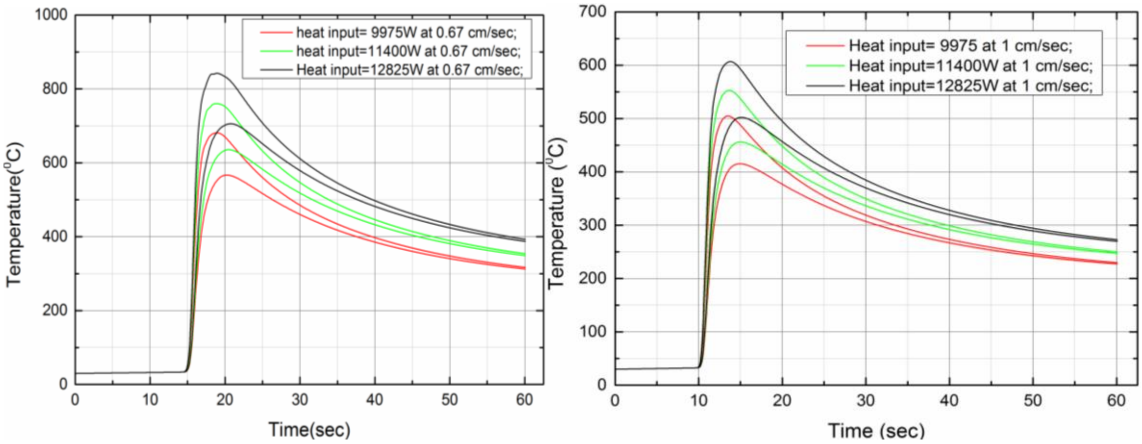
Fig. 6: Peak Temperature distribution in weldment(at x=10cm, z=0.6 cm) for different values of welding parameters.

5.2. Parametric effect study:

To find out the effects of welding process parameters (welding speed and heat input) and geometric parameter (thickness of the weld plate), a series of calculations with different parameters have been performed. To explain the temperature distributions at different node of the weld plate is taken in cases of different welding parameters.

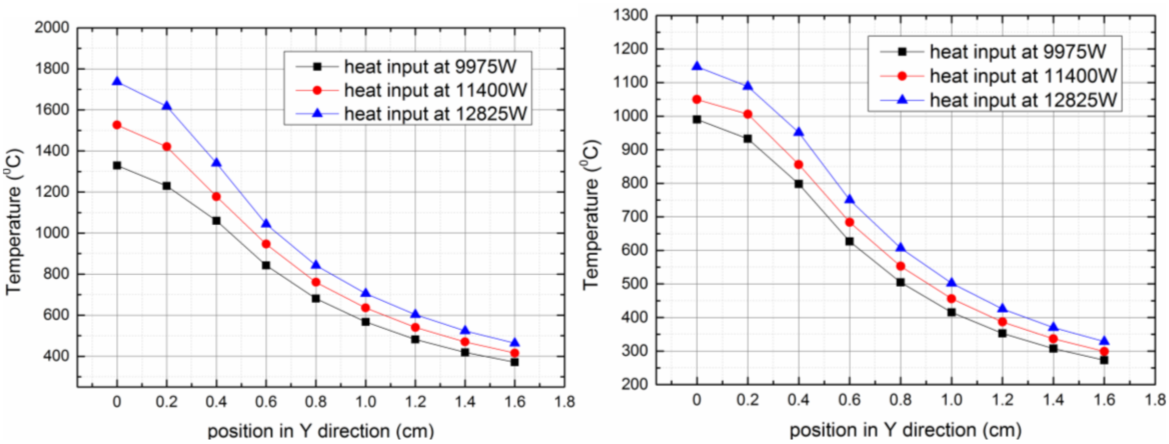
5.2.1. Effect of welding heat input on thermal profiles:

The heat input has obvious effects on the temperature of weldments and the change in temperature is approximately directly proportional to the heat input. For the purpose of finding out the effects of heat input on temperature distribution of weldments, with different welding parameters have been performed. For corresponding temperature distributions, keeping the constant welding speed (0.67cm/sec or 1cm/sec) with varying the heat input to 9975W, 11400W and 12825W at thermocouple T2 and T3 are plotted in Figs. 7 (A) and (B). From Figs. 7 (A) and (B), it can be seen that the heat input influenced on temperature distribution of weldment, i.e. high temperature with high heat input for constant welding speed**.**



(A) **(B)**

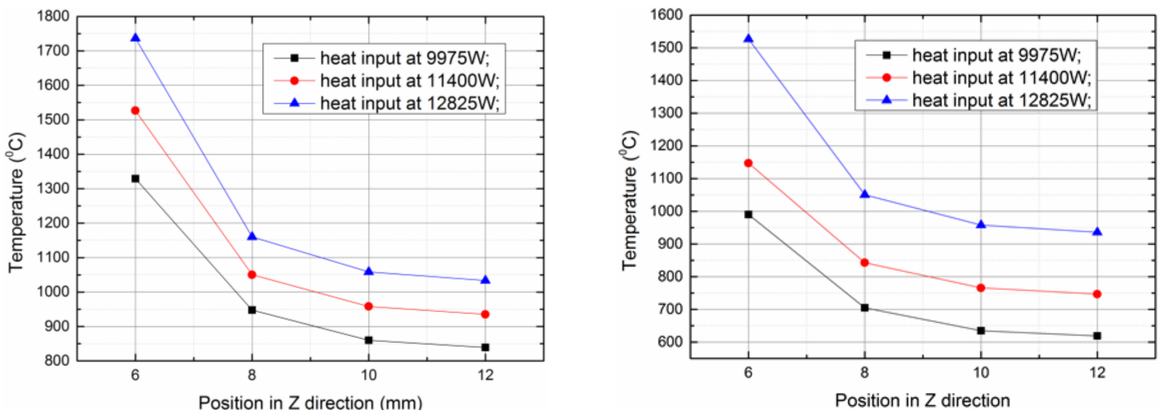
Fig. 7: Temperature- Time distribution at T2 [10, 0.6, 0.8] and T3 [10, 0.6,1.0] (all dimension in cm) for different values of heat input with constant welding speed.



(A) (B)

Fig. 8: (A) and (B): Effects of heat input for temperature along transverse direction at (x=10 cm and z=0.6 cm) for speed of 0.67 and 1 cm/sec respectively.

When the energy input rate has been changed from 11.11% to 22.22% of the original value of 12825W, the temperature distributions at the (x=10cm and z= 0.6 cm) along the transverse directions is shown in Fig. 8 (A) and (B). The change of heat input causes obvious temperature decreases in transverse direction with an approximate linear relationship between the temperature and heat input changes.The effect of the plate thickness on the temperature of weldments is shown in Figs. 9 (A) and (B), there are conducted in different heat input for speed of 0.67 cm/sec and 1 cm/sec, but the plate thickness changes as 6 mm, 8 mm, 10 mm and 12 mm. It can be proved in Figs. 9 (A) and (B) the temperature changes along the plate thickness, i.e., the thinner the plate the higher temperature is obtained.

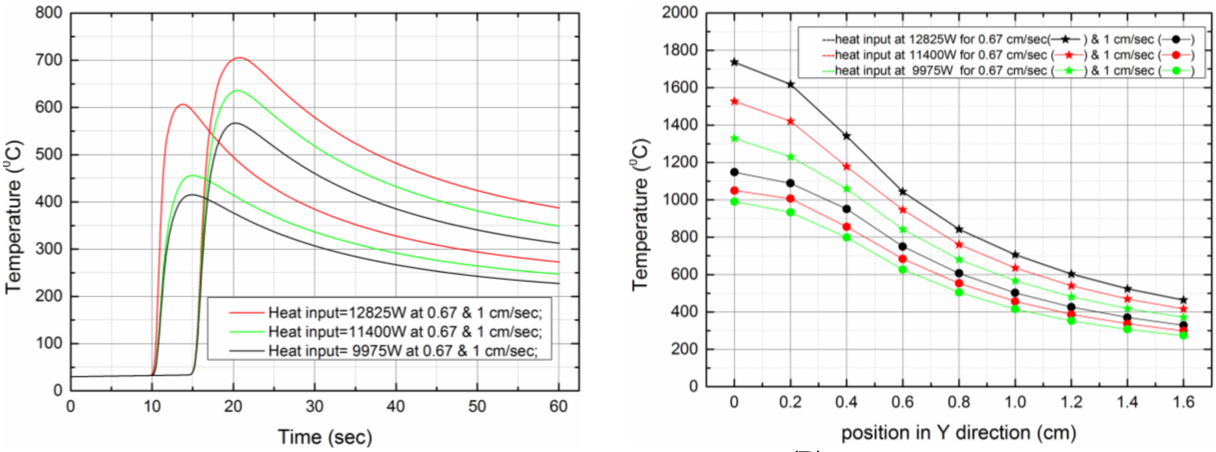


(A) **(B)**

Fig. 9: (A) and (B): Effects of heat input for temperature along plate thickness direction at (x=10 cm and y=0 cm) for speed of 0.67 and 1 cm/sec respectively.

5.2.2. Effect of welding speed on thermal profiles:

The temperature is inversely proportional to the welding speed (Alwan, 2011). Therefore, when the welding speed is slower the temperature is larger, for a constant heat input rate. In case of effects of welding speed condition, the temperature distributions in the weldment at thermocouple T2 for constant heat input (12825W or 11400W or 9975W) for variant welding speeds (0.67cm/s and 1 cm/s) are shown in Fig. 10 (A). From Fig. 10 (A), it can be concluded that with higher speed, temperature is decreasing in the weldments as the heat source applies for a shorter period of time when it moves faster. On the other hand, the change of heat input causes obvious temperature decreases in transverse direction with an approximate linear relationship between the temperature and heat input changes for different values of welding speed with constant heat input and it is shown in Fig. 10 (B).

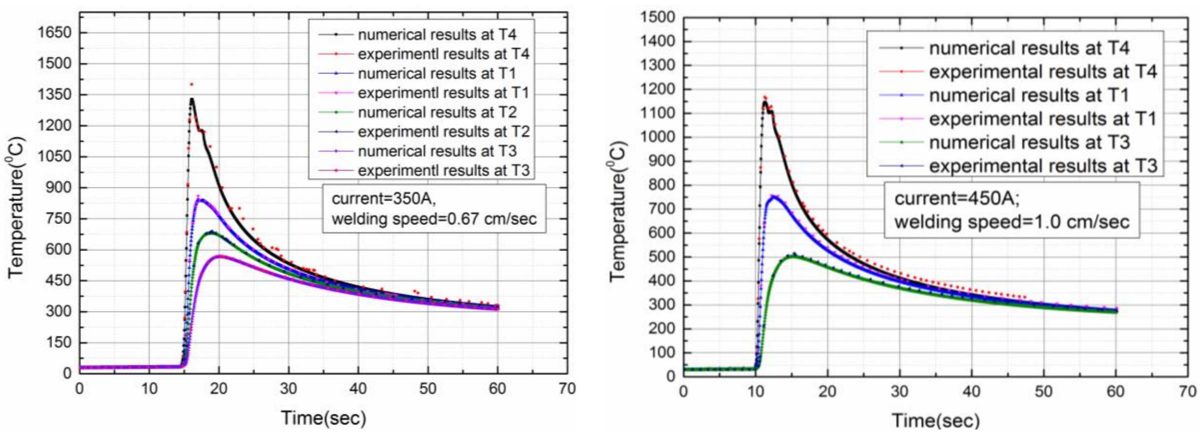


(A) **(B)**

Fig. 10: (A) Temperature-Time distribution at T2 [10, 0.8, 0.6] (all dimensions in cm) and (B) Effects of heat input for temperature along transverse direction at (x=10 cm and z=0.6 cm) for 0.67 and 1 cm/sec respectively for different values of welding speed with constant heat input.

6. Verification of experimental and calculated thermal profiles

The validation of numerical results is made by comparison with experimentally obtained results as shown in Fig. 11. Comparative thermocouples such as T1, T2, T3 and T4 for measure temperature distribution located at 6 mm, 8 mm, 10 mm and 0 mm away from the weld line. In this study, validation of numerical and experimental result of obtains temperature distribution at distance 0, 6, 8 and10 mm from weld line are observed and shown a fairly good agreement between the measured and numerical results.



(A) (B)

Fig. 11: (A) and(B): Comparison of numerical and experimental result for current 350A and 450A with welding speed 0.67 cm/sec and 1 cm/sec respectively at different thermocouples

Conclusion

A simple mathematical model is developed based on the finite difference method which has been used to find out the temperature distribution at different welding parameters and also the validation of the model has been checked with the experimental results. The effects of welding speed, plate thickness and heat input on temperature field distribution were discussed. It has been proved that all those heat source parameters play an essential role in affecting the final temperature distribution. Based on the result and discussion the following conclusions may be drawn:

1. The validation of the model is checked by experimental results and found a good agreement with numerical model.

2. The maximum percentage error between experimental and numerical data is found at 6%.

3. The peak temperature with all welding parameters and distance can be found out by the model and the distances between the center of welding line and the location where the peak temperature occurs increases slightly as the current is increased, but decrease with the increase in the welding speed.

4. From parametric result, it can be concluded that the temperature profiles increase for decrease in welding speed as well as the increase in heat input.

5. This method can be used in future developments to select the process and the welding parameters that meet the thermal necessities of the plan.

Acknowledgement

The author offers his sincere thanks to Prof. S.C. Saha of Mechanical Engineering Department and Instructors of Workshop, NIT, Agartala for their valuable help in finishing this work.

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