SMiRT-12 / K. Kussmaul (Editor)

G06/2

NEW EXPERIMENTS ON LEAK BEHAVIOR OF NATURAL CRACKS IN SMALL-BORE PIPES AT THE HDR FACILITY

H. Hunger[1] and H. Grebner[2]

[1]Project HDR-Safety Program (PHDR), Kernforschungszentrum Karlsruhe, Germany
[2]Gesellschaft für Anlagen- und Reaktorsicherheit, Köln, Germany

ABSTRACT

Within the HDR Safety Program (PHDR) test group E22 "Leakage Behavior of Small Austenitic Pipes" comprised experiments on crack opening and leak rate of piping components under near-to-reality operating conditions. The components tested included straight pipes with circumferential cracks, pipe branches with simulated weldment cracks and pipe bends with longitudinal or circumferential cracks. The three chosen piping components are representing typical small LWR pipework. In all tests the load consisted of the superposition of internal pressure together with bending moments resulting in additional crack closing or opening. In the last series (5 experiments) a straight pipe and a thin-walled pipe elbow as well as a thick-walled one were tested. The experimental set-up, results of the measurements and problems that arose during the tests are presented; a second paper reports on the pre- and post-calculations and on comparisons with the experimental results.

1 INTRODUCTION

The materials nowadays used for the large amount of pipings with small diameter in NPPs ensure leak-before-break behavior. In order to assess the danger caused by a leakage (after having been found by a qualified leak detection system) knowledge of the through crack's size is needed; as this is directly not possible it is necessary to conclude the crack size from the leak rate depending additionally from the opening and closing effect of transient bending moments and from the roughness of the crack surface.

The experiments of the test group E22 carried out within Phase III of the Project HDR Safety Program (PHDR) by Karlsruhe Nuclear Research Centre (KfK) at the HDR Facility /1/ (HDR = test facility based on the decommissioned Hot Steam Reactor in Karl-stein/Bavaria) therefore investigated the crack opening behaviour and the resulting leak rates of different cracked austenitic piping components (pipes, branches, bends) of small diameter (less/equal than 100 mm); all cracks were loaded by internal pressure and a variable bending moment simulating operating transients. The sum of all E22 experiments in the years 1988-91 amounted to eleven /2,3/. The last five of these are explained here. All tests have been accompanied by pre- and post-calculations performed by GRS Köln; these calculations are presented in a separate paper /4/ together with comparisons of measurement and analytical or Finite Element Method results, respectively (displacements, strains, crack opening displacement, the fracture mechanic J-integral, and leak rate).

2 EXPERIMENTAL SET-UP AND INSTRUMENTATION

The three components of the last test series in 1991 /5/ were a thin-walled pipe elbow (test E22.21), a thick-walled one (E22.22), and again a straight pipe (tests E22.06, E22.061, E22.062) all with a nominal diameter of 80 mm. The through cracks - a circumferential one in the straight pipe (outside angle 32°, inside notch 90°) and in the thick-walled elbow (inside angle 32°, outside notch 60°), an axial crack at the flank of the thin-walled elbow (outside angle 10°, inside notch 60°) - had started each from eroded initial notches (a/t=0,5) and had grown by cyclic fatigue (manufactured at the laboratory of MPA Stuttgart). All test sections consisted of the austenitic steel X 10 CrNiMoTi 18 10. The test set-up (see Fig. 1) allowed the successive examination of two cracked components each. The fluid (p=10.8 MPa, T=300°C) was supplied by the former HDR pressurizer (volume 20 m^3). The stepwise changing bending moments acting on the test pipes clamped on one side in a support frame were furnished by one hydraulic cylinder each. Fig. 2 gives a schematic view of the measuring devices used in the tests for displacement, force, strains, pressure, temperatures inside and outside the pipes, crack opening with clip-gages and diverse types of mass-flow measurements (variable diaphragm, correlation method, and condensation chamber). Before the main tests with pressure "cold" pre-tests showed the influence of pure mechanical loads (without mass-flow).

3 TEST RESULTS

The outside crack length of the straight pipe found out after the three single test steps E22.06/061/062 by destructive examination was 65°; that means a growth of 100% probably due mainly to an overload during pre-test E22.061. Fig. 3 shows cylinder displacement and force of E22.06 together with the resulting mass-flow; after the warm-up phase the step-wise varying values of the latter correspond rather to the load (CMOD defect). In the second test E22.061 (Fig. 4) crack closing and zero mass-flow did not occur probably due to plastic deformation of the crack; the maximum leak-rate was that of E22.06 (ca. 1.6 kg/s). In order to investigate the typical change of the bending moment (cylinder force and strains) during a fixed load step (already noticeable in Fig. 3,4) the temperature distribution along the test pipe was measured by some 30 thermo-couples. Figs 5 and 6 show the temperature distribution of a cross-section in about one meter distance from the leak. In the case of free discharge without insulation (test E22.06) a distinct stratification in the pipe has to be assumed together with some "cooling" of the pipe's outside as a result of the blowing medium; the stratification (colder fluid at the bottom, hot fluid at the top) leads to a "bimetal effect" and additional bending. As expected the effect is decreasing when the condensation chamber and insulation are used (similar to reality) in test E22.062, but is yet existing.

The expected problems arose from thermal transients and defect when measuring the crack opening with "clip-gages"; at least in the pre-tests some usable data could be found. In the pre-test of E21.21 (thin-walled elbow), s. Fig. 7, the CMOD is clearly proportional to cylinder displacement and force. In the main test E21.21, see Fig. 8, the outside length of the longitudinal crack increased after loading with pressure from 10° to 52° so that leakage flow exceeded the normal measuring range of 2.2 kg/sec; in spite of that the correlation method produced useful measurement (2.5-5.5 kg/s). Due to the high mass-flow the test duration had to be reduced. In the last test E22.22 with the thick-walled elbow the clip-gage did not fail; therefore pre-test, mass-flow and CMOD are shown in Figs. 9 to 11. This circumferential crack was the only one in which the mass-flow could nearly be stopped by a negative (crack closing) bending moment; the maximum value amounted to 1 kg/s together with a CMOD of 1 mm. During the test the outside crack angle had grown from 32° to 41°.

4 SUMMARY

The measurements of the test series E22 generally show that crack opening displacement and leak rate are following the stepwise changing bending moments. Plastic deformation after a single overload causes increasing leak rates that cannot be avoided in spite of crack closing bending moments. In all tests failure did not occur due to the high toughness of the austenitic steel (leak-before-break). The accompanying calculations (see Paper F06/5 /4/) are compared with the experimental results; the mechanical part of these could mostly be verified, whereas difficulties arose in comparing measured or calculated leak rates. A final evaluation of the E22 test series is ongoing.

Acknowledgment
The authors appreciate the sponsoring of the E22 work by the German Federal Ministry of Research and Technology (BMFT).

REFERENCES

/1/ Müller-Dietsche, W., Katzenmeier, G. October 1988. HDR Safety Program - Phase III, PHDR Work Report No 05.44/88. Kernforschungszentrum Karlsruhe.

/2/ Hunger, H., Katzenmeier, G., Grebner, H. 1991. Experiments on crack opening and leak rate behavior of small piping components at the HDR Facility. SMiRT 11 Trans. Vol F: p. 225-230.

/3/ Grebner, H., Höfler, A., Hunger, H. 1991. Pre- and post-calculations for crack opening and leak rate experiments on piping components within the HDR program. SMiRT 11 Trans. Vol G: p. 201-212

/4/ Grebner, H., Hunger, H., Höfler, A. 1993. Calculation of crack opening and leak rate of piping components with comparison to experiments at the HDR facility. SMiRT 12 Trans.: Paper F06/5.

/5/ Schramm, P., Hunger, H. 1993. Quick Look Report - Tests E22.05 to E22.22. PHDR-Technical Report No. 110-93: Kernforschungszentrum Karlsruhe (in German)

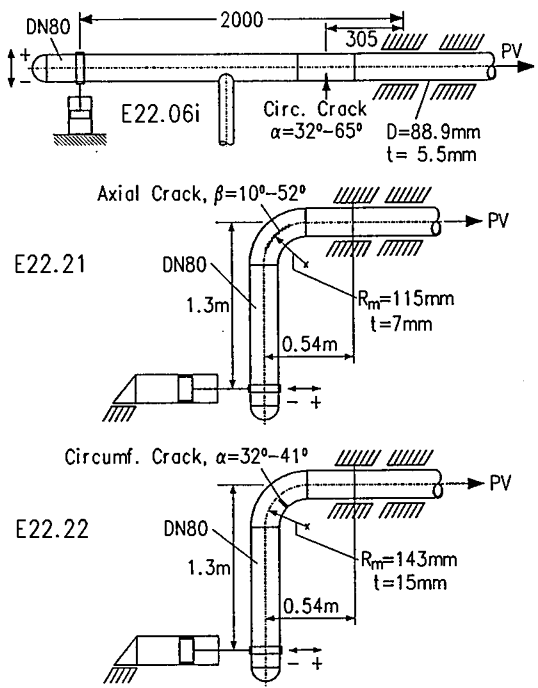

Fig. 1 E22 test arrangements for straight pipe and pipe elbows (schematically)

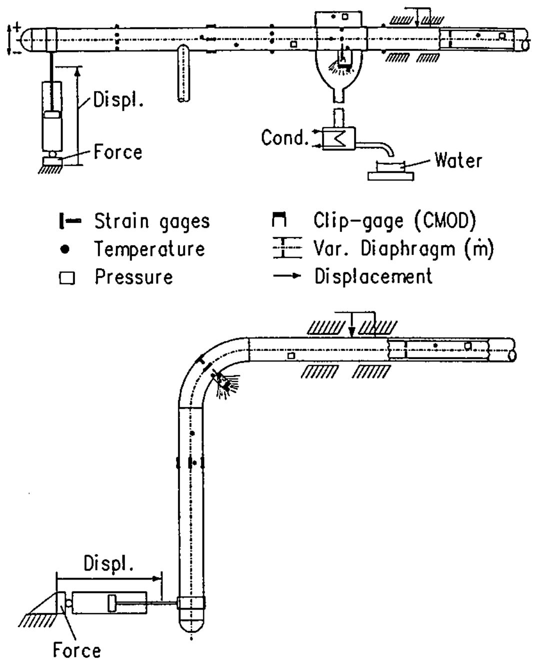

Fig. 2 Overview of the measuring instruments used in E22 tests

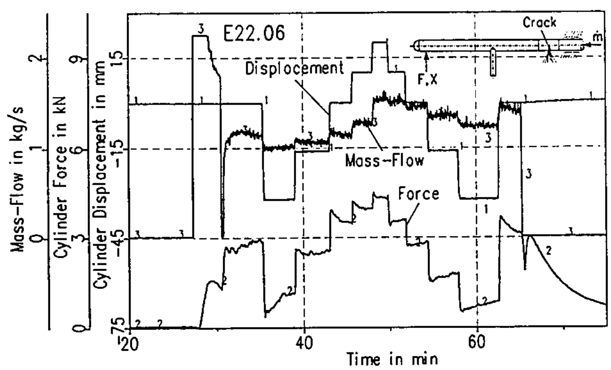

Fig. 3 Load (cylinder displacement and force) and mass-flow in straight pipe test E22.06

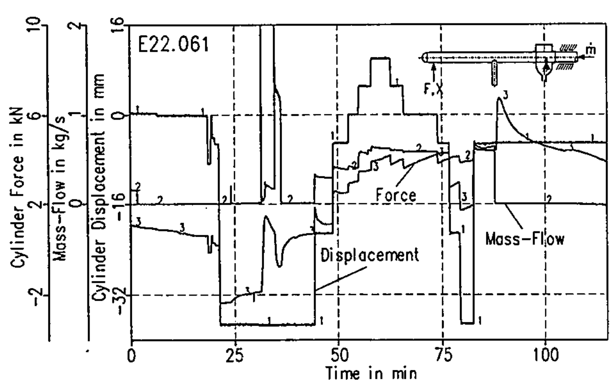

Fig. 4 Load (cylinder displacement and force) and mass-flow in straight pipe test E22.061 with cond. chamber

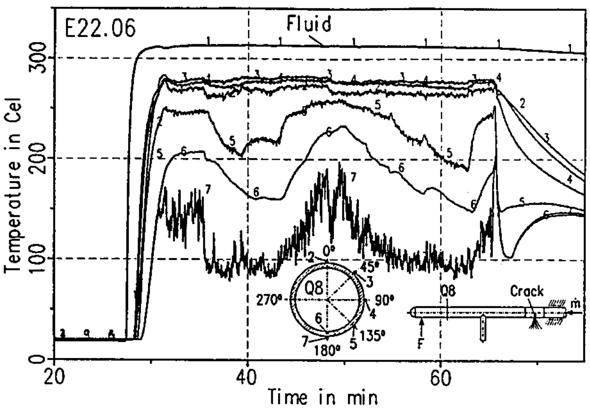

Fig. 5 Wall temperature distribution in cross-section Q8 during straight pipe test E22.06

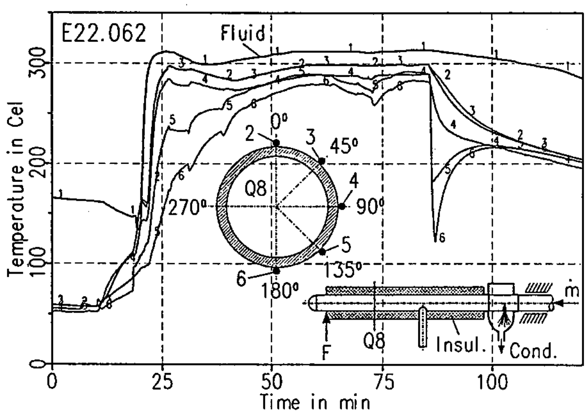

Fig. 6 Wall temperature distribution in cross-section Q8 during straight pipe test E22.062 with cond. chamber and insulation

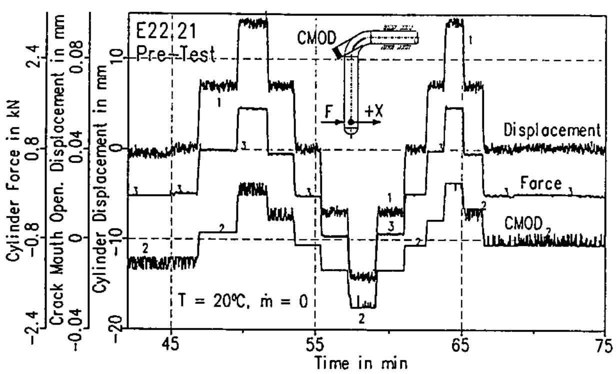

Fig. 7 "Cold" pre-test E22.21: Load and resulting CMOD of the thin-walled elbow

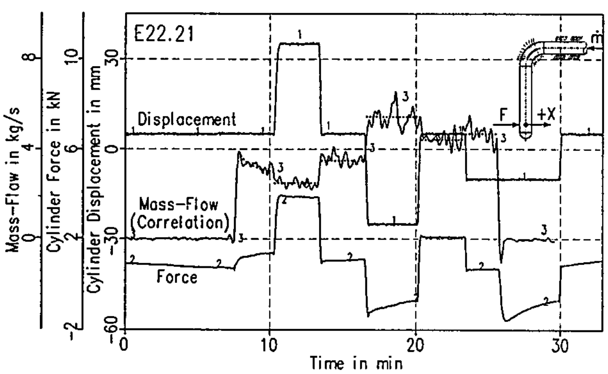

Fig. 8 Load and mass-flow (correlation method) in test E22.21 with the increased axial crack in the thin-walled elbow

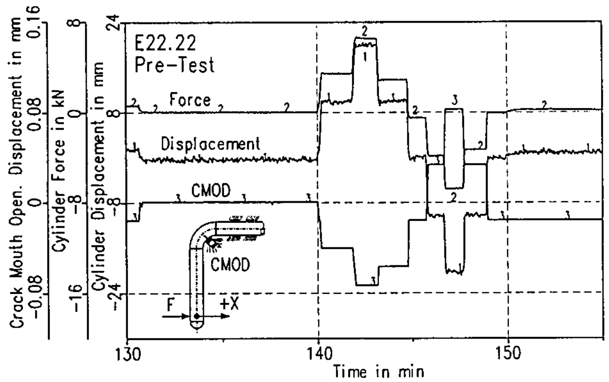

Fig. 9 "Cold" pre-test E22.22: Load and resulting CMOD of the thick-walled elbow

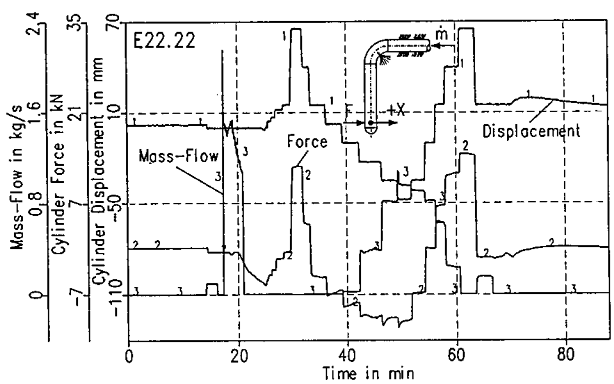

Fig. 10 Load and mass-flow in test E22.22 with the thick-walled elbow

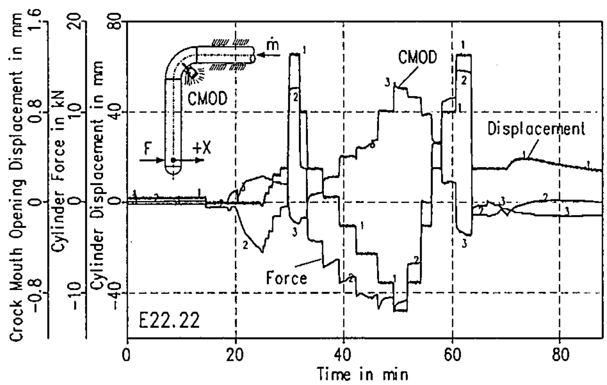

Fig. 11 Load and CMOD in test E22.22 with the thickwalled elbow