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ETUDE EXPERIMENTALE ET NUMERIQUE DE LA LIGNE D'ASPERSION AUXILIAIRE DU PRESSURISEUR SOUMISE A DES TRANSITOIRES THERMIQUES DE FORTE AMPLITUDE

EXPERIMENT AND NUMERICAL ANALYSIS OF THE NPP PRESSURIZER AUXILIARY SPRAY LINE SUBMITTED TO LARGE THERMAL SHOCKS

94NB00135

EDF
Electricité de France
Direction des Etudes et Recherches

EXECUTIVE SUMMARY :

The pressurizer auxiliary spray line of PWR nuclear power plants may be submitted to severe temperature transients during upset conditions : a 325°C cold thermal shock in one second is followed by a 200°C hot thermal shock. For such transients, the RCC-M French design code rules that prevent the ratcheting deformation hazard are not respected for the components with thickness transition.

Consequently, Electricité de France has realized twenty thermal cycles under pressure on a representative mock-up. During these tests, many temperature, strain and diametral variations were measured. No significant ratcheting deformation was detected on all components, except on the 6" x 2" x 6" T-piece, where a weak progressive diameter increase was observed during a few cycles.

Moreover, computations of a 2" socket welding were made with the non linear kinematic hardening Chaboche model which also showed a weak progressive deformation behaviour.

authors 7 figs 7 refs

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SERVICE RÉACTEURS NUCLÉAIRES ET ECHANGEURS
Département Mécanique et Technologie des Composants

Mars 1994

COUTEROT C.
GEYER P.
PROIX J. M.

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SYNTHÈSE :

La ligne d'aspersion auxiliaire du pressuriseur des centrales nucléaires REP peut être soumise à de sévères chocs thermiques lors de situations incidentelles : un choc thermique froid de 325°C en une seconde est suivi d'un choc chaud de 200°C. Lors de telles transitions, les règles RCC-M, destinées à prévenir du risque de déformations progressives, ne sont pas respectées pour les composants présentant des transitions d'épaisseur.

Aussi, Electricité de France a réalisé vingt cycles thermiques sur une maquette représentative sous pression. Au cours de ces essais, les écarts de température, de déformation et de diamètre ont été mesurés. Aucune déformation progressive importante n'a été décelée sur les composants, à l'exception du tc de 6" x 2" x 6", sur lequel a été observée une faible augmentation progressive du diamètre sur quelques cycles.

Par ailleurs, les calculs de la jonction emmanchée-soudée 2", effectués avec le modèle élastoplastique de Chaboche à deux variables d'écrouissage cinématique non linéaire de durcissement cinétique ont également montré une faible déformation progressive.

C. COUTEROT*, P. GEYER*, J. M. PROIX**

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Consequently, Electricité de France has realized twenty thermal cycles under pressure on a representative mock-up. During these tests, many temperature, strain and diametral variations were measured. No significant ratcheting deformation was detected on all components, except on the 6" x 2" x 6" T-piece, where a weak progressive diameter increase was observed during a few cycles.

Moreover, computations of a 2" socket welding were made with the non linear kinematic hardening Chaboche model which also showed a weak progressive deformation behaviour.

1 - INTRODUCTION

The pressurizer auxiliary spray line of PWR nuclear power plants may be submitted to severe temperature transients during upset conditions. During these shocks, components with thickness transition do not respect the RCC-M rules that prevent the ratcheting deformation hazard.
In order to justify the inoffensiveness of ratcheting deformation, Electricité de France has undertaken thermal cycle testing on a representative mockup. Also, computations of some components are performed with the non linear kinematic hardening Chaboche model.

2 - PROBLEM PRESENTATION AND SIMPLIFIED ANALYSIS

Primary system lines of pressurized water reactor power plants are exposed to thermal shocks, the amplitude and the occurrence of which are chosen at the design stage. Some of these transients are rare but have a high amplitude (variation of fluid temperature > 300°C/hour). They are affecting some auxiliary line components, and especially the pressurizer auxiliary spray line.

Some of these components do not verify the present RCC-M French design code rules [1], which prevent the ratcheting deformation. The same rules also exist in the ASME code [2]. In the case of thermal loading alone, the formulae of the equations (10) and (13) corresponding to the above rules in [1] reduce to :

- (A) : $E \alpha / 2(1-\nu) \mid \Delta T_1 \ (i,j) \mid$
- (B) : $C_3 E_{ab} \mid \alpha_a T_a(i,j) - \alpha_b T_b(i,j) \mid$

where :

- $|\Delta T_1|$ is the absolute value of the range of the linearised temperature difference between the outside surface and the inside surface,
- Ta and Tb are average temperatures on two sides of gross structural discontinuity or material discontinuity,
- E_{ab} is the average modulus of elasticity of the two sides of the discontinuity,
- C_3 is the secondary stress index ; for the socket welding, $C_3 = 2$ and $C'_3 = 1$.

The linear stress S_n of equation (10) is the sum of (A) and (B), the stress Sq of equation (13) is equal to (B) when we change C_3 by C'_3.

Equation (10) insures plastic shakedown and is verified if ("3 S_m" rule) :
$S_n < 3 S_m$, where S_m is the allowable design stress.

Equation (13) has the same objective as equation (10) but with exclusion of thermal bending and thermal expansion stresses and is written as :
$S_q < 3 S_m$

Auxiliary lines include straight and welded pipes, socket weldings, isolation valves and nozzles. Their common feature is thickness transition. During a thermal shock, two things are important : thermal gradients in the component thickness and different average temperatures between the thin part and the thick part.

Components of auxiliary spray line are submitted to rare severe temperature transients (figure 1) : about ten occurences during the power plant life. Equation (13) is not verified for most components : for instance, the estimated stress amplitude S_q of a socket welding reaches 630 MPa while 3 Sm is 336 MPa. The stress ratcheting rule of the Bree diagram [1] can't be verified.

3 - EXPERIMENTAL RESULTS

3.1. Mock-up and instrumentation

The representative mock-up contains different elements (figure 2) in austenitic stainless steel, most of them in 304L (French standard Z2 CN 18-10), consisting of :

- some 2" pipes (external radius of 60.3 mm and thickness of 8.7 mm),
- a socket welding with a reinforcement (external radius of 103 mm and thickness of 30 mm),
- a monobloc pipe with a reinforcement (same dimensions),
- a 2" welded elbow,
- a temperature nozzle,
- a 6"x2"x6" tee (external radius of 193 mm and thickness of 33 mm),
- a 2" valve (in austenitic stainless steel 316L, French standard Z2 CND 17-12).

The instrumentation is composed of 16 displacement sensors, 8 strain gauges and 29 thermocouples, 3 of them being installed on internal skin.

3.2. Material characterization

The 304L characterization tests consist of chemical analyses, tensile test and low-cycle fatigue tests, using specimens obtained from the 103 mm thick cylindrical bar.

The chemical composition is given below :

C	Si	Mn	S	P	Ni	Cr	Cu	Mo	N
0,027	0,56	1,56	0,008	0,020	9,35	18,8	0,30	0,26	0,065

Since the tensile and low-cycle fatigue tests were not finished before the preliminary calculation, the following results were used, which come from RCC-M code and private studies [4].

The main properties of 304L steel at 50°C and 300°C are given by the RCC-M code :

T (°C)	Young's modulus E (MPa)	thermal expansion coefficient α (m/m.°C)	allowable design stress S_m (MPa)
50	195000	$1{,}684\ 10^{-5}$	114
300	176500	$1{,}881\ 10^{-5}$	97

One should know that properties of 316L steel are near those of 304L steel. We also generated uniaxial low-cycle fatigue data on a 316L steel at 20°C and 350°C with different deformation levels [4], in order to determine the parameters of the non linear kinematic hardening Chaboche model [3]. For the nomenclature of these parameters, see [3] :

	20°C	350°C
E (MPa)	188000	164000
R_∞	150	136
R_0	150	97
b	0	1,9
k	0,75	0,46
w	9,02	5,77
a1	143	181
a2	84	38
C1	425	309
C2	6590	7566

3.2. Description of the thermal shocks

The mock-up is submitted on CUMULUS facility [7] to 20 thermal cycles (figure 3) under an internal pressure of 15,8 MPa. The model is initially heated to 345°C.
At this point, 20°C cold water is injected in the mock-up with a 15 m^3/h flow during 53 seconds. The experimental measurements show that the cold shock of 250°C lasts 1 second.
Then 250°C hot water is made to circulate in the mock-up with at first a 13 m^3/h flow during 3 minutes and then with a 9 m^3/h flow during 9 minutes. In this case, the thermal shock of 200°C lasts 80 seconds. Then the model is isolated and heated to 345°C.

3.3. Thermal shock results

In addition to the diametral changes measured during the tests, external measurements are done at room temperature before and after the first cycle and after the twenty cycles. The evolution of each external diameter is shown below. Most components do not undergo an external ratcheting deformation : the evolution is in the order of the measurement precision. On the other hand, the T-piece presents a progressive deformation which accomodate plastically during the first cycles.

Component	Initial diameter (mm)	Evolution after 1 cycle (µm)	Evolution after 20 cycles (µm)
socket welding	205.0	-15	-12
welded elbow	160.1	-5	10
temperature nozzle	159.7	-20	10
2" T-piece inlet	203.9	50	160
6" center T-piece	273.5	135	210
6" T-piece outlet	277.1	85	90
valve	159.2	5	-2

Some internal measurements are performed at room temperature before the first cycle and after the twenty cycles (they are also made after the first cycle for two accessible diameters). The internal diameter changes of the monobloc sleeve, socket welding, welded elbow and valve are lower than 40 µm : these components do not undergo internal ratcheting deformation.

4 - COMPUTATIONAL RESULTS OF THE SOCKET WELDING

4.1. Thermal finite element calculation of the design transient

The numerical analysis is performed using finite element EDF code Aster [5] developed at the Research and Development Division of Electricité de France. The axisymmetrical socket welding is modelled with 6 and 8-node quadratic elements and contains about 1250 nodes. The mesh is shown on figure 4 with the boundary conditions and the main node numbers. The gap between the tube and the sleeve allows to modelize the heat conduction through the water.

4.2. RCC-M simplified method results

The maximal values of the temperature differences between the outside and the inside surfaces and between the two sides of the discontinuity are :

	$\lvert\Delta T_1\rvert$ (°C)	$\lvert T_a - T_b\rvert$ (°C)
cold shock	168	160
hot shock	116	71

Application of the RCC-M simplified method gives the linear stress S_n of equation (10) equal to 2190 MPa > 3 S_m and the stress Sq of equation (13) equal to 760 MPa > 3 S_m.
Moreover, the socket welding verifies neither the plastic accomodation criterion nor the ratcheting deformation criterion.

4.3. Description and results of the elastic-plastic computation

For the simulation of cyclic loading, elastic-plastic Chaboche numerical model [3] is used with two kinematic hardening variables. This model uses a combination of kinematic and isotropic hardening according to the evolution of the yield stress.

An important feature of this model is that it contains several parameters which are identified using uniaxial cyclic loading on the 316L stainless steel material at 20°C and 350°C (see § 3.2).

Figure 5 describes the evolution of the radial displacement Ux at nodes 3 and 47 for the two first cycles. At the end of the first and the second cycles, the residual displacements are -3 and -7 microns at node 3, and -10 and -19 microns at node 47. These results show that we have a progressive deformation, but the evolutions are lower than the measurement precision.

Figures 6 and 7 show the circumferential strain path in terms of circumferential stress for three loading cycles at nodes 47 and 418. These nodes are representative of maximal residual strain zone. We get a ratcheting behaviour with a cyclic increase of 0.04% at node 47 and 0.02% at node 418.

It is well known that the Chaboche model over-estimates the ratcheting deformation. If we make an extrapolation for 20 cycles, we should obtain a conservative strain value which should be acceptable from the point of vue of the damage criterium used. We can notice the complexity of the loading path which results from the thermal loading.

5 - CONCLUSION

The pressurizer auxiliary spray line may be submitted to severe temperature transients during upset conditions ; during these shocks, components do not respect the ratcheting deformation rules given is the French RCC-M code.

Thermal tests have therefore been realised on a representative mock-up : only one component, the 6"x2"x6" tee, presents progressive deformation behaviour which accomodates plastically during the first cycles.

Moreover, socket welding computation has been performed with the elastic-plastic Chaboche numerical model : it shows a weak ratcheting deformation. This model however overestimates the progressive deformation, so calculations will be made with a new model derived from Burlet and Cailletaud [6]. The material characterization of 304L steel will be made by traction - compression and traction - torsion testings.

An exhaustive computation will also be made on the tee tested on this program, since the experiments have showed that this component suffered a progressive deformation.

REFERENCES

[1] RCC-M Code : Design and Construction rules for mechanical components of PWR nuclear islands (Edition AFCEN June 1988)

[2] ASME Code, section 3, division 1, subsection NB, chapter 3650.

[3] J.L.Chaboche, 1991, "On the modifications of kinematic hardening to improve the description of ratchetting effects", International Journal of plasticity, Vol 7, pp. 661-678.

[4] J.J. Engel and G. Rousselier, "Comportement en contrainte uniaxiale sous chargement cyclique de l'acier inoxydable austénitique 17-12 Mo à très bas carbone et azote contrôlé. Identification de 20 à 600°C d'un modèle de comportement élastoplastique à écrouissage cinématique non linéaire", Internal note EDF HT/PV D559 MAT/T43.

[5] "Code Aster developed by Electricité de France", Internal note EDF HI-75/93/034.

[6] H. Burlet and G. Cailletaud, "Modeling of cyclic plasticity in finite element codes", 1987, 2nd conference on Constitutive laws for engineering materials : Theory and Applications, Tucson.

[7] J.C. Gaston, 1989, "Descriptif de CUMULUS", Internal note EDF HT24/89.20A.

FIGURES

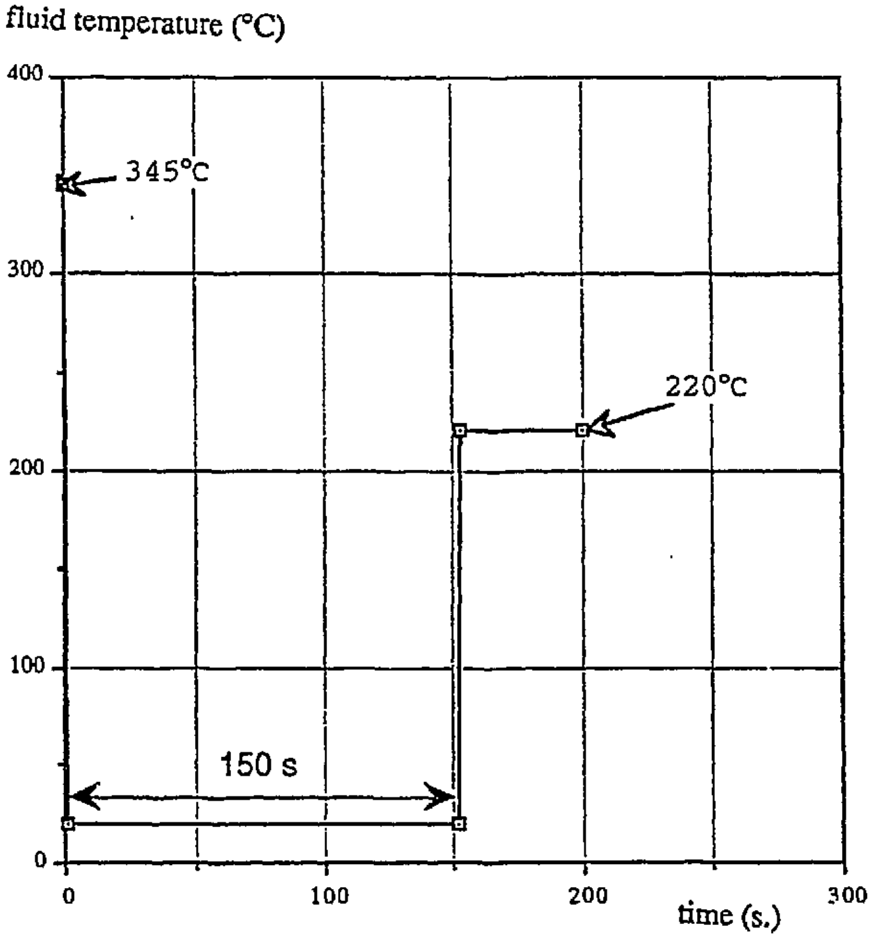

Figure 1 : Pressurizer auxiliary spray line transient.

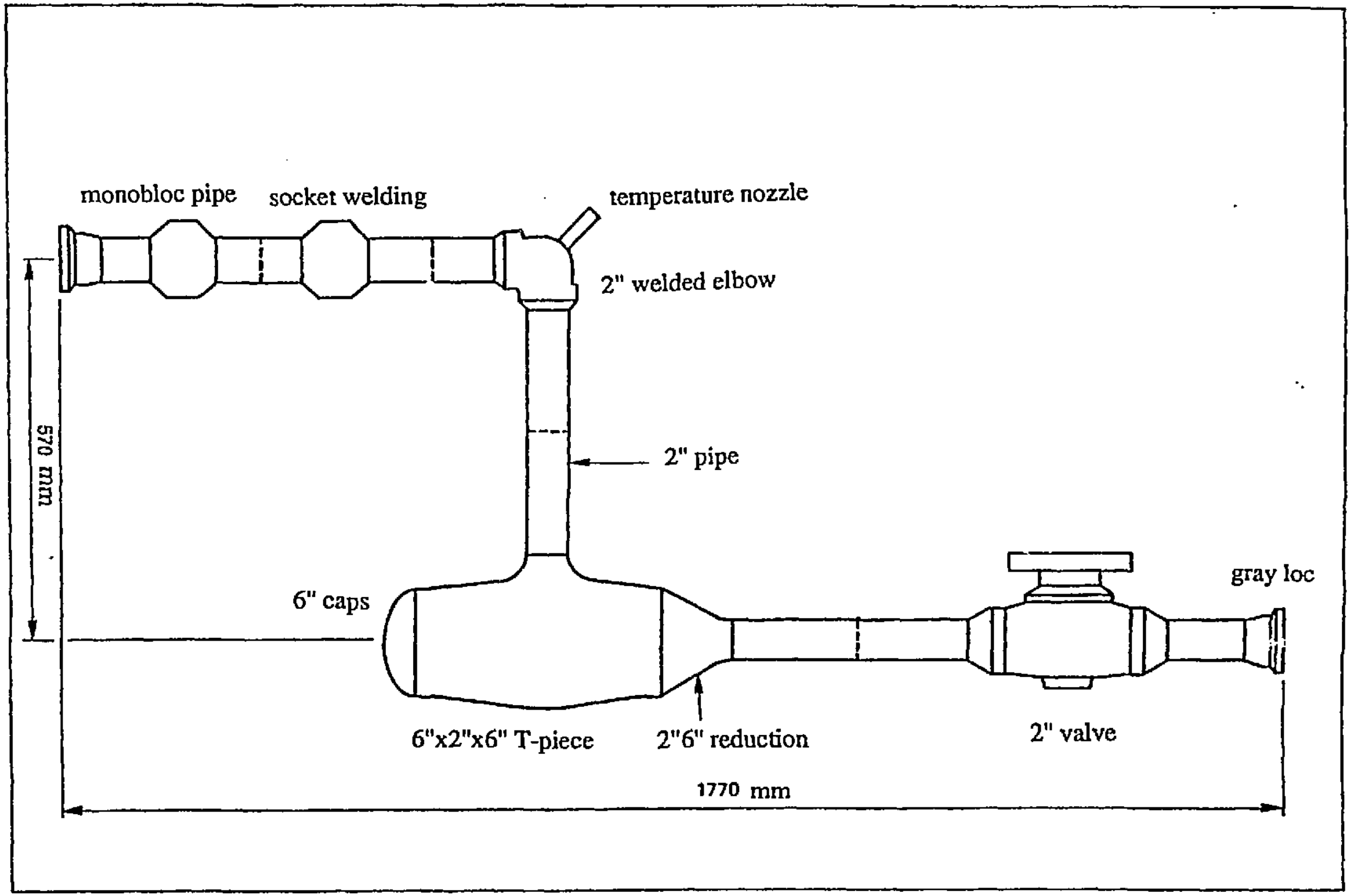

Figure 2 : mock-up schematic.

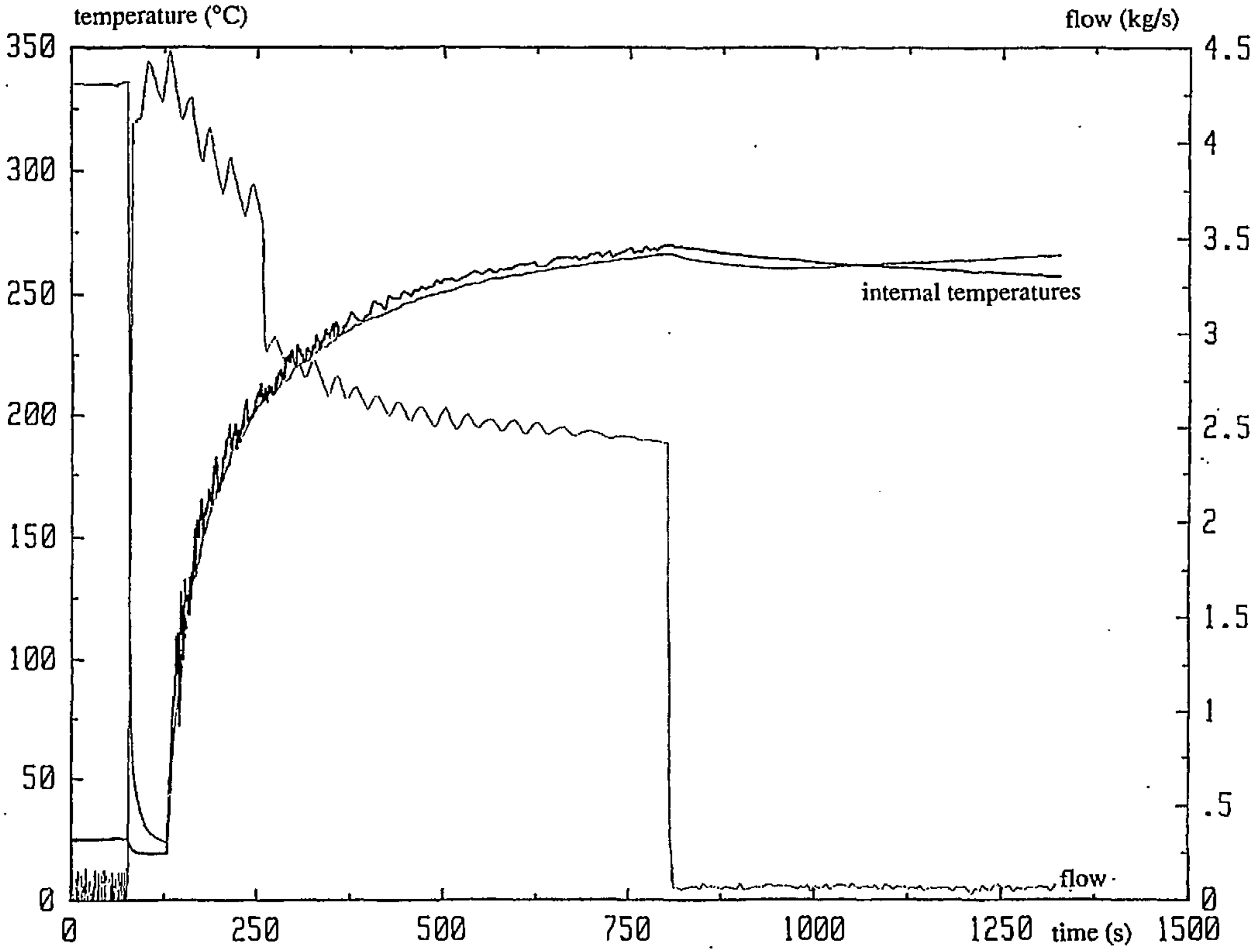

Figure 3 : thermal transient on CUMULUS facility.

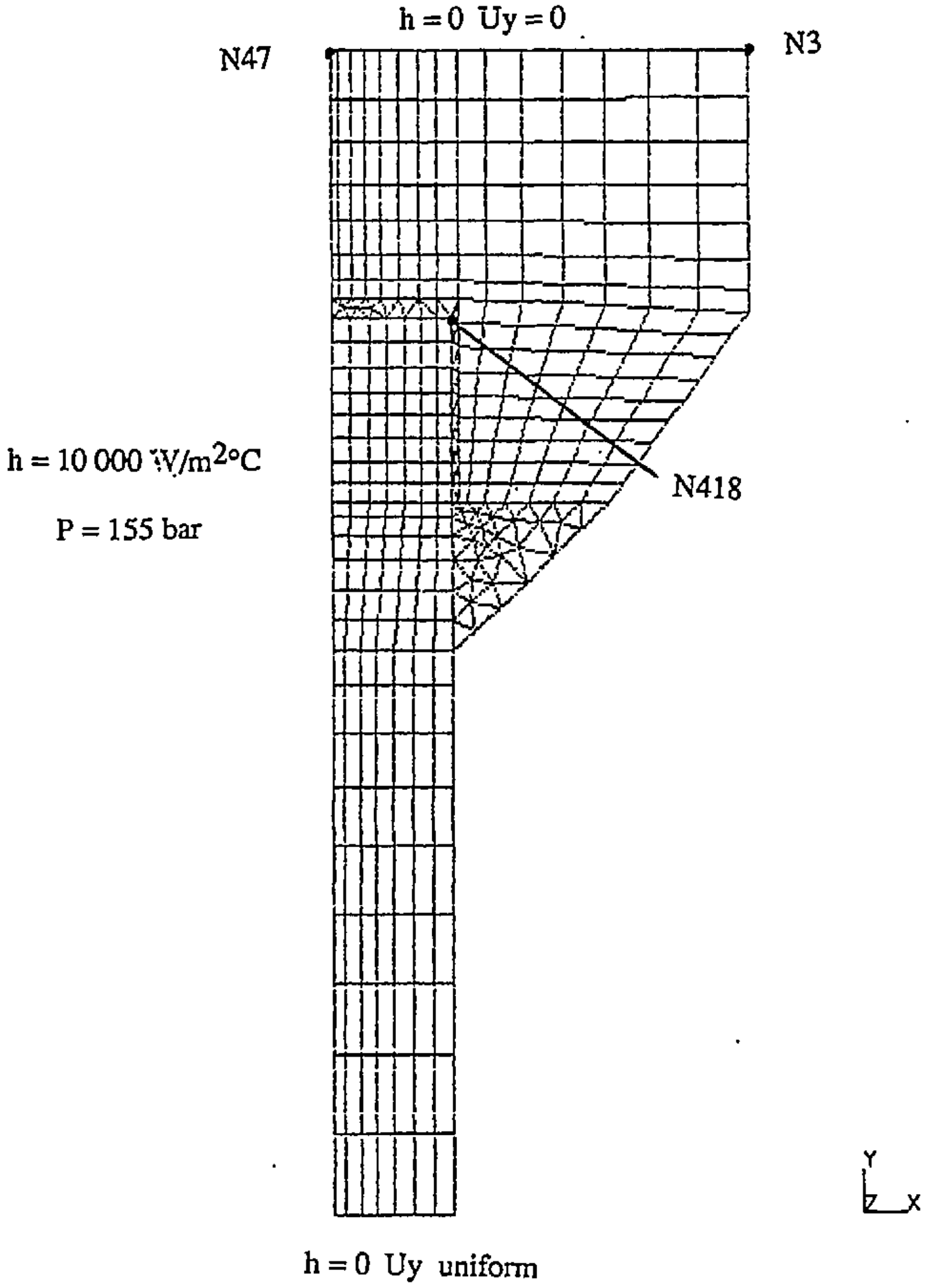

Figure 4 : view of the socket welding mesh.

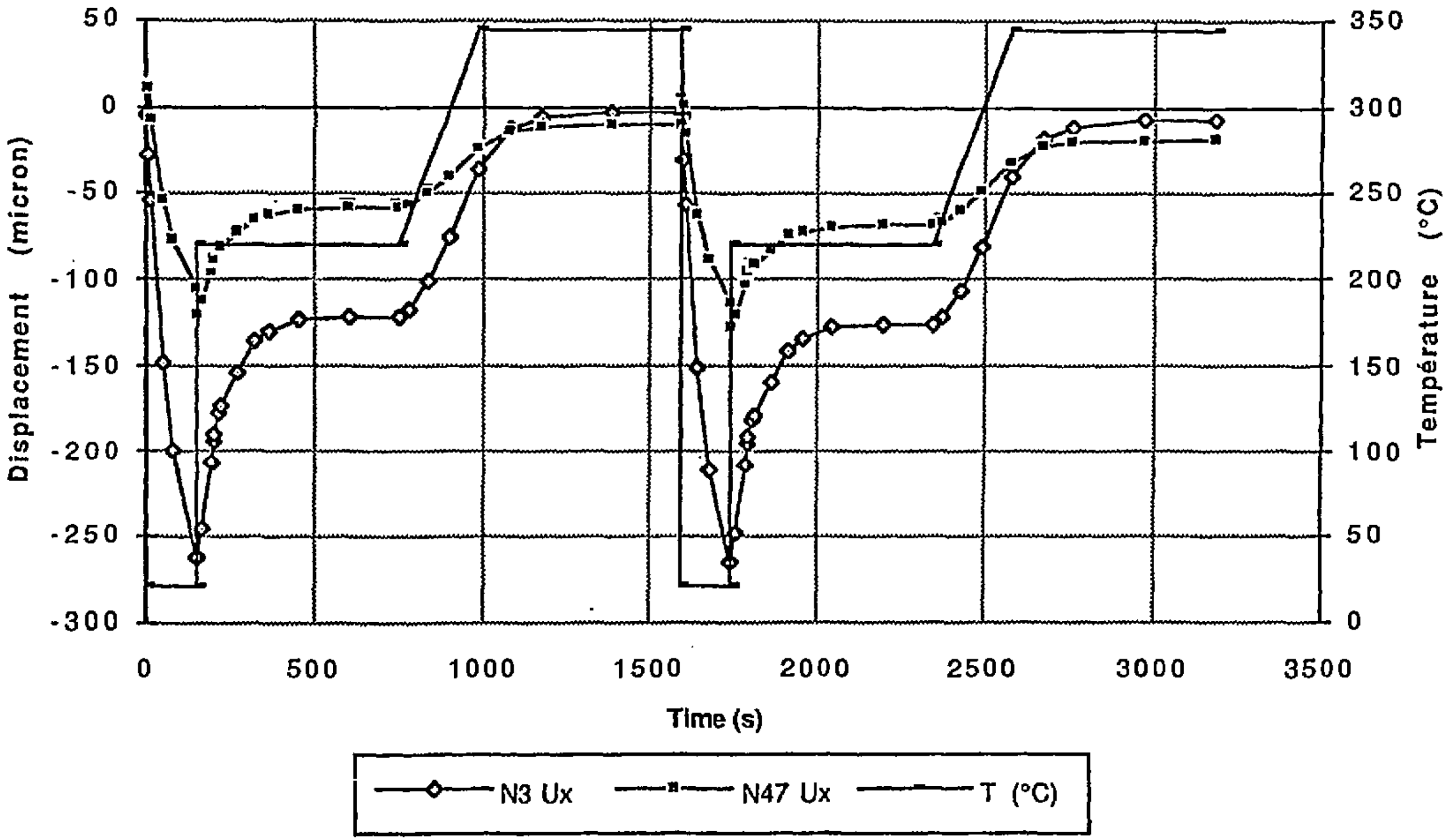

Figure 5 : radial displacement at nodes 3 and 47 during two cycles.

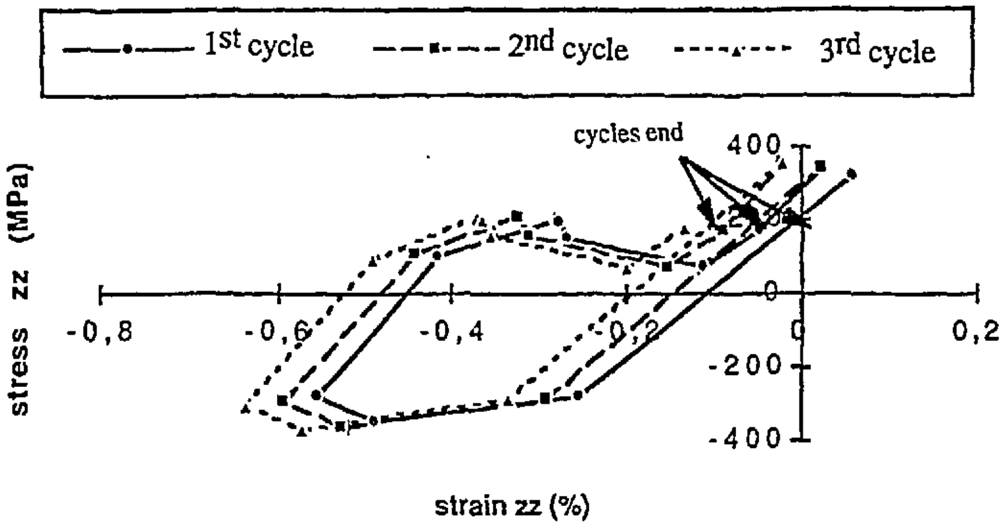

Figure 6: circumferential stress for three cycles at node 47.

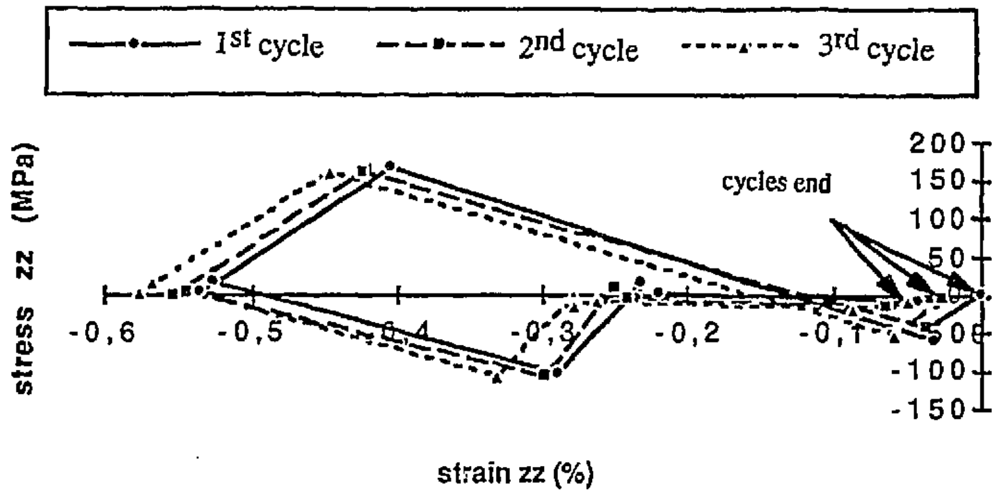

Figure 7 : circumferential stress for three cycles at node 418.

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