Large Scale Validation Tests of Pressurized Elbows with Additional Bending Moment at 550°C

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ABSTRACT

Full scale validation tests on elbows of 0.6Mo- and 12Cr-steel are performed under constant internal pressure and opening in-plane bending moment. After 12000 h, the maximum strain is measured at the elbows' extrados in circumferential direction. The maximum equivalent strain occurs at the elbows' intrados. Creep damage in form of cavities was found at extrados and intrados of the 0.6Mo-elbow. For the 12Cr-elbow, the results of a Finite Element calculation are in good agreement with experimental results.

1 INTRODUCTION

Creep damage in form of cavities and microcracks is found in pipe bends operating in the creep regime [1, 2]. Widespread premature creep damage occurring at the extrados of the bends even lead to failure by a longitudinal crack in individual cases . The cause of this damages was thought to be external additional forces and/or moments occurring in service. In order to prove this assumption and to clarify the complex correlations between loading, time, material behaviour and failure behaviour, a joint validation trial [3] is under way in the Federal Republic of Germany. Industry, associations, authorities and research institutes are participating in this validation project, Fig. 1.

2 TEST RIGS

One pipe bend of 12Cr- (German Standard X 20 CrMoV 12 1) and one of 0.6 Mo- (German Standard 14 MoV 6 3) steel is being investigated at 550 °C in this research project. The dimensions of the bends and the schematic set-up of the test rig can be seen from Fig. 2. Extensive numerical pre-calculations were carried out in order to define the load conditions. A combination of constant internal pressure applied by hot steam and constant opening in-plane bending moment, Fig. 2, should make the pipe bends fail at the extrados after approx. 30000 h. The intended time to failure of approx. 30000 h should make sure that the damage mechanisms occuring in the experiment would correspond to those observed in practice due to long time service.

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The test rigs are regulated and controlled by a computer. In order to record temperature, deformations and strains at the outside of both bends a large number of thermo-couples, capacitive transducers and capacitive strain gages have been applied. The measuring signals are recorded regularly and the data stored as well as made accessible for further evaluation. The tests are regularly interrupted to subject the two bends to extensive non-destructive testing.

3 EXPERIMENTAL RESULTS

3.1 Results obtained on the 0.6Mo-bend

The evaluation of strains measured at the outside of the bend made of 0.6Mo-steel showed that the maximum strains occur at the extrados in circumferential, at the intrados in axial direction. The strains measured at this positions and the respective equivalent strains calculated assuming volume constancy are shown in Fig. 3. They are compared with the creep curve of an uniaxial creep test at a nominal stress of 120 MPa and a fracture time of 20980 h. Obviously axial strain at the intrados and hoop strain at the extrados are of the same order of magnitude. In addition, there is only a small difference in the equivalent strains, which are somewhat higher than the results of the uniaxial creep test. As it is the case for the uniaxial test, the area of tertiary creep with accelerated creep velocity is reached in the elbow test. As would be expected from these measurements, replica taken during the 2nd revision after approx. 10000 h showed creep damage in form of cavities at the extrados and the intrados of the bend as well.

3.2 Results obtained on the 12Cr-bend

The circumferential respectively axial strain at the extrados and the intrados of the 12Cr-bend and the respective equivalent strains are shown in Fig. 4. The creep curve of a uniaxial creep test with an expected rupture time of approx. 30000 h is also depicted there. Opposite to the 0.6Mo-bend, there is still a decrease in creep velocity of the strains measured; consequently, no creep damage has been observed yet at the 12Cr-bend. Whereas the circumferential strain at the extrados is positioned distinctly above the axial strain at the intrados the equivalent strain at the intrados is on a higher level than on the extrados.

4 RESULTS OF FINITE ELEMENT CALCULATION

For the 12Cr-bend, an inelastic Finite Element calculation has been carried out. The creep behaviour of the material was characterized by an uniaxial creep law [4] describing primary, secondary and tertiary creep. Fig. 5 gives a comparison between results from experiment and analysis at the extrados of the 12Cr-bend; the coincidence between experiment and analysis is good. The stresses at extrados and intrados of the bend are depicted in Fig. 6. Whereas the stress state is nearly uniaxial at the extrados, a biaxial stress state with two tensile stresses of the same order of magnitude occurs at the intrados. The v. Mises equivalent stress is, however, nearly identical for both positions and decreases due to stress- and strain redistribution in the bend.

5 SUMMARY

Two large scale validation tests on bends made of 12Cr- and 0.6Mo-steel under static internal steam pressure and opening in-plane bending moment are carried out at 550 °C. A test duration of 12000 h (February 1991) has been reached. In both tests the circumferential strain obtained at the extrados is the largest single strain component. In both cases, the equivalent strain is, however, larger at the intrados of the bend. The difference between the equivalent strains at extrados and intrados is essentially larger at the bend made of 12Cr-steel. Finite Element calculations conducted for this bend are in good coincidence with experimental results. Both bends are expected to exhibit damage mechanisms comparable to those observed in practice due to the long test duration. The results of the research project will thus contribute to a qualified and validated assessment of pipe bends operating in the creep regime even for the case of external additional forces and moments.

ACKNOWLEDGEMENT

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LITERATURE

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INSTALLATION OF TEST RIG: INTERATOM GmbH
CONDUCTION OF TEST: MPA STUTTGART

TESTING SITE: STUTTGART
DESIGN AND INSTALLATION 1986 – 1988
CONDUCTION OF TEST: 1989 – 1991

CALCULATION OF DEFORMATION BEHAVIOUR OF ELBOWS, MATERIAL LAW, MATERIAL DATA
IA, MPA, RW–TÜV, MAB/MFI

DESIGN, MANUFACTURING AND PUTTING INTO OPERATION OF TEST RIG
IA, MPA, MAB/MFI, TÜV–R

MEASUREMENT TECHNIQUES
IA, TÜV–R, MPA

CONDUCTION AND EVALUATION OF ELBOW TESTS, MATERIAL DATA
IA, MPA, MFI

CREEP CRACK GROWTH
MPA, RW–TÜV, IWM

INSTITUTIONS INVOLVED

DDA DEUTSCHER DAMPFKESSELAUSSCHUSS
IA INTERATOM GmbH
MPA STAATLICHE MATERIALPRÜFUNGS–ANSTALT, UNIVERSITY OF STUTTGART
IWM INSTITUT FÜR WERKSTOFFMECHANIK
MFI MANNESMANN–FORSCHUNGSINSTITUT
MAB MANNESMANN–ANLAGENBAU
RW–TÜV RHEINISCH–WESTFÄLISCHER TECHNISCHER ÜBERWACHUNGSVEREIN
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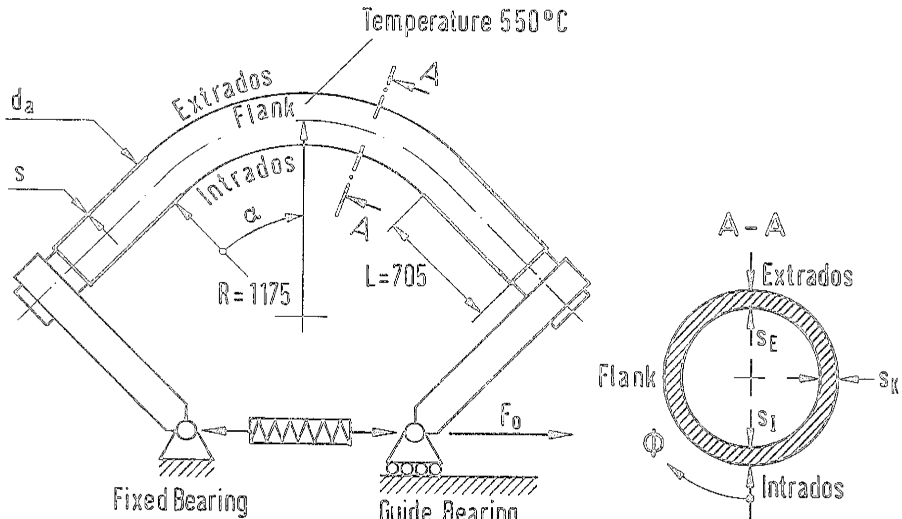
STATE BADEN–WÜRTTEMBERG

Fig. 1: Structure of the research project "Elbows".



Material	d_a [mm]	s [mm]	U_0 [%]	s_E [mm]	s_I [mm]	s_K Φ=90° [mm]	s_K Φ=270° [mm]	p_i [bar]	F_0 [kN]
14 MoV 6 3	235	30	1.1	26.96	32.02	29.22	29.04	200	48
X 20 CrMoV 12 1	235	25	2.5	23.20	25.84	23.86	24.02	234	56

Fig. 2: Schematic view of test rig.

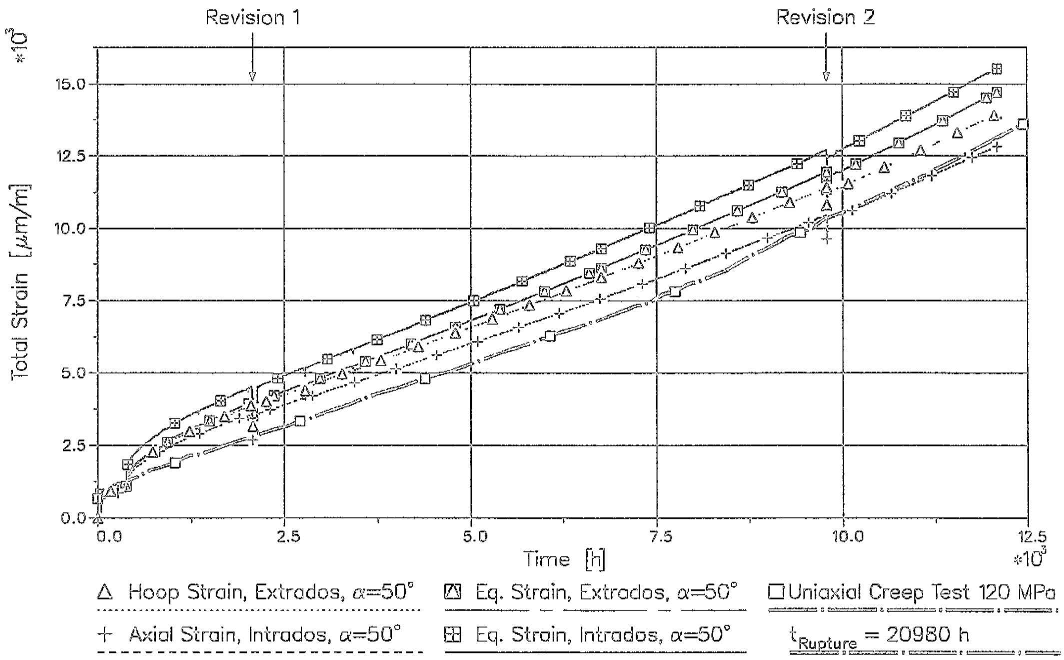


Fig. 3: Experimental results for the 0.6Mo-bend.

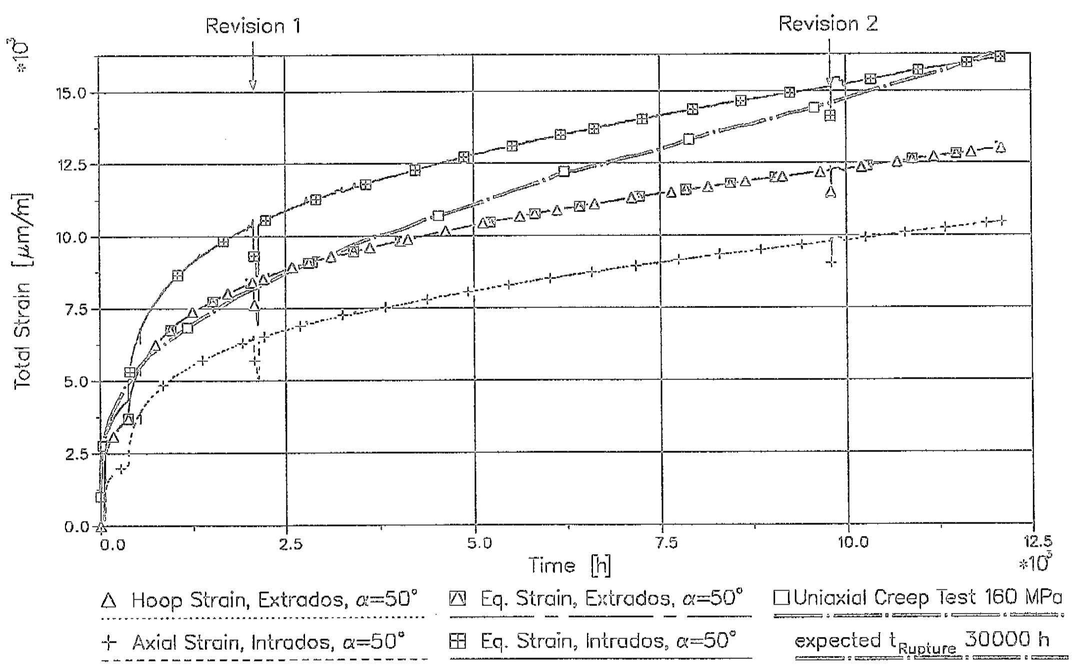


Fig. 4: Experimental results for the 12Cr-bend.

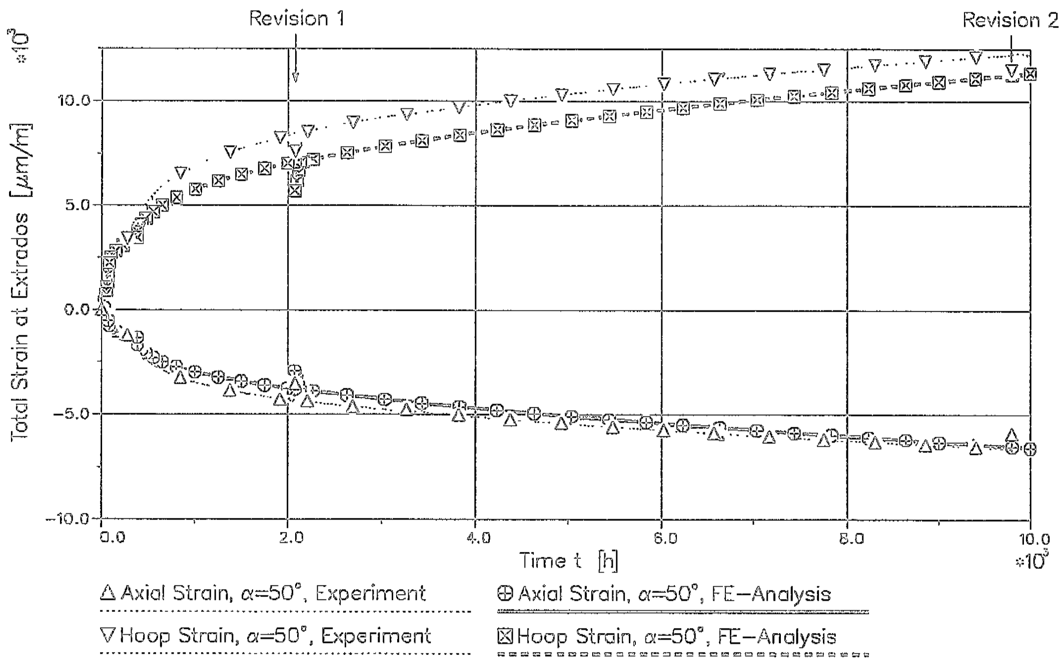


Fig. 5: Comparison of experimental and numerical results at the extrados of the 12Cr-bend.

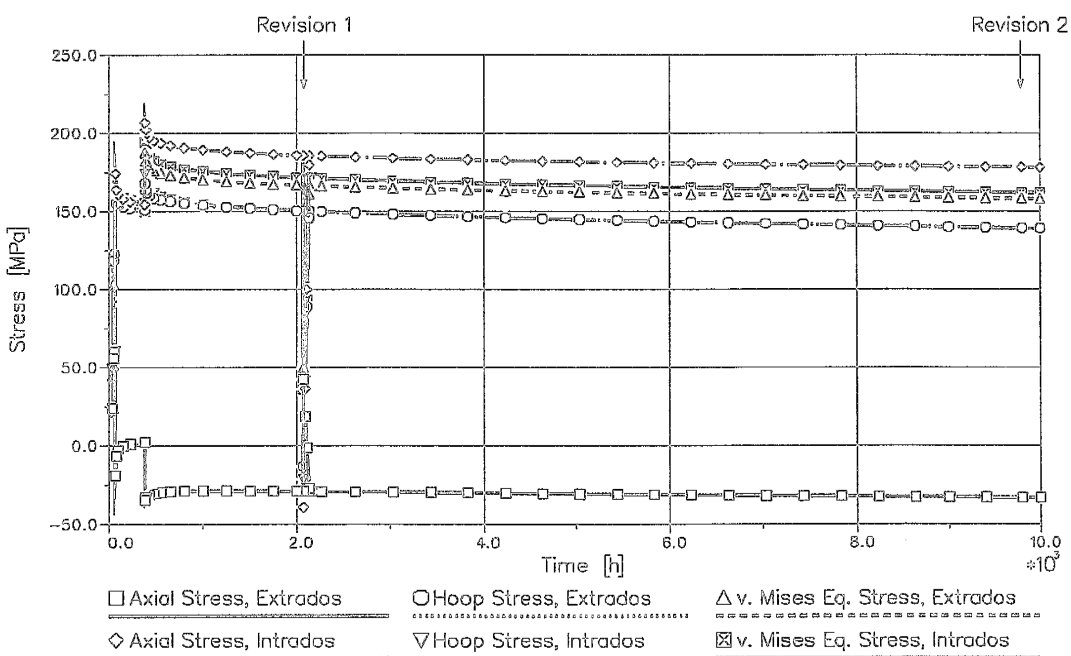


Fig. 6: Comparison of stresses at extrados and intrados of the 12Cr-bend obtained by Finite Element analysis.