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EVALUATION OF THERMAL RATCHETTING ON AXISYMMETRIC THIN SHELLS AT THE FREE LEVEL OF SODIUM - INELASTIC ANALYSIS

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1 INTRODUCTION

The starting and load variations in a FBR (Fast Breeder Reactor) type reactor produce level variations in the vessels which stress the emergent shells in the sodium free level area. The loading of these shells is mainly linked to the axial thermal gradient, primary type strains are usually weak or negligible as are the radial thermal gradients.

Under the effect of these axial thermal gradients, and even in the absence of primary type stresses, there is a risk of progressive deformation.

Given the current state of knowledge the design of this type of structure cannot be performed in a satisfactory manner: the existing elastic analyses are either inapplicable or over-conservative. For inelastic analysis, there are no constitutive equations describing correctly this kind of behaviour.

CEA at Cadarache is involved in a specific test programme, known as VINIL, in order to study this problem. The experimental objective being to reproduce stress fields equivalent to those estimated for the reactors on the test mock-ups ; the experimental results then being used to develop and test the simplified elastic or inelastic analysis methods.

Reference [1] describes the test facility and gives the main experimental results. There is also an evaluation of the risk of progressive deformation on an elastic basis using different simplified analysis methods.

Another aim of this test programme was to evaluate whether the available material behavior models could describe the progressive deformation effect correctly.

The purpose of this paper is to present the inelastic calculations performed in order to analyze the test results.

2 MOCK-UP LOADING

The test is described in Reference [1] Here is a brief reminder of the mock-up's geometrical characteristics and of the loading.

The mock-up studied is the "long mock-up" which has the following dimensions :

- diameter	800 mm
- thickness	1.2 mm
- length	350 mm

the upper part of this mock-up is embedded. The free level varies between levels 185 mm and 220 mm (values relative to the bottom of the shell). The emergent length is therefore always greater than the decay length of the shell ($5/\beta$ = 85.2 mm).

A schematic description of the loading cycle is given in figure 1 : the sodium level being at level 185 mm the sodium temperature increases from 200 to 620°C in 40 min. In order to simulate the level variation the mock-up is then lowered by 35 mm in 15 s and held there during the temperature step at 620°C which lasts 50 min. The sodium cooling is then initiated while the shell is simultaneously raised 35 mm in 15 s. The sodium temperature returns to 200°C.

3 THERMAL CALCULATIONS

An important thermocouple instrumentation provides a good knowledge of the thermal fields during the cycling.

The thermal calculations are carried out by means of the code DELFINE (CASTEM system). The calculations take into account the exchanges by conduction in the mock-up and by convection with sodium and argon respectively. The sodium temperature variation and the level variations are modellized.

A very good correlation was obtained between the temperature values recorded during the test and the values calculated. Some comparisons are shown by way of example on figure 2 and figure 3. Figure 4 shows the temperature evolutions along the length of the shell at different moments of the transient.

4 INELASTIC CALCULATIONS

The inelastic calculations were carried out using different hypothesis for the behaviour of the materials. Three different calculations were made :

1 plastic isotropic model identified on the mean monotonic curves of RCCMR.A3.1 S, taking into account the curves' evolution with the temperature. The creep was evaluated during the hold time at high temperature. The RCCMR laws were also used here, taking into account their evolution with the temperature,

2 plastic linear kinematic model identified on the mean monotonic curves for the material followed by the same creep model as above during the hold time.

These first two models are non-unified models.

3 unified Chaboche viscoplastic model. A model with two kinematic variables, one isotropic variable, time restoration for the different variables and strain memory, was used for these calculations. The identification for this model for steel 316 is given in Reference [2]. The identifications for the different temperatures are taken into account.

The first two calculations were carried out over three cycles as there is a rapid stabilization of the stresses and strains whereas with the Chaboche model they go on to evolve after five cycles.

Figures 5 and 6 show the circumferential stress - elastoplastic circumferential strain cycles obtained during the first three cycles with the linear kinematic model and the Chaboche model respectively at a point located on the mean fibre in the free level variation zone.

It is noted that the cycle merge with the linear kinematic model and that from the second cycle on and after there is very little plastification.

The results obtained with the Chaboche model are markedly different. It is noted that there is a progressive deformation towards negative strains with high plastification during each cycle.

As concerns the stresses, both models result in cycles with symmetrical stresses but with a greater stress range for the linear kinematic model ($\Delta\sigma\theta \simeq 250$ MPa) than for the Chaboche model ($\Delta\sigma\theta \simeq 200$ MPa).

Figures 7 to 9 show, for each of the models, the residual radial displacement obtained over the entire length of the shell at the end of each cycle. This moment corresponds to a return to the isothermic state at 200°C.

We note :

1 that all 3 models forecast a reduction of the radius around the free level. This complies with the experimental results,

2 that the shapes given by the 3 models are relatively different : only one bump with the Chaboche model, two bumps of the same size with the isotropic model and two bumps of different sizes with the linear kinematic model.

The experimental results (see Reference [1]) would seem to comply with the findings obtained using the Chaboche model.

3 that the displacement amplitudes forecast by the three models are relatively different :

- isotropic model : the reduction of the radius is equal to 0.044 mm,
- linear kinematic model : it varies between 0.036 and 0.038 mm,
- Chaboche model : between cycles 1 and 5 it passes from 0.083 mm (i.e. twice as much as the other models in the first cycle) to 0.14 mm.

It is noted that after 500 cycles the tests gave an average radius decreasing of 0.8 mm and a maximum of 1.6 mm.

We conclude that the isotropic and linear kinematic models are not capable to give an estimation of the final deformations expected.

The Chaboche model allows to describe the progressive deformation effect but it is not possible to perform the calculation until stabilization is attained. It would be necessary either to use cycle-skipping methods allowing the calculation of greater numbers of cycles, or to associate extrapolation method allowing evaluation of the deformation for given number of cycles.

A method of this type is proposed in RCCMR Appendix A10.

Once a calculation over n cycles has been carried out (with n > 4) it allows an estimation of the deformation state which would result from N loading cycles using the formula below : for N > 4n.

$$\epsilon N = \epsilon n + n \frac{\delta \epsilon n}{m-1} (1 - 4^{1-m}) + \frac{\delta \epsilon n}{4^m} (N-4n)$$

$\delta \epsilon n$ being the strain increment for cycle n, and m a coefficient determined according to n and $\delta \epsilon n$.

By applying this method to the Chaboche model calculation results we forecast a ΔR radius variation equal to 2.5 mm for 500 cycles.

This gives an upper bound for the experimental value (comprised between 0.8 and 1.6 mm) which seems reasonable.

If the calculation had been continued for a few more cycles this would have allowed a reduction of the extrapolated value and therefore a closer correlation with the experimental results.

5 CONCLUSIONS

Different models of constitutive equations have been used to analyze the VINIL tests which were designed to study the problem of progressive deformation on shells submitted to thermal gradients which vary in time and in space near the free level of sodium.

We note that the simplest models : plastic isotropic or linear kinematic models, do not allow the progressive deformation effect to be described correctly.

The Chaboche viscoplastic model represents this effect but cannot be used alone to predict the final deformations. It is necessary either to make use of cycle-skipping techniques or to couple it with extrapolation methods. Exploration of this path of research must be continued in parallel with the use of better adapted constitutive laws.

REFERENCES

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[2] D. RIVE, C. ESCARAVAGE, B. RIOU, M.T. CABRILLAT
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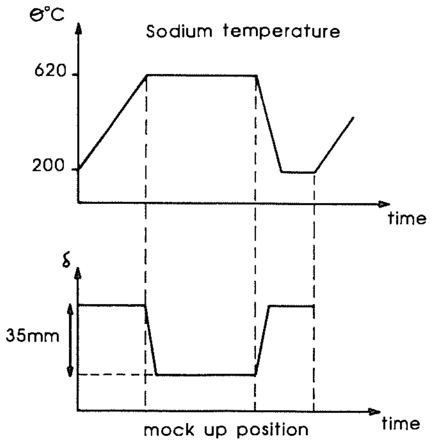

FIGURE 1

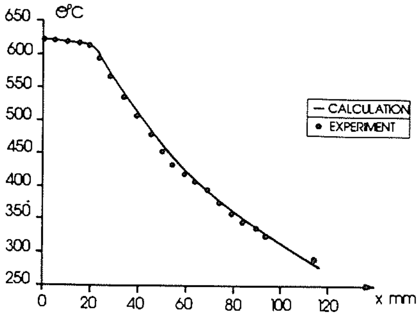

FIGURE 2 Comparison just before mock up displacement

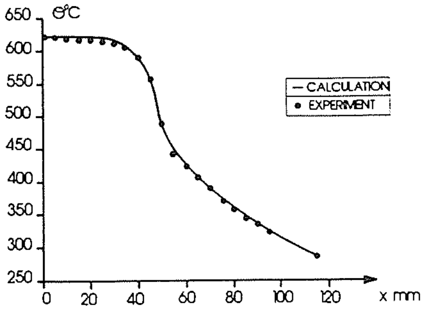

FIGURE 3 Comparison10s after beginning of mock up displacement

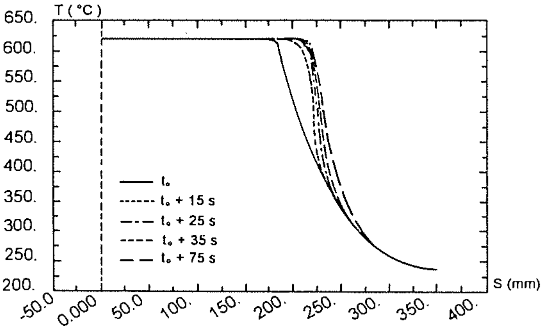

FIGURE 4

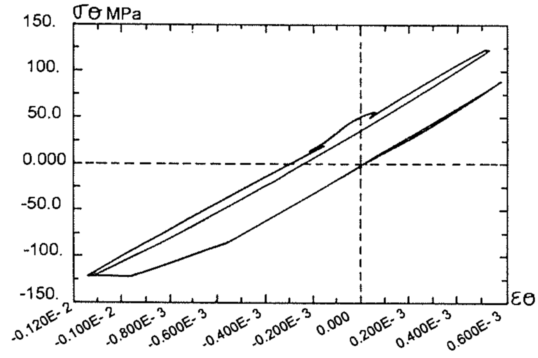

FIGURE 5 Linear kinematic model

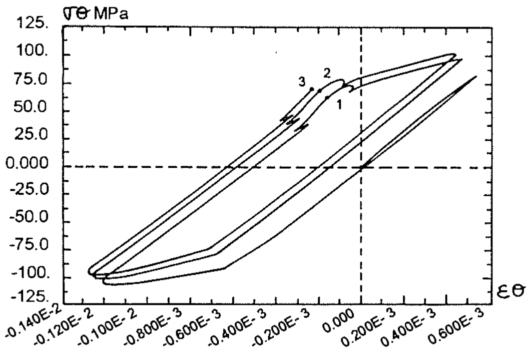

FIGURE 6 Chaboche model

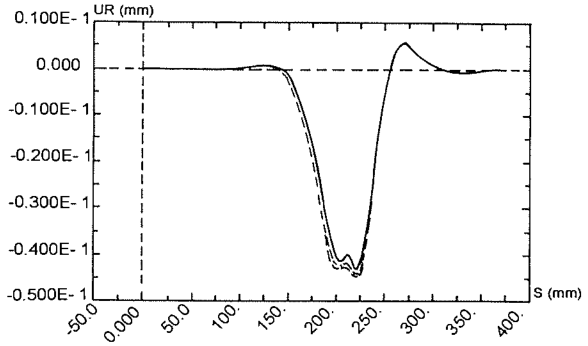

FIGURE 7 Isotropic model

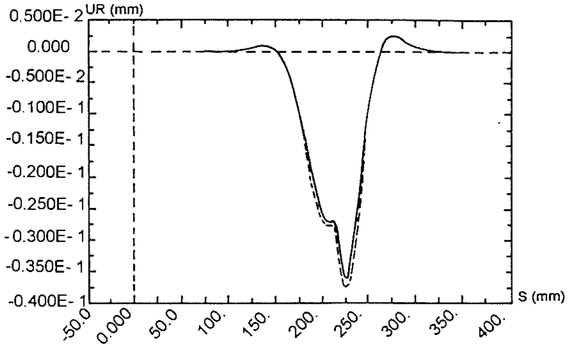

FIGURE 8 Linear kinematic model

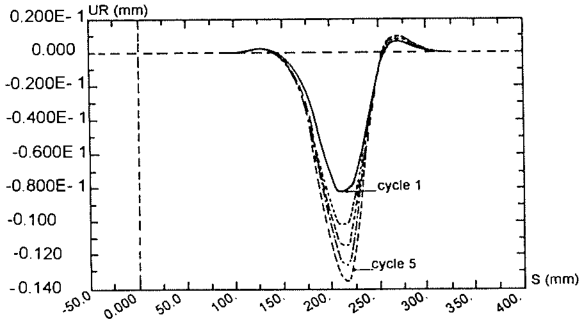

FIGURE 9 Chaboche model