On a Thermal Model for SAW Multipass Butt Weldments

T.E. Pérez, R.A. Radovitzky, and E.N. Dvorkin
FUDETEC
Buenos Aires, Argentina

ABSTRACT

A 2D finite element model of the thermal cycle during V multipass butt weldings is developed.
The results of the 2D model are compared against the results of a 3D model showing that it is reliable to use 2D models in engineering applications.
The results of the 2D model are also compared against experimental results and a very good agreement is obtained.

UNTIL A FEW YEARS AGO WELDING TECHNOLOGY was being developed mainly without the aid of numerical modelling techniques. This led to costly experimental programs using a trial and error methodology. In recent years the numerical simulation of welding processes and its application to practical engineering situations have become feasible (1-7).

The application of numerical methods to the modelling of welding processes was delayed, perhaps due to the complex phenomena involved. Nowadays much research effort is being directed towards the development of numerical methods which can provide solutions to the governing equations of welding processes.

In this paper we present our latest research on the subject consisting in the finite element modelling of the heat transfer problem in a butt multipass weldment done with the Submerged Arc Welding (SAW) process, and its experimental validation.

The ultimate goal of our project is the prediction of distortion and residual stresses in weldments for which the determination of the thermal cycle is necessarily the first step.

NUMERICAL MODELS

With the basic assumption of uncoupled thermo-mechanical behavior a FEM model of the thermal cycle is developed (8) using the multipurpose thermal nonlinear program ADINAT (9). This software allows to take into account all the nonlinearities of the problem.

The determination of the temperature distribution during welding is, in general, a three dimensional problem. From a computational standpoint, however, the cost of a three dimensional model can be extremely high.

A single pass weldment is analyzed using a two dimensional model of the plate section and a three dimensional of the complete plate, Figure 1. Their results are compared in Figure 2 . The thermal cycles predicted by both models are almost equivalent, but the CPU times required by each model are in the ratio 20/1. So the idea of facing this kind of engineering problems with two dimensional models results very attractive.

Description of the two dimensional model. A single V multipass weldment is modeled using isoparametric elements (8). In the near weld region, where severe thermal gradients are expected, 8-node isoparametric elements are used and the mesh is considerably refined, Figure 1. The rest of the mesh is completed with 4-node coarse isoparametric elements to lower the computational cost.

To simulate the addition of filler metal we use the ADINAT option of "element birth", which can be interpreted as an analysis with variable domain.

The time integration is performed using an implicit method (Euler backward) which is unconditionally stable.

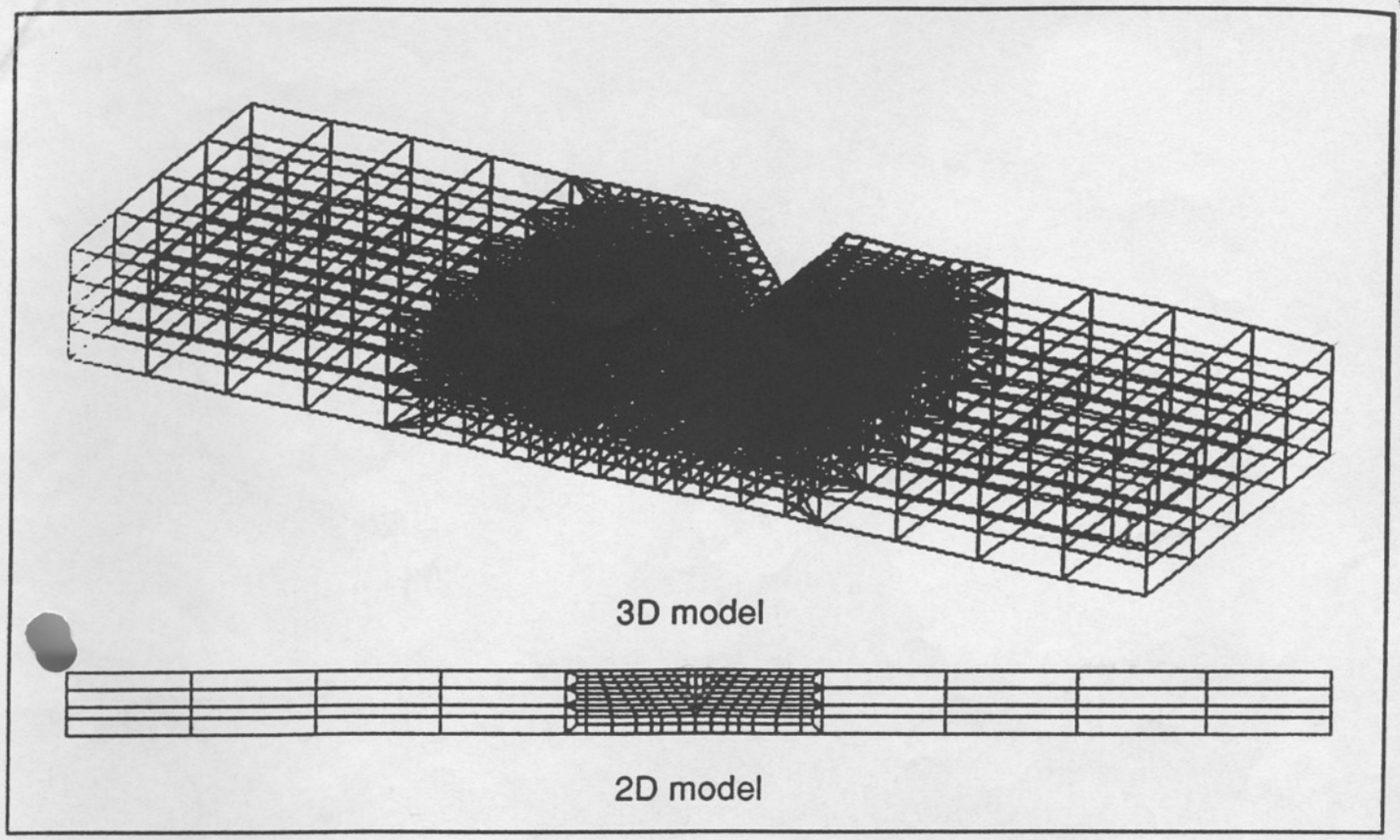

Figure 1: 3D and 2D meshes used in the analyses

As a first approach we adopt the following simplifying assumptions concerning the material thermal properties and the phenomena considered, with the aim of avoiding the inclusion of nonlinearities which increase the computational cost:

- We assume temperature independent thermal properties, with values surveyed from the literature (10-12), Table I.
- We neglect the radiation heat transfer, a reasonable hypothesis in a SAW weldment due to the flux cover (13).
- We neglect the effect of latent heats due to phase transformations.

The good agreement between the model predictions and our experimental measurements validates the above assumptions. The magnitude Q_T of the heat input from the welding arc and its distribution on the surface of the weldment, constitute basic input data to the model and are obtained from the welding parameters in the following way:

$$Q_T = \eta V I$$

where:

Q_T : effective power transferred by the arc [Watt]
η : arc efficiency (0.9)
V : voltage [Volt]
I : current [Ampere]

The total heat input is supposed to be decomposed in surface flux and in energy carried by the molten filler metal.

$$Q_T = Q_S + Q_L$$

$$Q_L = \left[\int_{\theta_o}^{\theta_a} \rho c \, d\vartheta + \sum_i \rho \, L_i \right] V_m$$

Q_S: surface heat flux [Watt]
Q_L: heat stored in the filler metal [Watt]
θ_o: room temperature [C]
θ_a: adopted molten filler metal temperature [1530 C]
ρc: specific heat per unit volume [J/mm^{3}C]
L_i: Latent heat per unit mass [J/grC]
V_m: filler metal deposition rate [mm^3/sec]

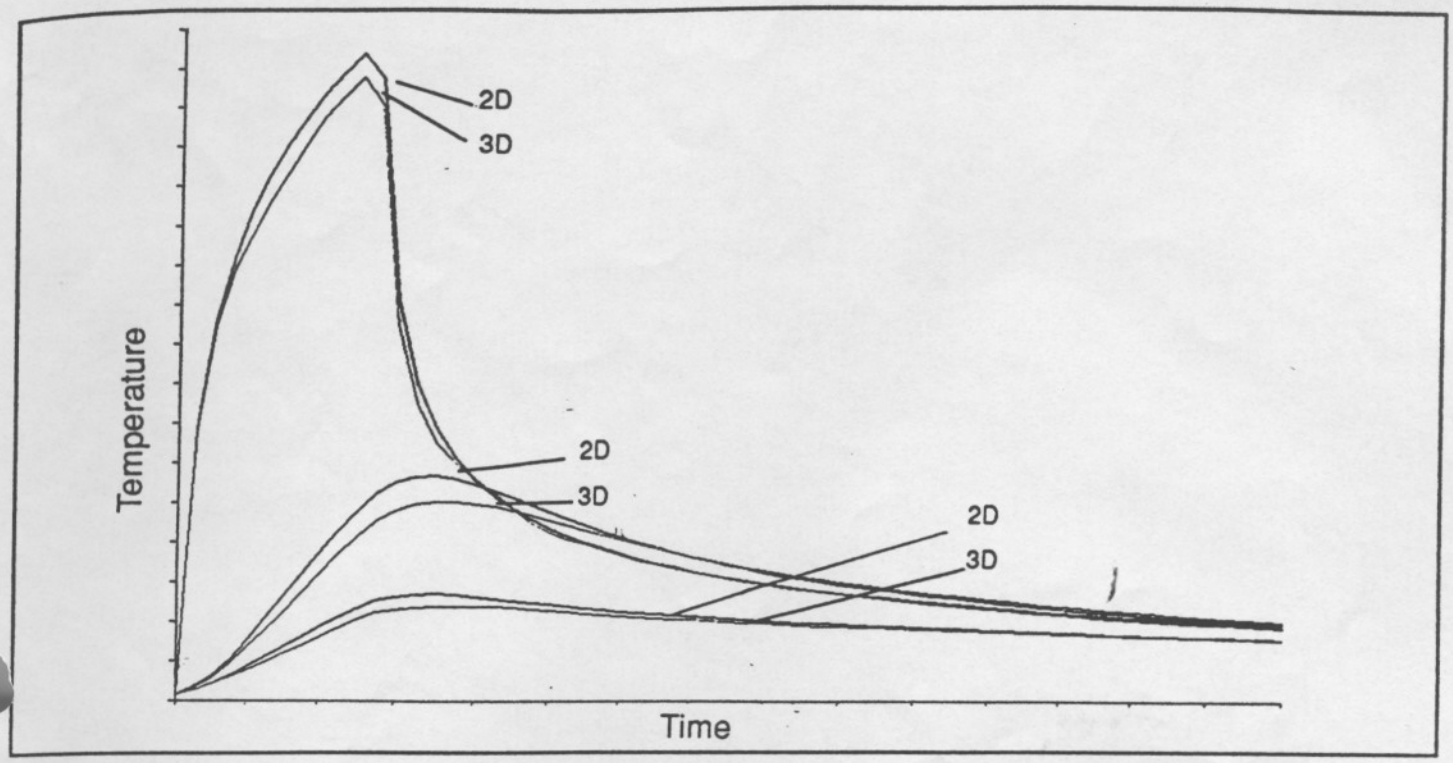

Figura 2:Thermal cycles predicted with 2D and 3D FEM models at points A,B and C (see Fig.3) during a single pass weldment.

Following other authors' approach, e.g. (2), the surface flux is, at a given time, supposed to follow a Gaussian distribution in space:

$q(r) = qo\ e^{-Cr2}$ [Watt/mm²]

where:

C: concentration coefficient,
approx: 0.01-0.05/mm² (SAW) (2)

r: distance to the wire center measured on the plate surface.

From the condition: $\int_0^\infty q(r)\ dr = Q$

we calculate qo

EXPERIMENTAL VALIDATION

In order to assess the model accuracy, a program of experiments was elaborated. Butt weldments using SAW process were performed in a low alloy carbon steel (SA 516-GR 60). Two plate thicknesses were used (30 and 16 mm) with a 70 V joint.

The plates were instrumented with eight Chromel-Alumel thermocouples. Data were acquired using a graphic recorder.

The experimental setup is shown in Figure 3.

In Figures 4a and 4b we compare the model predictions with the experimentally determined temperatures for a multiple pass procedure with the following parameters:

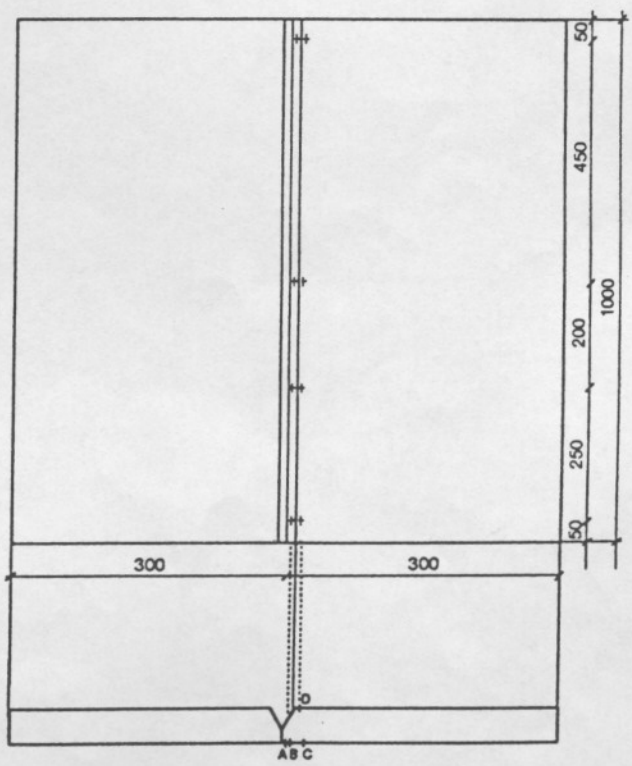

Figure 3:Experimental set-up

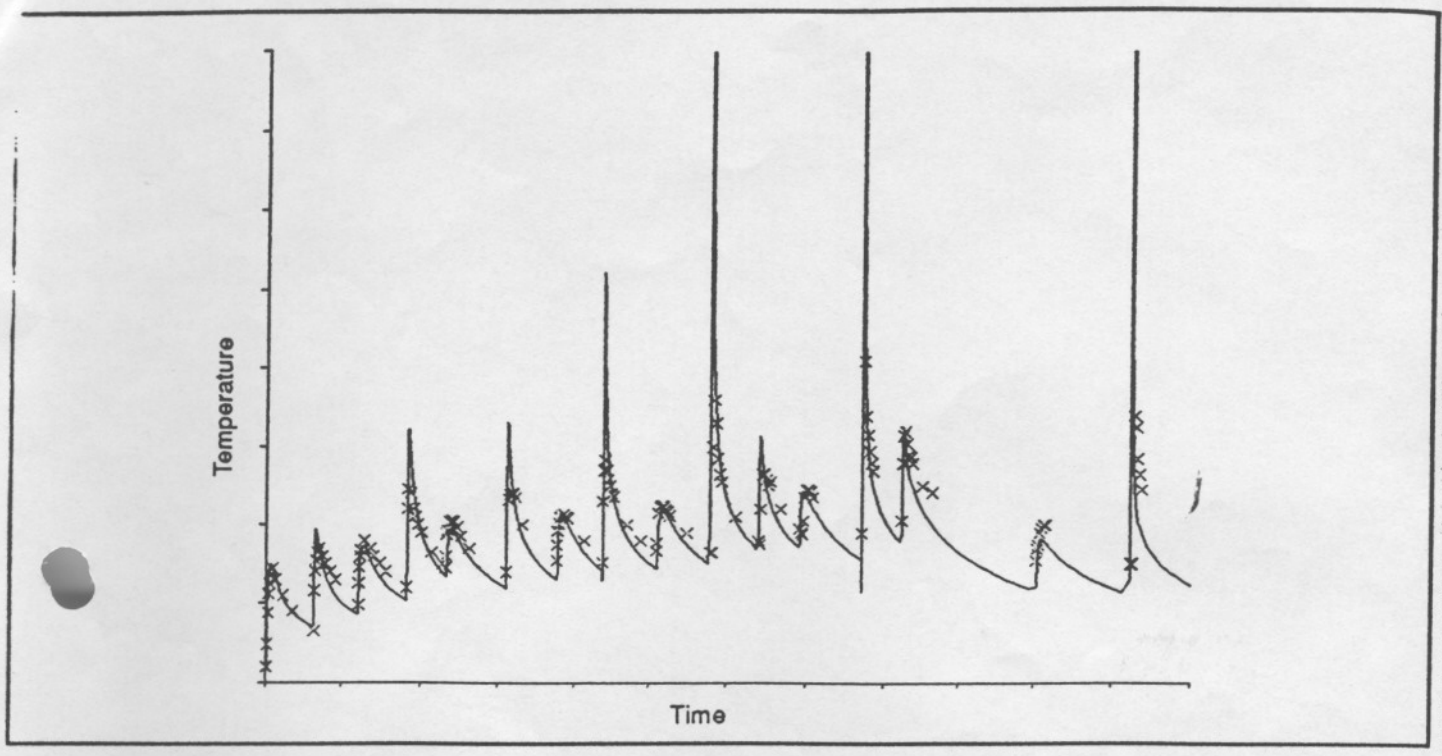

Figure 4a Measured temperatures at point D compared with FEM results

I = 425/450 A
V = 28/29 Volt
v = 48/50 cm/min
resulting a heat input:
HI= 1.4/1.6 KJ/mm

A very good agreement is observed.

It is important to note that similar thermal cycles in corresponding points along the weld line confirm our assumption of a 2D model.

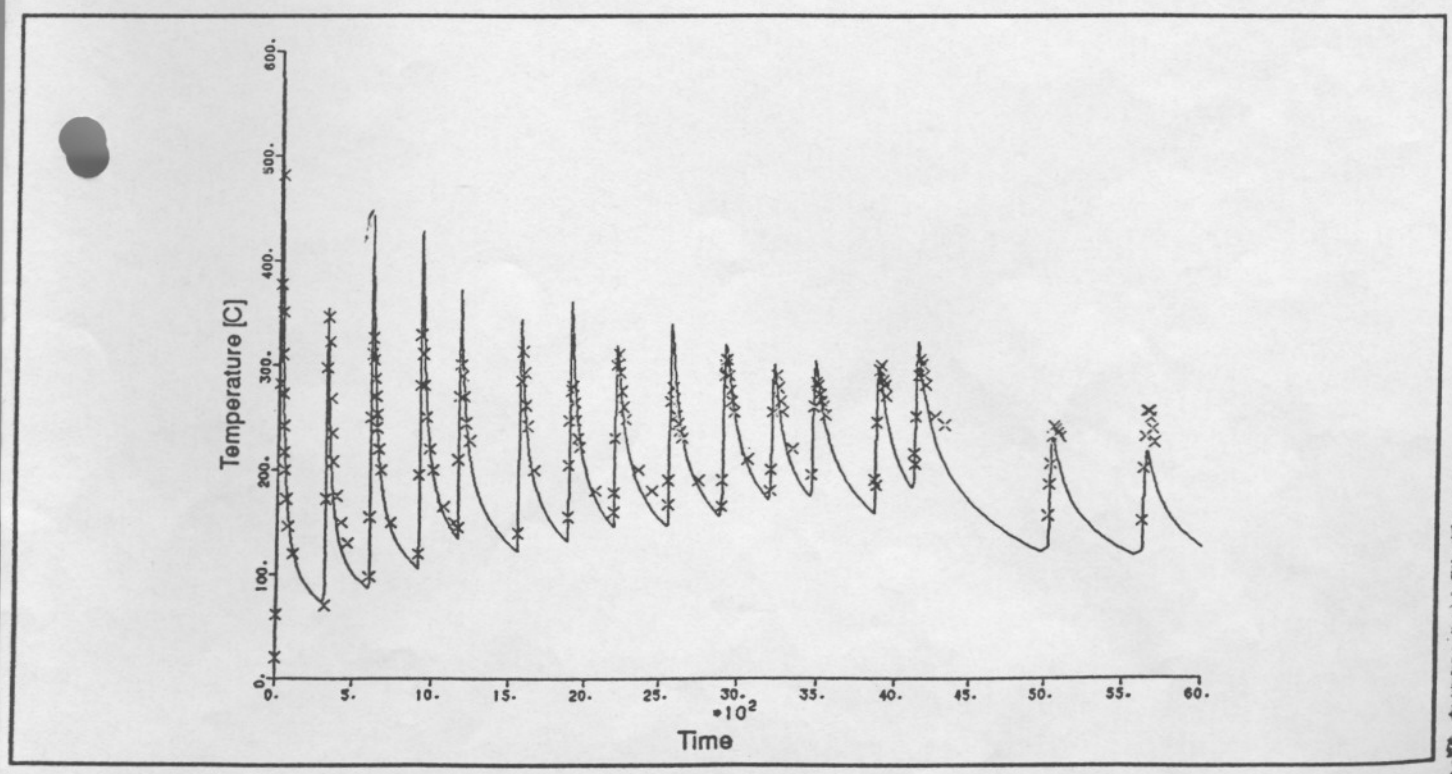

Figure 4b Measured temperatures at point B compared with FEM results

Table I - Thermal Properties.
Adopted convection coefficient h=48e-4 W/mm²C

Ref.	Conduct."k"[W/m C]	Spec. Heat "ρc" [J/mm3 C]	Latent Heat
[1]	3D: 25 2D: 40	ρc=ρc (θ) 0.005-0.010	Included in ρc
[2]	k=k (θ) 26-36	ρc=ρc (θ) 0.003-0.005	Included in ρc
[3]	A: 45 B: 120	.....	.....
[5]	k=k (θ) 40 -70	ρc=ρc (θ) 0.002-0.005	Algorithm
[6]	idem [5]	idem [5]	Included in ρc
[10]	k=k (θ) 32-66	ρc=ρc (θ) 0.003-0.006	.....
[11]	k=k (θ) 28-60	ρc=ρc (θ) 0.004-0.007	.....
[12]	k=k (θ) 48-65	ρc=ρc (θ) 0.004-0.007	.....
Adopted	60	0.006	.....

CONCLUSIONS

- A bidimensional model that allows thermal cycles prediction in multipass butt weldments is devéloped.
- Thermal cycles are predicted reliably in points out of the weld metal.

Our next steps will be:

- The extension of the thermal model to other joint geometries
- The development of the mechanical model with the aim of predicting distortions and residual stresses due to welding.

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