Contribution of the Study of Metallic Structures Under Mechanical and Cyclical Thermal Loading

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Abstract

The study concerns the behaviour of metallic structures submitted to the combination of a primary loading and a secondary cyclic thermal sollicitation.

An original experimental device was conceived and carried through in order to apply on thin stainless steel cylinders a tensile and an axial cyclic gradient of temperature of variable intensity.

Numerical calculations are led by taking in account several models of the material behaviour laws. The identification of the different model is made from monotonous and cyclic caracterisation tests according to temperature.

The comparison of the test results with those stemming from calculation allows a better comprehension of the thermoelastoplastic behavior of the structure.

I. Introduction

More and more complex models allow to bring out the cyclic-plastic behaviour of materials. Nevertheless, many difficulties still remain in analysing the behaviour of structures. The very conservative nature of the rules of construction shows the uncertainties within this field.

A better comprehension of the phenomena is likely to be brought by experimental studies. Most of the experimentations that have been developped these last years essentially concern the structure of "type BREE". As a matter of fact, concerning the question of the three bars as well as for the test of tensile-twisting or tensile-bending, such applied are the sollicitations that they produce a state of stresses wich is the same on the whole structure. Therefore, such studies bring out behaviours of materials more than behaviours of structures. Tests on structures are still very few and especially tend to observe the total behaviour. Necessity has become obvious to increase experimentations where the combination of primary and secondary sollicitations touches a restricted volume of the structure and where an adapted device of measures allows the study of the local and global behaviours of structure.

It's for that purpose that we have developped the experimental study, which results are compared with those stemming from numerical calculation.

The study concerns the behaviour of thin stainless steel cylinders of large size submitted to a tensile and to cyclic thermal axial step.

II. Experimental device [1]

II.1. Loading [figure 1]

The primary loading is a tensile whose intensity is constant in time. The secondary loading is a cyclic thermal axial step. The intensity of this gradient can reach 350°C/cm. This value corresponds to an intensity of thermal stress three times the yield stress of the material. The axial step in temperature is obtained by forced internal convection. The escape gas of a burner are aired into the cylinder where a deflector forces them to hit the internal side very locally at high speed. A watering by means of jets of water focussed on the same level allows refreshing and getting supply of wanted temperature.

The radial thermal step is insignifiant, considering the small thickness of the cylinder and the mode of heating used here.

II.2. Device of measurements

The interest of the choosen method for creating thermal sollicitation is to keep the external side of the cylinder quite unoccupied for the measurements. The instrumentation must enable the measure of residual displacements round important displacements caused by the primary and secondary sollicitations. This necessity has obliged us to concieve and realize captors of axial and radial displacements adapted to the measure under rigorous thermal conditions.

III. Experimental and numerical results

III.1. Applied loading [table 1]

The exact definition of the secondary loading is given by the temperature cards along a generator at different steps of the rising and falling temperature.

III.2. Modelization of the material

Caracterisation'tests under monotonous tensile and cyclic strains imposed upon at different temperatures allow to point out the material behaviour law according to different types of modelization.

III.2.1 - Kinematic hardening model

As for this type of modelization, we have choosen a bilinear hardening. Figure 2 shows the models built from the monotonous traction curves.

III.2.2 - CHABOCHE model [2]

This five parameters model is identified from cyclic tests done on adapted test specimen. The choosen model does not take any isotropic hardening into account and proves the kinematic hardening by summing up two exponentials.

III.3. Numerical modelization

One has selected the CASTEM CODE [3] whose INCA part expecially gives the possibility of taking a cyclic hardening of the material into account with a development of the parameters of temperature. The spacial and transient discretisations are shown on figure 3.

III.4. Comparison of experimental and numerical results

The comparison concerns the results of test 6 (Gmax = 300°C/cm ; P = 470 kN).

III.4.1 - Displacements

After 3 cycles the CHABOCHE model and the kinematic model perfectly describe the behaviour of the structure, as it's proved by the different curves relative to the displacements (figure 4).

After 10 cycles, results of calculation made with the numerical models bring out a different behaviour on a level with the warm and cold hinges (figure 5). The zones of maximal plastic strains are the starting-point of a ratcheting which in not true to the real observation of structure.

III.4.2 - Strains

The axial strains are represented on figure 6. The ratcheting is quite well shown by the study of axial strains on the level with the cold hinge : the test discloses a stabilization which is not expressed by calculation.

IV. Conclusion

The comparison of the results brings out a wrong determination of the ultimate state of structure by means of numerical modelization. However, the right description of the behaviour in the course of the first cycles promises well about the capacities of the calculation codes to find the solution of such problems.

An improvement is sure to go through the elaboration of models of law of behaviour which should be adapted to complex states of stresses.

The main knowledge of this work is to bring points of reference not only useful for the validation of the codes, but also of the simplified methods which remain a finality within this field.

V. Reference

[1] - COUSIN M. - "Contribution à l'étude des structures métalliques sous chargement mécanique et thermique cyclique" - Thèse d'Etat - Mars 1984 - I.N.S.A. de LYON

[2] - CHABOCHE J.L., DANG Van K., CORDIER G. - "Modelization on the strain memory effect on the cyclic hardening of 316 stainless steel" - SMIRT - Vol. L - 1979

[3] - HOFFMANN A., COMBESCURE A., CHAVANT C. - "Calcul linéaire et non linéaire des coques" IPSI - Janvier 1977

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tests	number of cycles	P kN	G °C/c	$\frac{\sigma_t}{\sigma_e}$	$\frac{\sigma_p}{\sigma_e}$
1	1	0	60	0.38	
2	4	300	80	0.53	0.38
3	5	450	125	0.86	0.60
4	20	450	250	1.95	0.66
5	10	470	240	1.87	0.69
6	31	470	300	2.32	0.72
7	1	470	300	2.32	0.72

Table I : Experimental tests

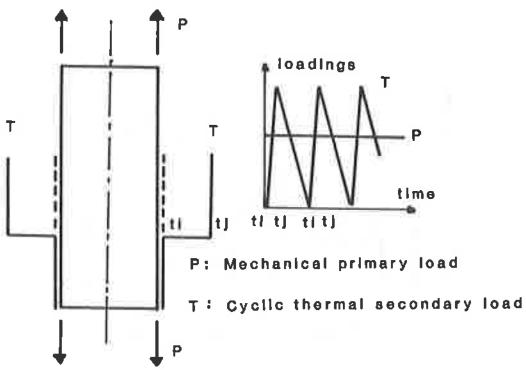

Figure 1 : Applied loadings

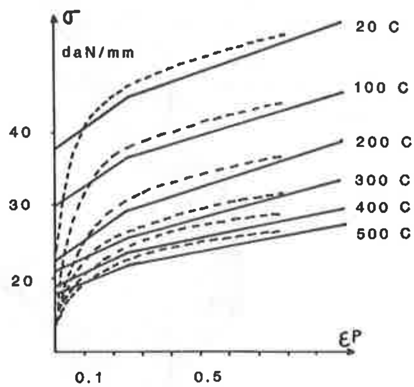

Figure 2 : Kinematic hardening model

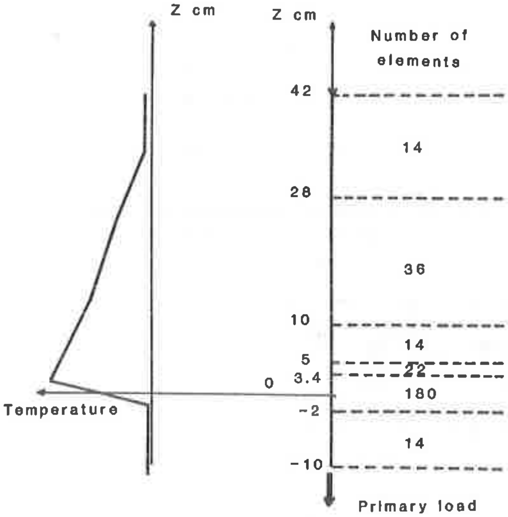

Figure 3 : Mesh of the structure

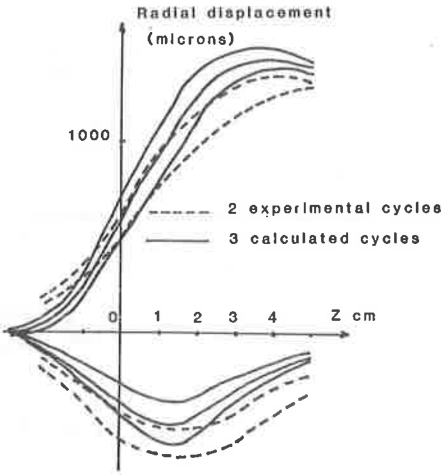

Figure 4 : Radial displacements for 3 cycles

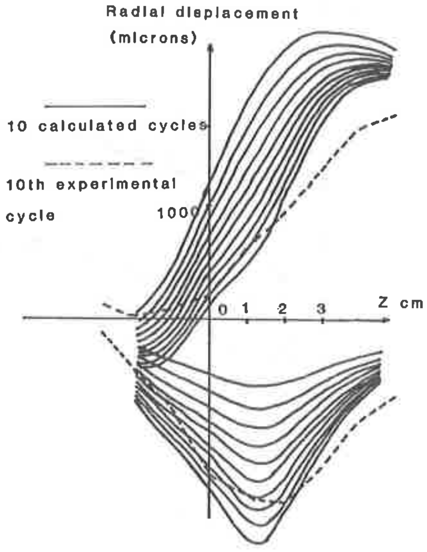

Figure 5 : Radial displacements for 10 cycles

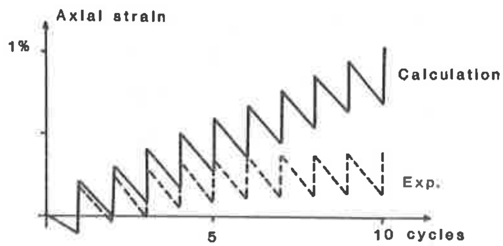

Figure 6 : Axial strain