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Multiaxial Fatigue Behavior of Welded Flange-Tube Connections under Combined Loading. Experiments and Lifetime Prediction.

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ABSTRACT: In the case of nonproportional multiaxial loading, most existing strength hypotheses are not able to give a satisfying lifetime prediction. This investigation builts the experimental basis to test and modify strength hypotheses for multiaxial, nonproportional loadings. Two types of welded joints are tested with a large field of various parameters. The specimen is a flange-tube connection with a welded joint with and without seam preparation. The flange material is from S 460 M and the tube is made of St E 460. The institute is developing a new program for fatigue life calculation with multiaxial loadings. This software runs on a PC and has a clear and simple structure. It is easily possible to modify the program to test new concepts for fatigue life calculation.

Introduction

Under operating conditions most of the welded components are loaded with a combination of different variable forces and moments. They often cause a state of multiaxial stress and strain in the fatigue critical areas of the construction. The present knowledge of welded components under multiaxial, nonproportional loading does not allow for a satisfying lifetime prediction. Up to now there is not enough experimental data to develop and verify new concepts for fatigue life calculation.

This investigation is a cooperation of three research institutes (LBF, Fraunhofer Institut für Betriebsfestigkeit, Darmstadt; Institut für Stahlbau und Werkstoffmechanik, TH Darmstadt; Institut für Maschinelle Anlagentechnik und Betriebsfestigkeit, TU Clausthal) and wants to build an experimental databasis for the verification of different concepts of lifetime prediction. At the same time existing concepts for fatigue life calculation are checked and improved.

Specimen material and geometry

For this investigation a typical flange-tube connection is used (Fig. 1).

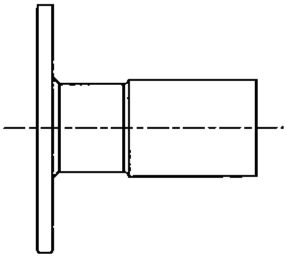


Fig. 1 Geometry of the specimen

The flange is made of rolled plate (steel: S 460 M) with a thickness of 30 mm. The tube is made of rolled tube material (steel: St E 460) with a diameter of 88,9 mm and a wall thickness of 10 mm. Both materials are employed in steel and pressure tank constructions and they are similar to materials used in previous research programs (1).

Two different types of welded joints are to be tested. The main part of the specimens are welded joints with seam preparation (seam 1). The other part are welded joints without seam preparation (seam 2) (Fig. 2).

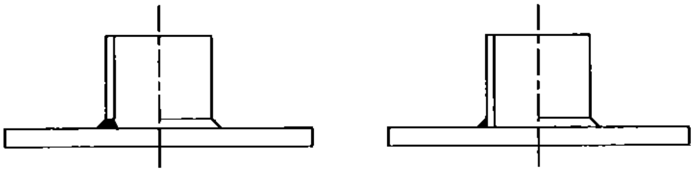
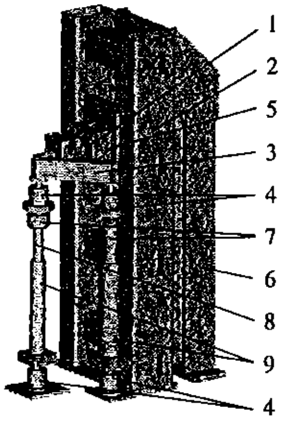


Fig.2 Welded joint with and without seam preparation

Single stage tests (pure bending, pure torsion, bending and torsion in phase and out of phase) shall show the influence of the seam preparation on the fatigue lifetime of the connection. Both types of specimens are stress-relief annealed.

Testing machine

The idea of the testing machine for flange-tube connections is taken from LBF and adapted to the local requirements (Fig. 3).



1	Specimen
2	Frame
3	Sample Holder
4	Bearing
5	Holder
6	Strut
7	Force cell
8	Adapter
9	Hydraulic Actuator

Fig. 3 Testing machine

The tests are executed at both institutes at the same time. The transferability of the results is given by special test series that are the same at both institutes.

Bending and torsion are completely seperated by using two hydraulic actuators with force control. For applying bending and torsion to the specimen, a 100 kN and a 250 kN actuator, respectively, are used. Each actuator is held in two bearings. The geometry of the sample holder ensures that there is pure torsion without bending in the critical area of the specimen.

The tests are stopped when the crack has grown through the wall of the tube. Therefore the specimen is closed in an airtight manner and vacuum is generated in the tube. When a crack grows through the wall there is a pressure compensation (leak) that can be registered and the test stopped.

Crack initiation detection

For these tests and later on for the calculation it is very important to detect the crack initiation as early as possible and to document the growth of the crack.

Previous tests at the LBF have shown that the ultrasonic testing is not able to detect the crack initiation satisfactorily. For this reason another testing method had to be found. Extensive tests with different methods of crack initiation detection followed.

It started with the *"Delta-Analyser"* of Fa. Reilhofer KG. The *"Delta-Analyser"* is able to examine and control signals in the frequency area (Fig. 4).

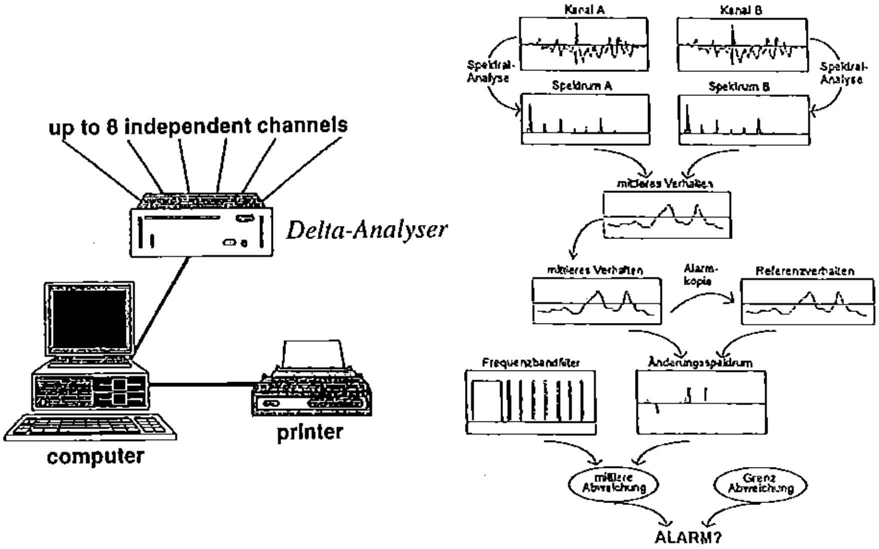


Fig. 4 "*Delta-Analyser*" of Fa. Reilhofer KG (2)

The idea of this method is that a crack in the specimen changes the stiffness of the whole system. By controlling the force and the displacement signals of both actuators, a crack initiation will cause a distinct change in these signals.

The detectable crack depth (4 - 5 mm) and a crack length about 30 - 40 mm are too large to call it a technical crack. In addition to this a calibration of the signals was impossible. Therefore this procedure prove unsuitable.

Another method for finding small cracks is the DC potential probe. This procedure is used for the crack initiation detection at all seam 2 specimens. A direct current of 30 A runs through the specimen. In the critical area are 8 measuring points to measure the voltage (Fig. 5).

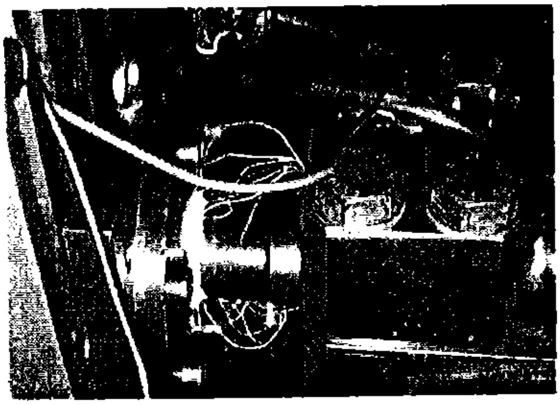


Fig. 5 DC potential probe

The rising of the voltage is related to the crack depth. At the welded flange-tube connection it is possible to find cracks with a depth between 0.5 and 1 mm.

The disadvantage of that method is that the test must be interrupted and the measuring results scatter. There is also an influence of temperature on the results.

Therefore and in order to have the same criterion for crack initiation detection, all involved institutes use an AC potential probe. The procedure is nearly the same as the DC potential probe but without the described disadvantages. The alternating current is only 1 A but with a frequency of 1000 Hz. Each measuring point has its own pair of power contacts (Fig 6).

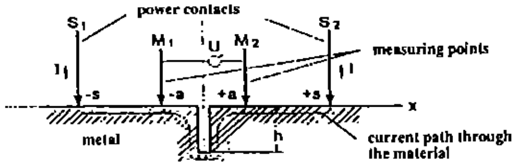


Fig. 6 AC potential probe (3)

First results

At pure bending the welded joint breaks at the transition between tube and seam. The crack grows in form of a long ellipse from both sides straight through the tube (Fig. 7). The crack geometry of every specimen is very similar and independent of the height of the load.

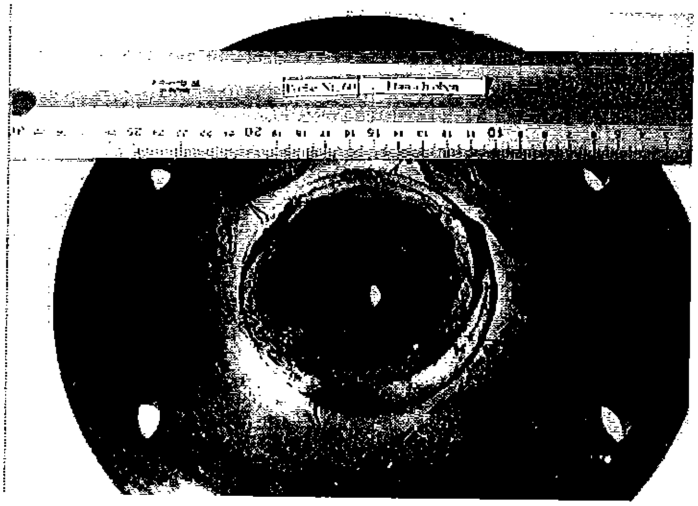


Fig. 7 flange pure bending (seam 2)

The S-N curve for pure bending is shown in figure 8.

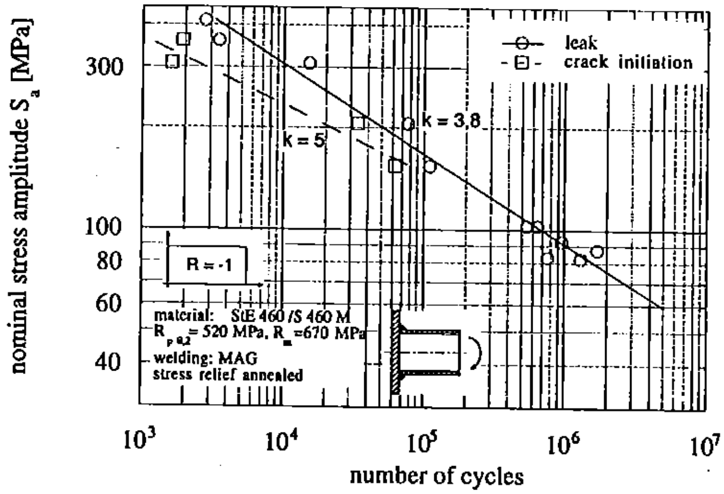


Fig. 8 S-N curve pure bending (seam 2)

At pure torsion the welded joint breaks at different locations. At high loads (205 MPa nominal shear/ 36.000 cycles) the crack looks like those at pure bending (Fig. 9). The crack initiation starts on the outer surface at the transition between tube and seam.

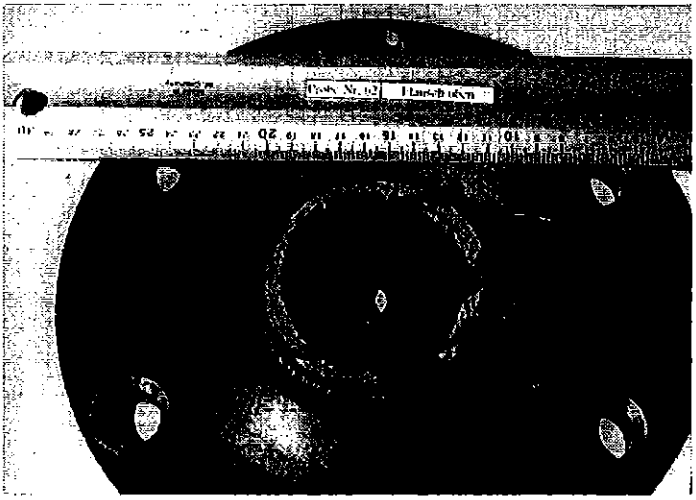


Fig. 9 flange pure torsion, high load (seam 2)

At a range of 150 MPa nominal shear there are two different kinds of cracks. Figure 10 shows a crack that looks similar to those described above.

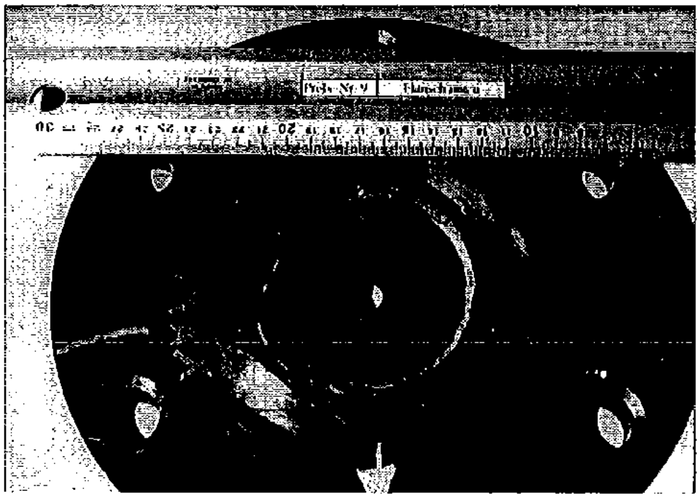


Fig. 10 flange pure torsion, medium load (seam 2)

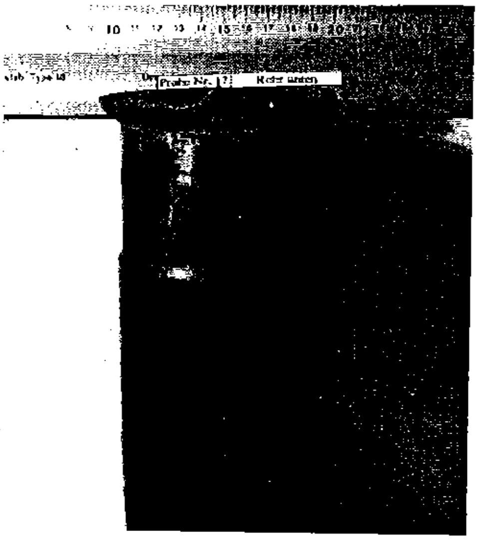


Fig. 11 flange pure torsion, medium load (seam 2)

ar the endurance limit cracks appear as shown in figure 12. The crack initiation st
the outer surface.

Fig. 12 flange pure torsion, medium load (seam 2)

The S-N curve for pure torsion is shown in figure 13.

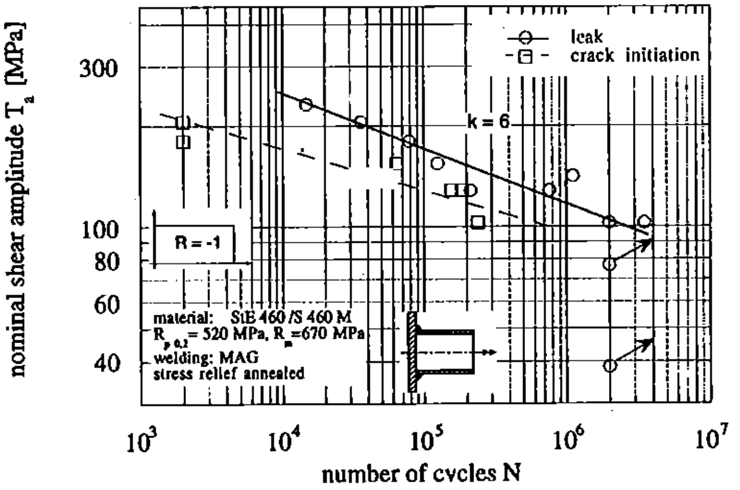


Fig. 13 S-N curve pure torsion (seam 2)

At bending and torsion in phase and out of phase the damage surface look very similar to those described at pure torsion, except for the fact that the cracks always start from the outer surface at the transition between the tube and the seam in the heat-affected zone (HAZ). The appearance of the crack is influenced by the height of the load (Fig. 14,15).

The S-N curves are shown in figure 16,17.

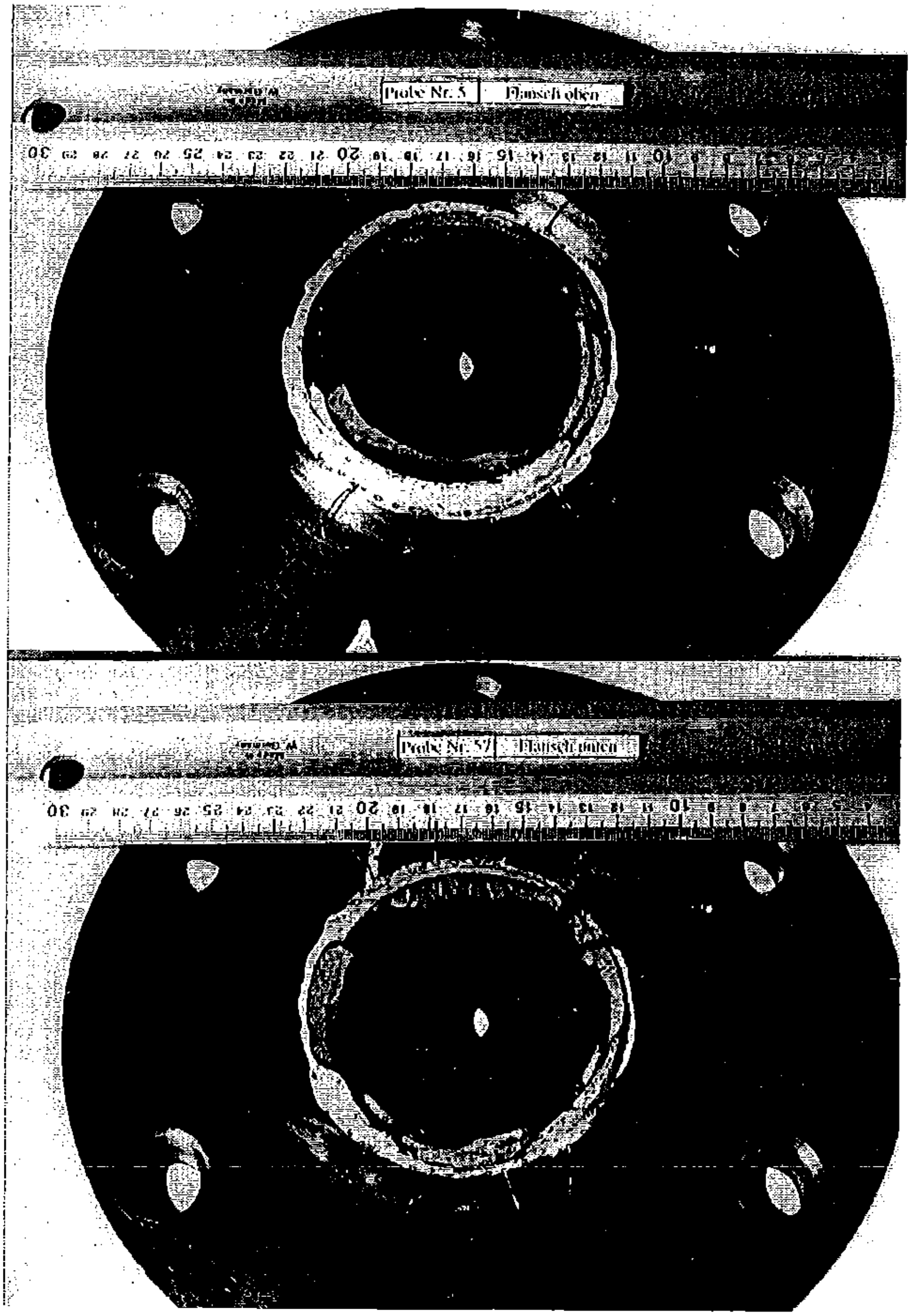


Fig. 14 top: flange bend/tors 0° phase, high load bottom: flange bend/tors 0° phase, low load

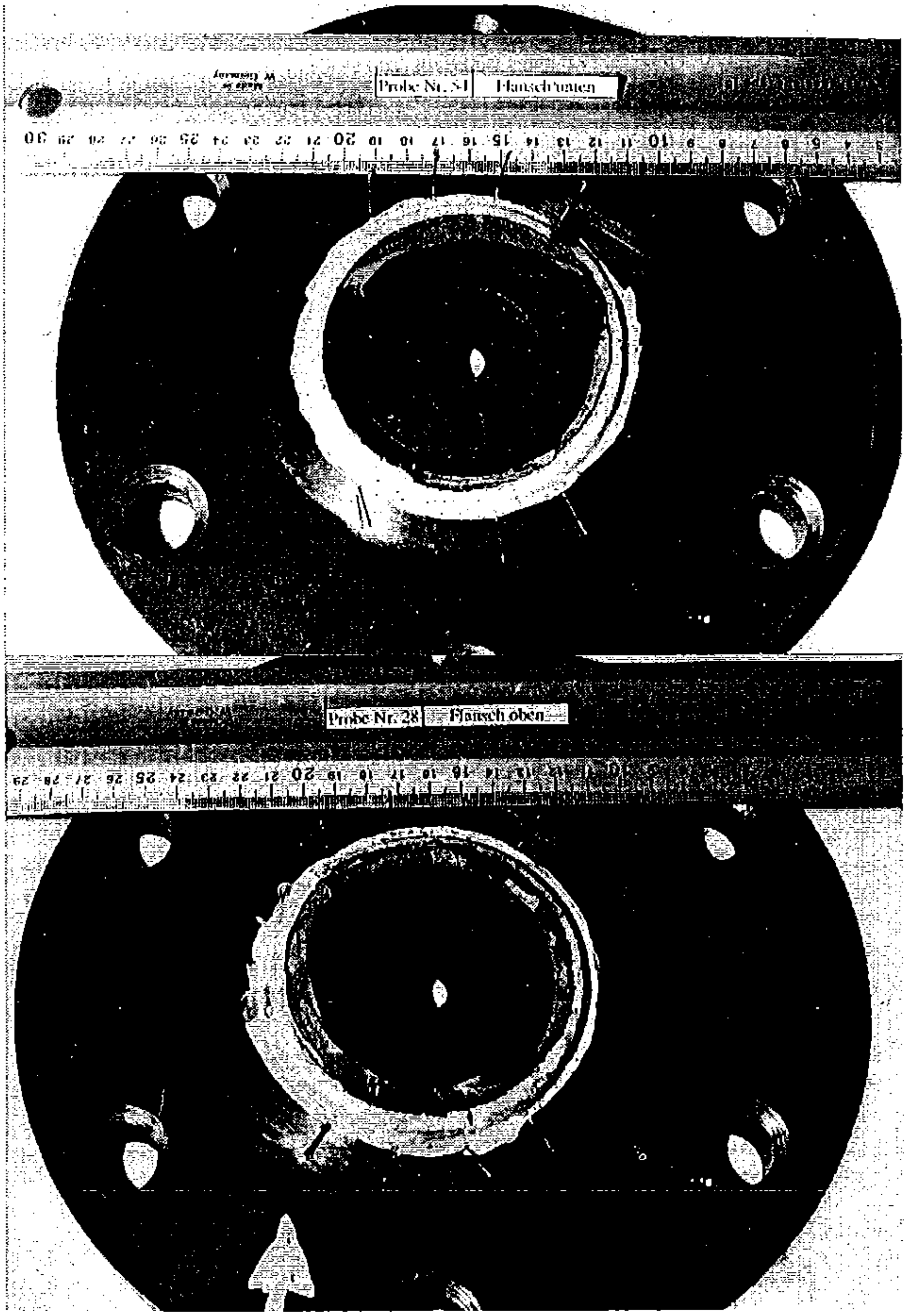


Fig. 15 top: flange bend/tors 90° phase, high load bottom: flange bend/tors 90° phase, low load

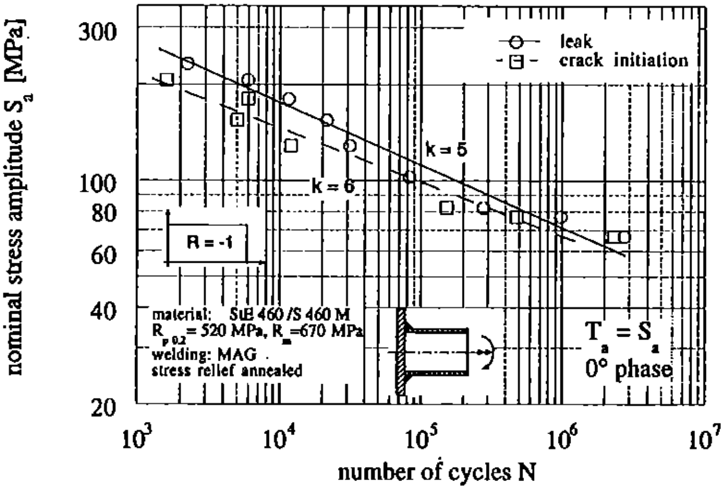


Fig. 16 S-N bending /torsion 0° phase (seam 2)

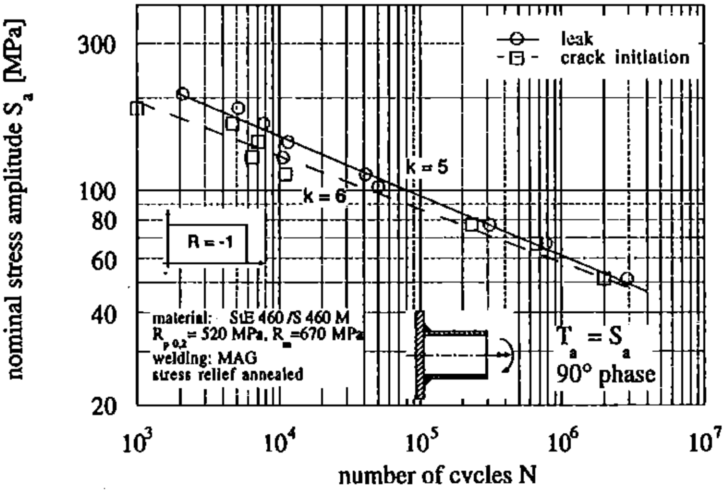


Fig. 17 S-N curve bending /torsion 90° phase (seam 2)

Lifetime prediction

The IMAB is developing software for lifetime prediction at multiaxial loading. The program has a clear structure and allows the use different concepts for fatigue life calculation. It is always possible to add a new calculation module or modify an existing one. Every step is documented and can be changed easily (Fig. 19).

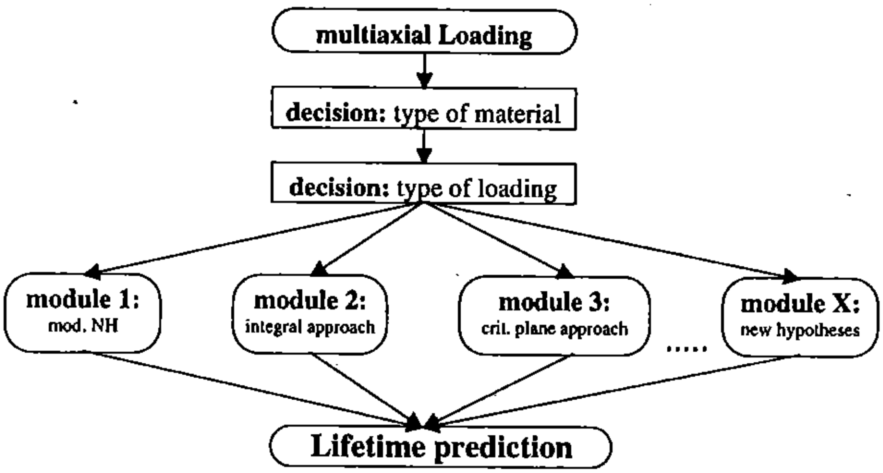


Fig. 19 structure of the program

The software allows lifetime calculation for two kinds of material as suggusted by Liu. The program distinguishes between:

- group A: ductile and defect-free
- group B: brittle or ductile and defective (micro cracks)

For each material group a different kind of strength hypotheses is used.

Following strength hypotheses shall be implemented:

- normal stresses hypotheses
- critical plane approach
- integrale approach

Up to now the module for brittle or ductile and defective materials is ready.

First tests are completed.

Prospects

The first part of the research program is completed. The results of seam 2 show some particularities (cracks from the root of the seam and zigzag cracks in the middle of the seam). The main part of the research program deals with a welded joint with seam preparation. A large field of parameters is covered. The AC potential probe is used successfully to detect safely crack initiation at the flange-tube connection with a depth of less then 0.5 mm.
At present, the tests with variable loading are under way.

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