STUDY OF THE INFLUENCE OF THERMAL STRATIFICATION ON THE BEHAVIOUR OF A PIPE WITH A CIRCUMFERENTIAL CRACK

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In this paper parametric numerical studies of stratification effects in a pipe are presented. The pipe contains a circumferential throughwall crack and was part of a series of leak rate experiments performed during phase III of the HDR-Safety-Program. The temperature measurements in the experiment under consideration indicate stratification over the whole pipe length.
In this presentation post-calculations of the experiments are described. For the calculations the finite element method is used, with a model consisting of isoparametric 20-node elements.

INTRODUCTION

During phase III of the HDR-Safety-Program experiments have been performed in subgroup E22 concerning the crack opening and leak rate behaviour of through cracks in piping components of smaller diameter (up to 100 mm). Applied loads were internal pressure and bending moments under realistic PWR-environmental conditions of subcooled hot water (300 °C, 10 MPa).

An overview of the test program is given in (1), further details may be found in (2, 3).

The experiments were accompanied by calculations, mostly post-calculations, of structure mechanical and leak behaviour. An important aim of the studies was to qualify the numerical models by comparison of calculated and measured results.

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In the course of the experiments it showed up that thermal effects play an important role and cause problems for the interpretation of the experimental results.

In this paper a straight pipe experiment performed in 1991 (experiment E22.06) is considered, where a rather large number of temperature measuring devices was used.

SHORT DESCRIPTION OF E22.06

The arrangement and the main dimensions of the pipe considered are shown in Fig. 1. The pipe has a nominal diameter of 80 mm and is fabricated of the austenitic steel X10 CrNiMoTi 18 10.

The pipe has a circumferential crack, which has been grown through the wall by fatigue before the experiment at the MPA Stuttgart. The complex shaped crack had an angle of 90 degrees at the inside of the crack and of 32° degrees at the outside before the experiment. During the test further stable circumferential crack growth occurred resulting in an outer crack angle of 65 degrees at the end of the experiment.

In addition to the internal pressure the pipe is loaded by bending moments generated by an up or down movement of the closed pipe end by a hydraulic cylinder (see Fig. 1).

The main measuring devices are also shown in Fig. 1. A typical temperature distribution measured at cross section Q8 is shown in Fig. 2.

CALCULATIONS

A finite element model consisting of 20-node elements was used for the complete pipe between hydraulic cylinder and pipe clamp fixities. For symmetry reasons only one half of the cross section of the pipe is modelled. The model has 6077 nodal points, 864 elements and 17507 unknown degrees of freedom. The following cases were considered:

- Temperature everywhere 300 °C; displacement + 20 mm (case 1); reference loading case.
- Temperature in the upper half of the model 300 °C, in the lower half 150 °C; displacement fixed (case 2).

- Temperature 150 °C in the lower half of the model between hydraulic cylinder and crack, 300 °C in the rest; displacement fixed (case 3).
- As case 3 but smaller cold zone (only one quarter of cross section with 150 °C; case 4).
- Realistic temperature distribution according to measured values; displacement fixed (case 5).
- As case 5, but with displacement of + 20 mm (case 6) (most realistic).

In all cases also internal pressure (maximum 10 MPa) was applied.

The calculations were performed with the nonlinear Finite Element program ADINA (4), with temperature dependent elastic-plastic material data. ADINA contains some fracture mechanics options, e.g. possibilities to calculate J-integral values according to the methods proposed in (5).

Calculated reaction forces at hydraulic cylinder, crack opening values and J-integral results for all cases are presented in Figs. 3 to 5. As loads and the sequence of their application are not the same in the different cases, only results of the last load part are shown, for instance the prescribed displacement in case 6. P/P_{max} is defined in this case as the fraction of the displacement in the step considered by the maxium displacement value.

SUMMARY

Finite element post calculations of a leak opening experiment under LWR operating conditions were performed. The calculations also include different temperature distributions, which model stratification effects occurring in the experiment.

The calculations show a very significant influence of the temperature assumptions and distribution on the reaction force, the crack opening and the J-value. For instance the reaction force for case 6 at maximum load is more than 2 times higher than the corresponding value for case 1 and the J-integral value more than 10 times.

Through this investigation of the influence of the stratifiction effect some of the measured results hitherto not totally understood can be explained better now.

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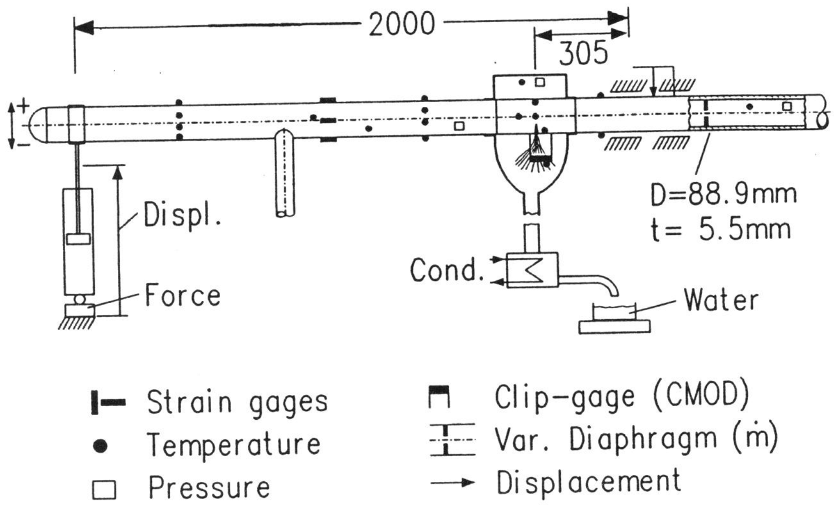

Figure 1 Experimental arrangement, measuring devices, E22.06

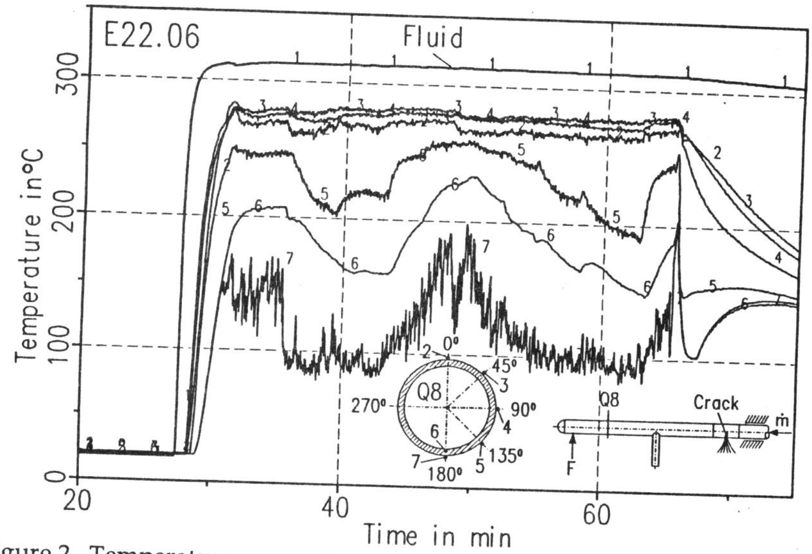

Figure 2 Temperature measurements at cross section Q8

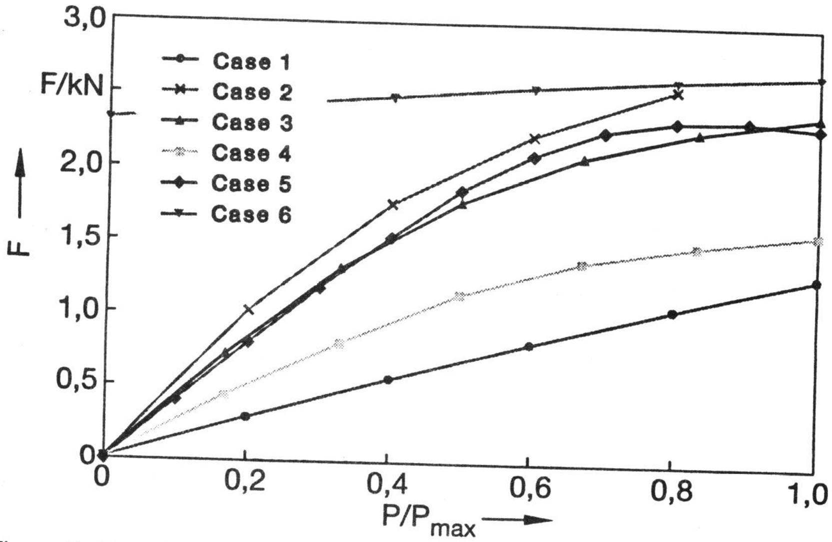

Figure 3 Reaction forces for different cases, E22.06

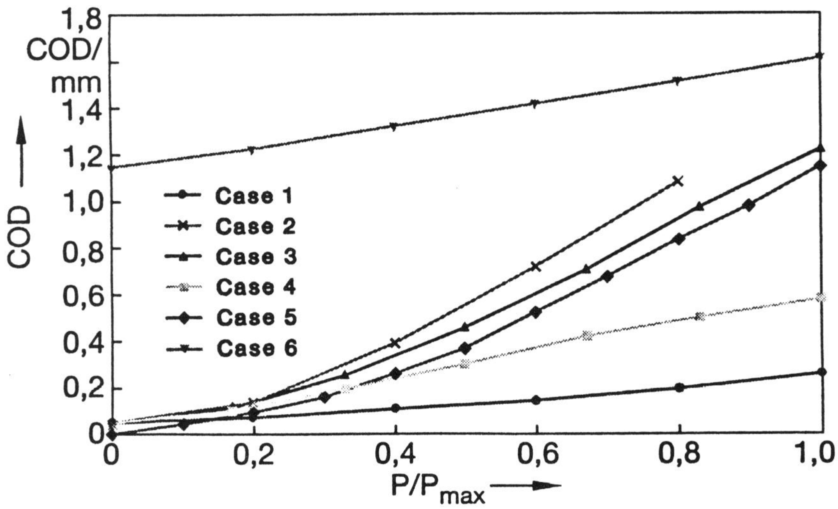

Figure 4 Crack opening displacement at outside for different cases, E22.06

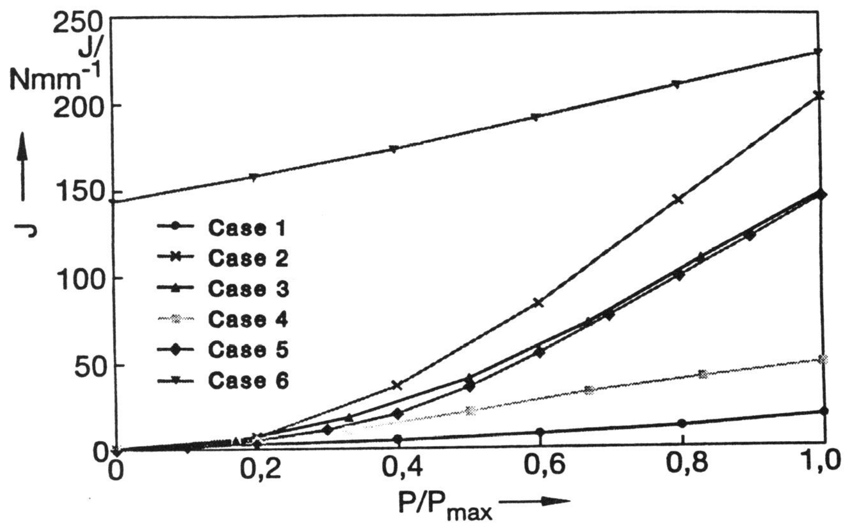

Figure 5 J-integral results for different cases, E22.06