Crack growth measurements in notches under cyclic internal pressure loading

Rayk Thumser[1*], Martin Schickert[1*], Susanne Kleemann[1*], Jörg Winge[1*] and Uwe Gerth[1*]

[1*] Institute of Materials Research and Testing at Bauhaus-University Weimar, Coudraystrasse 9, 99423 Weimar, Germany

ABSTRACT

Advanced life predictions in cyclically loaded components consider both crack initiation and crack propagation phase with its quite different damage mechanisms. In components under internal cyclic pressure loading the notches are located in the pressurized inside, so that crack initiation and crack propagation cannot be observed directly. Usually only the total life up to the leakage of the component can be determined. Due to the lack of experimental data for crack initiation and crack growth phases the corresponding life predictions cannot be validated separately. Therefore for components under internal cyclic pressure loading an experimental method has been developed for the separate determination of crack initiation life, crack shape development, crack opening pressure and crack growth life. The two-dimensional ultrasonic scanning method has been proven to be applicable. First experimental data are shown.

KEYWORDS crack growth measurements, internal pressure loading, two-dimensional ultrasonic scanning

INTRODUCTION

Pressures in cyclically loaded components are continuously rising, e.g. in Diesel injection parts. To meet these challenges life prediction methods were developed and verified by experiments with some hundred notched specimens [1-4]. There are only final fracture data available. The prediction methods always combine crack initiation and crack growth. Only the sum of crack initiation and crack growth lives could be compared to the experimental final fracture lives.

Today's requirements for fatigue strength can only be achieved by autofrettage or case hardening. In the autofrettage process a single internal pressure overload generates a compressive residual stress field in the notch leading to an increase of fatigue strength up to a factor of 3.5 [1]. The case hardening process also increases the fatigue strength considerably [2] and additionally improves the wear and cavitation pitting resistance.

CROSS BORE SAMPLES

A typical feature of an internal pressure loaded component is the intersection of two borings. For research purposes cross hole specimens were developed, as shown in table 1. This design is multi symmetric. The cross hole specimens are disks with perpendicular borings of 5 mm with different disk thicknesses. The thicknesses were designed in a way that the fatigue strengths of all three specimens are 2000 bar.

	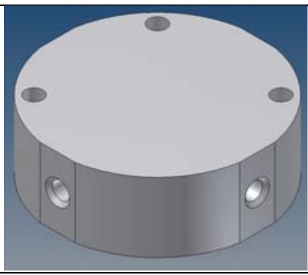	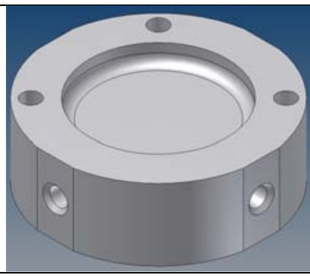	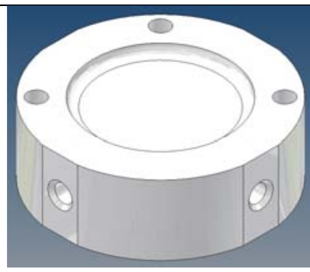
Material	42CrMo4 (1.7725)		18CrNiMo7-6 (1.6587)
	quenched and tempered		case hardened
Disk diameter	58 mm		
h/d	20 mm / 5 mm	10 mm / 5 mm	15 mm / 5 mm
Autofrettage	-	6000 bar	-

Table 1: Cross hole specimens

SIMULATION OF CRACK INITIATION AND CRACK GROWTH

The residual stresses due to autofrettage are determined regarding Bauschinger effect [5] by the aid of various plasticity models [6],[7], the residual stresses due to case hardening by a new model [8].

Crack initiation life is predicted by the aid of the Local Approach [9] taking into account residual stresses from Autofrettage and case hardening.

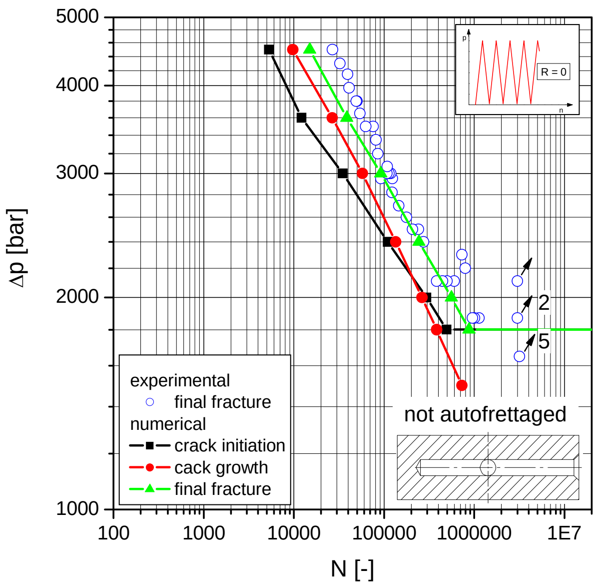

Fig. 1: Numerical and experimental results - not autofrettaged specimen

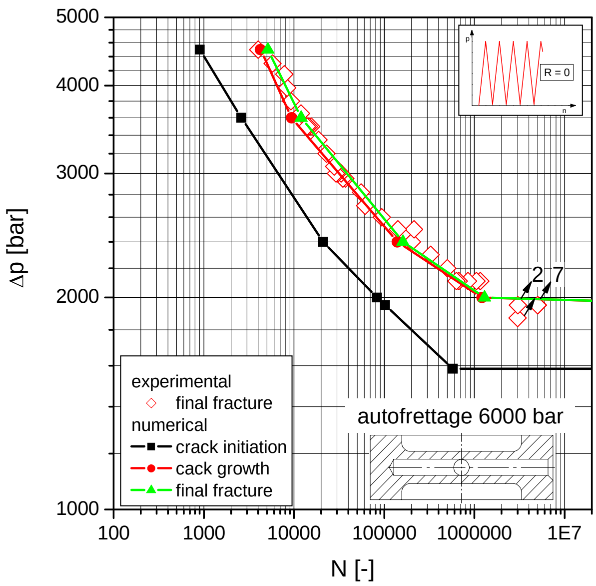

Fig. 2: Numerical and experimental results - specimen autofrettaged with 6000 bar

The crack propagation simulation is based on Linear Elastic Fracture Mechanics, using the following features:

- stress intensity factor (sif) evaluation with 2D weight function [10],[11] allowing free development of geometric crack front shape,

- crack opening behaviour with Ibrahim's et.al. formula [12] and
- crack propagation law with effective sif.

A more detailed description of the used model is given in [13].

For two specimens the predictions of crack initiation, crack growth and final fracture lives in comparison to the experimental final fracture lives are given in figures 1 and 2 for constant amplitude loading. In both cases the final fracture life can be predicted with good accuracy, the ratio crack initiation to crack growth life differs considerably for not autofrettaged and autofrettaged specimens. It can be concluded that the crack initiation life as well as the crack propagation life can apparently be predicted well, but it is not experimentally verified.

CRACK LENGTH MEASUREMENT

For the future development of crack initiation and crack propagation models the crack initiation and the crack propagation behaviour must be experimentally investigated in a detailed way, especially

- Crack initiation life,
- Crack shape development,
- Crack opening pressure and
- Crack growth life.

For the experimental measurement of this behaviour the ultrasonic scanning method has been selected. For each measurement the specimen has to be removed from the internal pressure fatigue test rig to avoid vibrations on ultrasonic measurement equipment. In the internal pressure fatigue test rig several specimens can be tested simultaneously. The test run needs to be interrupted only for a short period of time to remove and mount again a specimen. The specimens can then be scanned with ultrasonic one by one without any delay on the fatigue test.

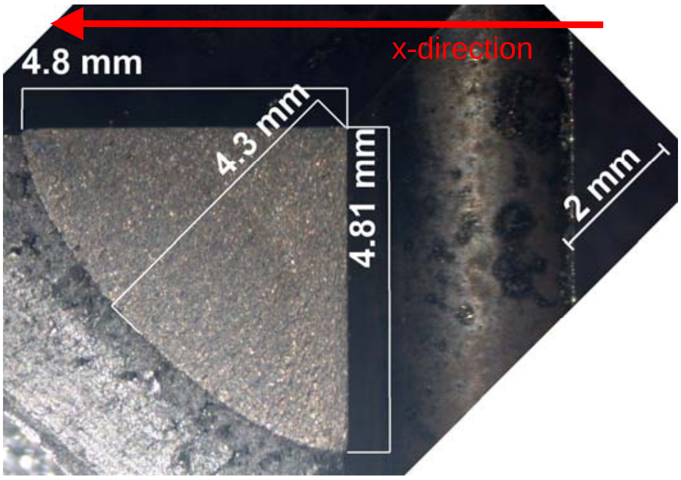

Fig. 3: Fractography and scanning path

A first feasibility study with an available ultrasonic scanning system was performed. A cross hole specimen was subjected to cyclic internal pressure until a certain crack depth was reached. The respective number of cycles was estimated by the above mentioned prediction methods. The removed specimen was manually displaced step by step under the ultrasonic transceiver along the x-axis, fig. 3. The measurement was carried out twice, firstly without internal pressure and secondly under static internal pressure of 500 bar. The two B-scan images are shown in figs. 4 and 5. Measured crack lengths were 4.9 mm and 5.4 mm respectively. Afterwards the specimen was broken up and the crack was measured by Fractography to 4.8 mm. The comparison of the measured crack lengths indicates that the ultrasonic measurement is appropriate. These quantifications have to be calibrated. The influence of a static internal pressure is probably due to crack closure phenomena and has to be investigated.

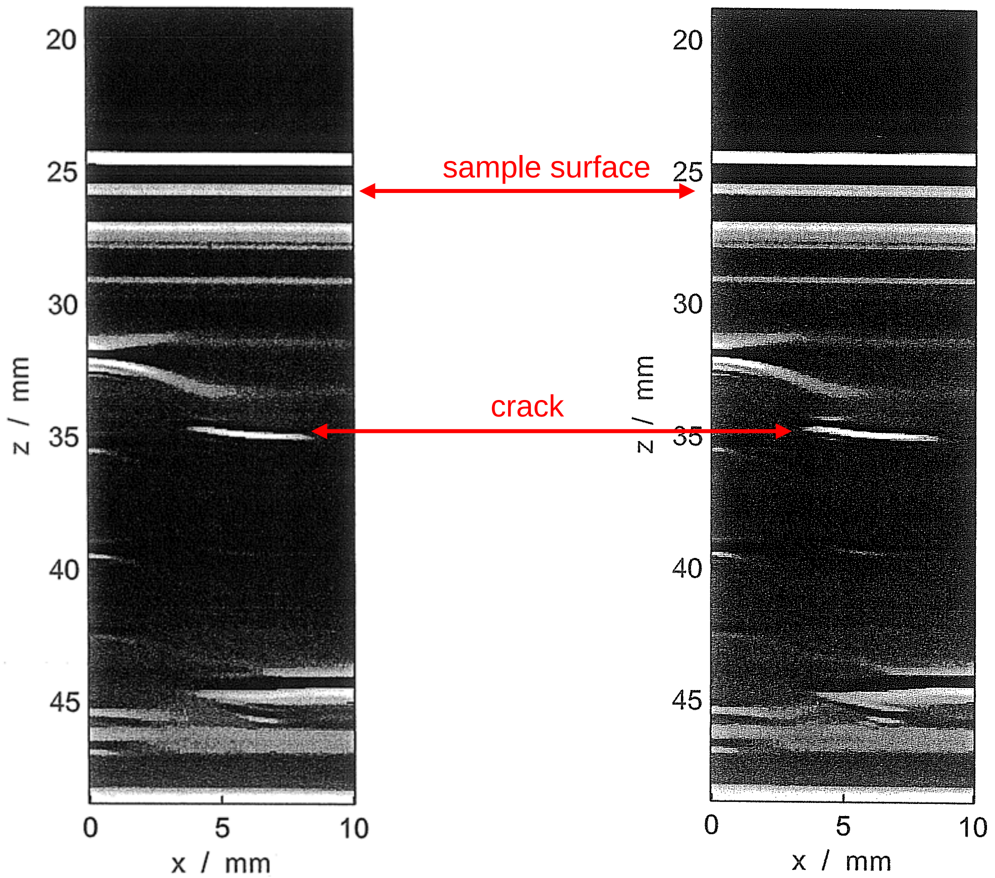

Fig. 4: B-scan image - without internal pressure

Fig. 4: B-scan image - with internal pressure of 500 bar

A new 3-axes step controlled scanning system was acquired and is to be built up. With this equipment the transceiver can be dipped into the coupling medium (z-direction) on the top of the sample and moved in xy-plane to reach the whole sample. The software for automatic control and subsequent evaluation is under development.

SUMMARY

The crack initiation and crack growth behavior in components under cyclic internal pressure cannot be observed optically. Therefore an ultrasonic test system is used to determine crack initiation life, crack shape development, crack opening pressure and crack growth life. This information is a prerequisite for a better understanding of the fatigue behaviour and the further development of fatigue life prediction methods in the field of high pressure components. The feasibility has been proven. A full automatic scanning procedure and a subsequent image processing are under development.

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Corresponding author: rayk.thumser@mfpa.de