Transactions of the **13th International Conference on Structural Mechanics in Reactor Technology** (SMiRT 13), Escola de Engenharia - Universidade Federal do Rio Grande do Sul, Porto Alegre, Brazil, August 13-18, 1995

Simulation of a stainless steel multipass weldment

Lejeail, Y., Cabrillat, M.T.
CEA Cadarache, Saint-Paul-Lez-Durance, France

SUMMARY : The shrinkage and distortion of welded structures and the associated residual stresses create a lot of problems in nuclear power stations and thus generate research programs to understand them.

In this context, a stainless steel multipass weldment realized in a H type constrained specimen has been calculated by means of finite element method.

The temperatures obtained from a 3D modified Rosenthal equation are compared with the experimental ones, and are then used for the 2D simulation in which a linear kinematic hardening is assumed in relation to a Von Mises plasticity criteria. Materials data are well known up to very high temperatures (1200°C) and are introduced in the model.

Then, experimental and calculated displacements after the first pass are compared and a discussion points out what improvements should be made for a better agreement.

1 INTRODUCTION

In order to acquire a better knowledge of the way to obtain efficient thermomechanical simulations of welding in terms of stresses and displacements, an experimental and computational programme is actually in progress at Cadarache. In fact, welding process involves complex physical phenomena such high temperature inducing important material property variations, liquid-metal phase transformation, metal deposit, radiation, convection... explaining the problems encountered during its simulation.

Experimental programme consists of H type specimens welded at Framatome/Chalon, temperatures have been recorded at each welding pass and displacements every two pass. This permits the comparison with calculation of the first pass in plane strains conditions, using a linear kinematic hardening model, temperature dependent material data, and the temperatures issued from a 3D equation representing the heat source propagation during the stationary state.

2 EXPERIMENTS

The specimens are squarred plates of thickness 30 mm, width and length 390 mm containing H shaped holes (figure 1). They have been machined in a 316L SPH type steel. The weld was made by means of TIG Narrow Gap process in 18 pass, using a type 316 steel to fill.

Temperatures were recorded every pass with 18 type K thermocouples placed at different transversal (between 6.5 and 10.6 mm of the weld center) and longitudinal positions, and at different height in the thickness.

Some longitudinal and transversal displacements have been measured at the end of every two pass (that was favoured by grooves machined at the specimen surface).

3 SIMULATION

A simulation has been performed with CASTEM 2000, finite element code developed at CEA [1]. The mesh is composed of 844 six nodes triangles and represents a transverse section of the plate (figure 2). The first three pass are also represented from the beginning of the computation.

The restraint is taken in account by an equivalent stiffness calculated with 3D shell simulations, leading to the beam characteristics shown on figure 2.

The temperatures were calculated by a modified 3D type Rosenthal equation [2], issued from the problem of the ponctual heating source moving at the surface of an infinite plate of thickness h at rate v, during the stationary phase :

$$T - T_0 = \frac{Q}{2\pi\lambda}\left[\frac{\exp\frac{-v}{2k}(w+R_0)}{R_0} + \sum_{n=1}^{\infty}\left\{\frac{\exp\frac{-v}{2k}(w+R_n)}{R_n} + \frac{\exp\frac{-v}{2k}(w+R'_n)}{R'_n}\right\}\right]$$

where
$$\begin{cases} R_n = \sqrt{w^2 + y^2 + (2\,nh - z)^2} \\ R'_n = \sqrt{w^2 + y^2 + (2\,nh + z)^2} \\ w = x - vt \end{cases}$$

The moving direction is x, y being perpendicular to x in the plane of the plate. Mean values between 20 and 1200°C (see ref. [2]) have been taken for the conductivity λ and diffusivity k.

This equation was modified by introduction of a fictitious thickness to take in account the real position of the source in the thickness. Then, the effective power Q has been calculated every pass to adjust the 18 experimental temperatures. Finally, an other modification was applied as in reference [3] to obtain a good agreement between calculated and experimental results (figure 3). This proceeding was necessary because of the overestimated temperatures near the heat source due to the analytical solution (and attributed to the ponctual form of the source).

Concerning the material properties, they were choosen temperature dependent as it can be seen in table 1. A linear kinematic hardening model has been taken to represent the material plastic behaviour. It was identified on the available 316L SPH material data. In addition, the temperature of the non-existent pass is kept at 1498°C, the melting point, giving a very low mechanical strength.

After 166 steps and 4 hours of calculation, the end of the first pass was reached.

It can be seen on figure 4 that the calculated sag, equal to 0.48 mm, is 1.3 times greater than the experimental ones. The transversal displacement at 12 mm of the center is equal to 0.12 mm on the lower side and is two times lesser than the experimental result (in absolute value, as shown on figure 5). On the upper side the displacement is very low (as in experiment) as shown on figure 6 representing the structure at the end of the first pass.

The final isovalues of longitudinal (i.e. perpendicular to the plane of the mesh) exhibits very high tension level near to the first pass (figure 7). The same behaviour is observed on figure 8 for the transversal stress and is discussed there after.

4 DISCUSSION

The simulation has been stopped at the end of the first pass after the discovered discrepancy between calculated and measured displacements, allowing a discussion about the possible causes. Also, this pause was necessary owing to the very high longitudinal and transversal stress levels obtained near to the deposit metal zone.

First, we think this problem arises from a well known limitation of the linear kinematic hardening model adjusted on 316 L SPH material data. Generally, the coefficient's identification can't be perfect in any point of the structure : the stresses are overestimated where high strains occur and underestimated where low strains exist. So it is actually considered to fit the hardening slope on the high strain level of the tensile curve, in view of obtaining a more relalistic stress level in the weld region.

A better way may consist on a non linear kinematic hardening model identification because this model, choosen with two internal kinematic variables, is more able to reproduce the 316L SPH tensile curve.

The metal deposit is an other point which could be improved in our future numerical simulations. For this purpose, an attempt to link the displacements of the non existent pass will be made, avoiding stresses at this place and respecting the real force equilibrium at high temperatures. Additionally and for the same purpose, a smaller Young's modulus will be imposed in the non existent pass,

At this point, it should be noticed that the equivalent stiffness representing the restraint conditions were not so well adjusted. The beam geometry would be improved because of its influence on stresses and strains near to the weld.

To conclude this paper, it should be pointed out that measured displacements at the first pass end are obtained by interpolation, a possible cause of discrepancy between numerical and experimental results. So it would be better to compare the results at the end of the second pass for which the exact experimental data are well known.

5 CONCLUSION

A program of study including the participation of FRAMATOME, EDF, and CEA is at the present time in progress in France, in view of acquiring a better knowledge on the welding process simulation.

In this context, we are carrying out simulations of a multipass TIG Narrow Gap welding by finite element method.

Although the displacements are of the good sign, the numerical results of CEA Cadarache presented in this paper are 1.3 times greater for the sag and 2 times lesser for the transversal displacement, compared to the experimental data at the end of the first pass. In addition, the stresses reach very high levels in the deposit metal zone.

This behaviour is nowadays attributed to a not well fit linear kinematic hardening rule.

To conclude, it should be pointed out that the next simulation will be performed with an improved technique for the non existent pass treatment (linkage of the displacements in these regions and choice of a smaller Young's modulus).

Acknowledgements : This work was sponsored by EDF and FRAMATOME that we thank for financial and technical support.

REFERENCES

[1] A. HOFFMANN, A. COMBESCURE
"CASTEM (CEASEMT) : A Systeme of Finite Element Computer Programs"
Paper 40 presented at Conference on "Structural analysis, design and construction in nuclear power plant"
Porto Alegre, Brazil, 1978

[2] K. MASUBUCHI
"Analysis of Welded Structures"
© 1980, Pergamon Press

[3] T. HIRANO, R. KAMICHIKA, A. OKAMOTO
"A New Calculation Method by Two-Dimensional FEM Program For the Welding Temperature Distribution in a Plate Cross Section"
SMIRT 11, Transactions Vol. B (August 1991),
Tokyo, Japan, © 1991

Table 1 - Material characteristics used for the calculation

T (°C)	E (MPa)	σ_y (MPa)	H (MPa)	α (°C^{-1})
20	192000	268.6	6579	15.9×10^{-6}
200	178000	188	4338	$17. \times 10^{-6}$
400	161000	155	2806	17.9×10^{-6}
600	145000	140.5	2698	18.7×10^{-6}
800	81158	110	2100	19.4×10^{-6}
1000	50000	10	1500	19.9×10^{-6}
1200	50000	10	1500	20.3×10^{-6}
1500	50000	10	1500	20.5×10^{-6}

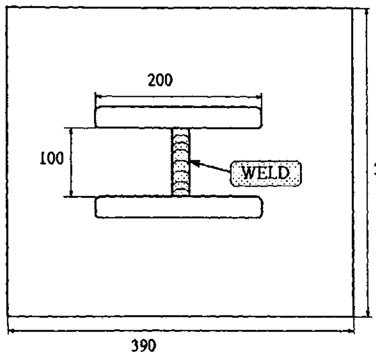

Figure 1 : schema of the H slit plate specimens welded by multipass TIG Narrow- Gap process.

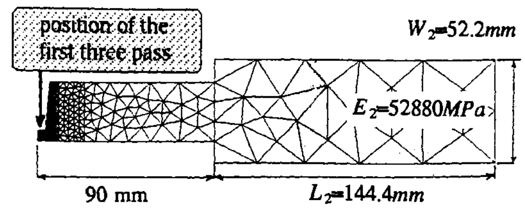

Figure 2 : mesh representing a transverse section of TIG specimens. The beam geometry reproduces the displacement restraint conditions and allows the calculation of a two-dimensional problem. The first three pass are meshed from the beginning of the calculation.

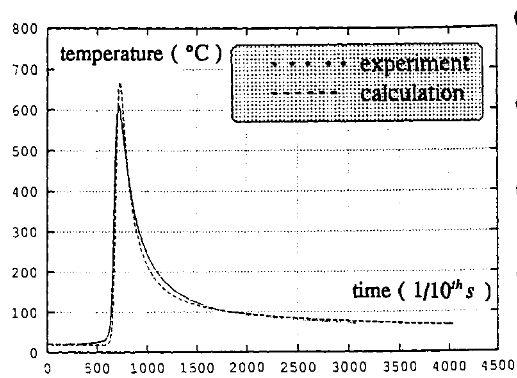

Figure 3 : comparison of experimental and computational temperature for thermocouple n ° 13, placed at 6.5 mm of the weld center, during the first pass.

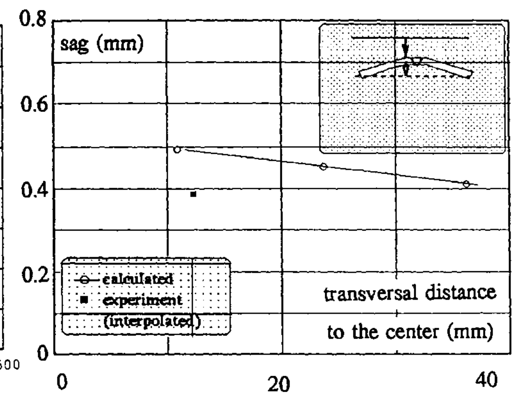

Figure 4 : comparison of numerical and experimental sag, measured at 12 mm of the center, at the first pass end.

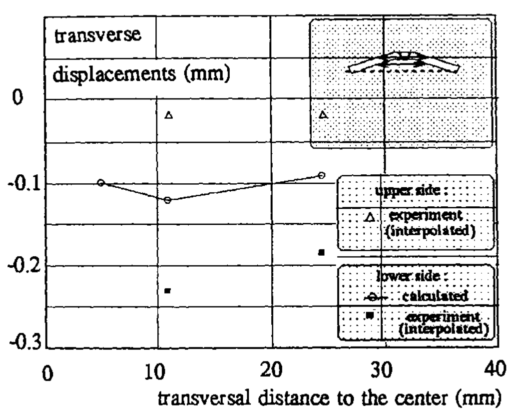

Figure 5 : comparison of numerical and experimental transverse displacements (measurements are interpolated between 0 and end of 2^{nd} pass).

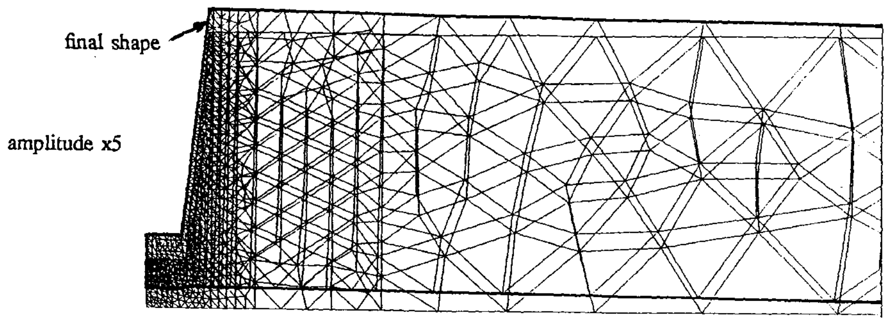

Figure 6 : zoom of the deformed plate at the end of the first pass. The initial shape is also reproduced.

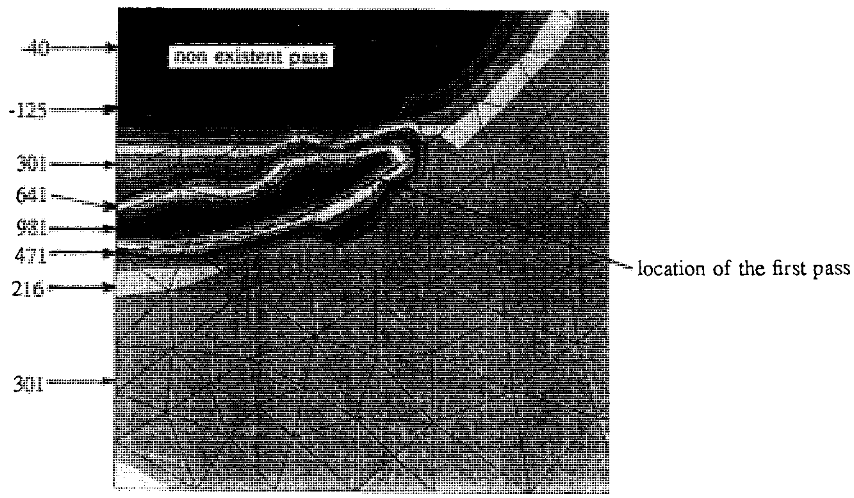

Figure 7 : zoom of σ_{zz} isovalues (MPa) near to the deposit metal. The z axis is perpendicular to the figure plane.

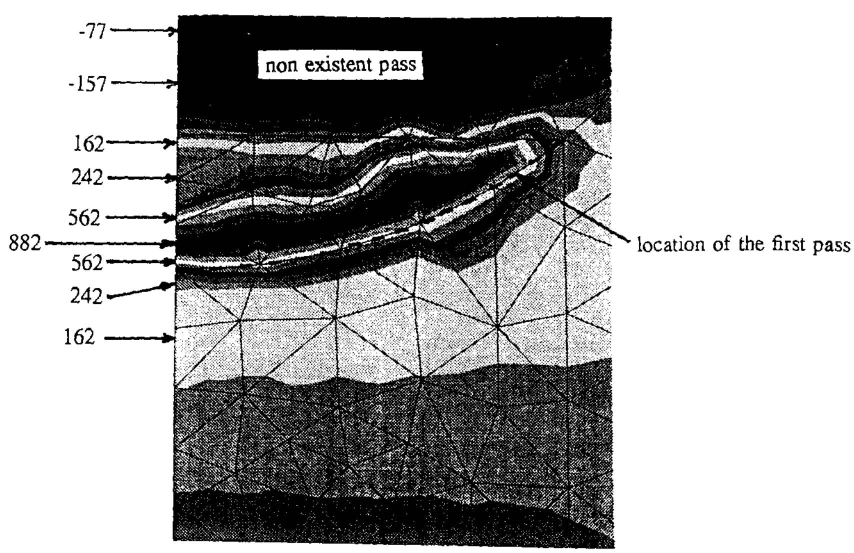

Figure 8 : zoom of σ_{xx} isovalues (MPa) near to the deposit metal.