# INVESTIGATIONS IN FRACTURE MECHANICS BY MOIRÉ TECHNIQUE

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The geometric moiré and the moiré fringe multiplication are applied to investigate fracture mechanical problems in the case of elastic–plastic as well as full plastic material behaviour. The experiments are carried out at SENB–specimens made of ductile steel and cast iron. Analysing the experimental displacement fields the COD curves measured directly along the crack flanks and the distribution of strain components are determined and discussed.

## INTRODUCTION

The in–plane moiré technique (1) is a suitable method to investigate fundamental problems of the behaviour of fracture mechanical specimens in the vicinity of the crack tip (2–4). Using metallic materials the experiments are limited to the surface. However, the displacement field is influenced by the three–dimensional state of stress in the interior of the specimen. Only transparent materials such as epoxy resin allow measurements in the interior. All experiments and evaluations are realized from the point of view of mechanics of continua.

The moiré techniques can be divided in the geometric moiré and the interferometric moiré methods.

The *geometric moiré* is based on the superposition of two amplitude gratings – the deformed object grating and the reference grating. The preparation of the object grating by a transfer grid method is shown in Figure 1. By using gratings with identical orientation and pitch $p$ each moiré fringe – the so–called

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isothetic – represents the geometrical location of all points with the same cartesian displacement component. Taking the fringe order $m_i$ into account the in-plane component $u_i$ of the displacement vector can be calculated by

$$u_i = p\, m_i \qquad\qquad i = 1, 2. \tag{1}$$

The relatively low sensitivity permits especially the measurement of the deformation field in the full plastic region.

The interferometric methods are subdivided in the moiré interferometry (5) and the *moiré fringe multiplication* (1), respectively. Their sensitivity is comparable with that of laser methods like the holographic interferometry as well as the speckle metrology. For that reason, the moiré fringe multiplication is used to analyse precracked specimens under both the elastic and the elastic–plastic material behaviour. Thereby, a high–precision phase grating is prepared by a special replica technique on the object, Figure 1. Advantages of the moiré fringe multiplication are the application of a real reference grating and the variable fringe density as a function of the multiplication factor.

## GEOMETRIC MOIRÉ

### Experimental technique

A four point bending specimen made of spheroidal graphite cast iron $GGG\,40$ (2) is investigated in reflected light. The specimen geometry corresponds to ASTM E399–83 by the following parameters: $W = 20\,mm$, $B = 10\,mm$, $S = 80\,mm$, spacing of the load lines $S_{F/2} = 40\,mm$, $a_0 = 12.61\,mm$.

The optical set up required is thoroughly discussed in (1). According to the above–mentioned technique an indium cross grating with a pitch $p = 20\,\mu m$ is appliquéd in a soft epoxy resin. The specimen was loaded deformation controlled.

### Results

Figure 3 shows the isothetic field $u_2$ in longitudinal direction of the specimen. The density of the isothetics in the vicinity of the crack tip is caused by the large plastic deformations. In that area a partial separation of the graphite particles from the ferritic matrix can be observed which leads to a distributed microcracking as well as a local destruction of the object grating. Consequently, the fringes have a lower contrast and become "rough".

In Figure 4 the curves of the strain component $\epsilon_{22}$ derived from the measured displacement component $u_2$ are characterized by both the decrease of the strain values in direction of the ligament and local strain minima and maxima symmetrically to the $x_2$–axis. For the choosen load level the strain maxima of nearly 16 % – the elongation after fracture measured uniaxially is in the range of $A = 26\,\%$ – are obtained in a distance of $x_1 = 0.19\,mm$ from the crack tip.

## MOIRÉ FRINGE MULTIPLICATION

### Experimental technique

The elastic–plastic deformation behaviour of short cracks was evaluated at three point bending specimens made of ductile steel $X6\,CrNiTi\,1810$. The general geometrical parameters are the same like cast iron but for $a_0 = 8.75\,mm$ the fatigue crack is only $0.75\,mm$ long.

To enable the fringe multiplication a thin silicone rubber cross grating with a pitch of $p = 20\,\mu m$ is appliquéd. At each load level the deformed object grating is replicaded in order to obtain a phase grating for the optically spatial frequency filtering, Figure 2. Therefore, the combination of deformed object and reference grating in contact is placed in parallel light. The required multiplication factor $r$ can be selected in the plane of the discrete diffraction spectrum. Then the effective pitch $p_{eff}$ is a result of $p_{eff} = p/r$.

### Results

Due to the comparable small deformation a multiplication factor $r = 8$ has to be realized for generating a fringe density which can be analysed, Figure 5. In that case, the crack opening displacement is directly measured along one flank owing to the good symmetry, Figure 6. The crack blunting is determined as a function of the applied load.

## REFERENCES


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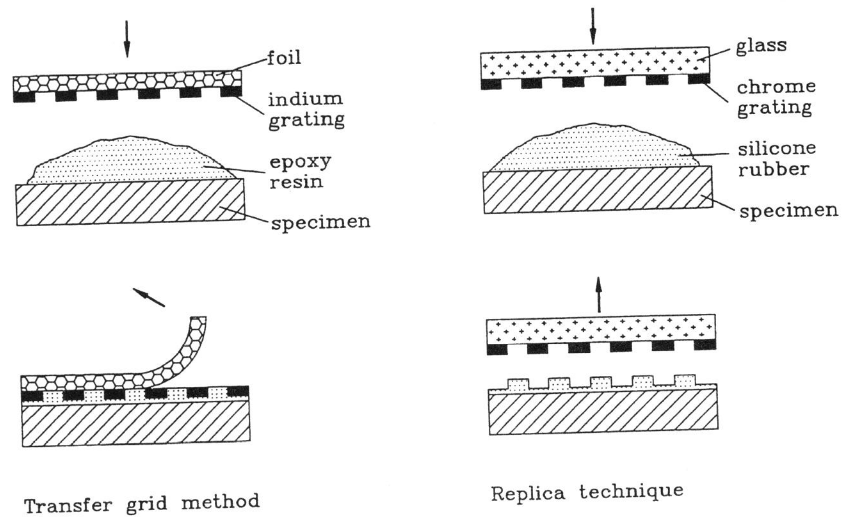


Figure 1 Experimental moiré techniques

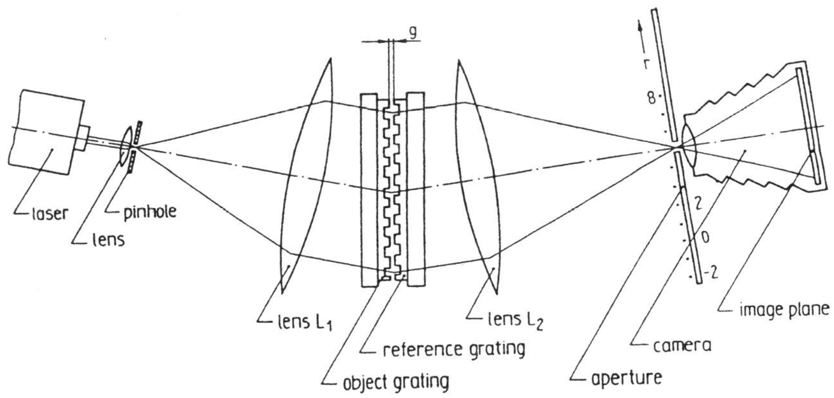


Figure 2 Optical arrangement for the moiré fringe multiplication in transmitted light

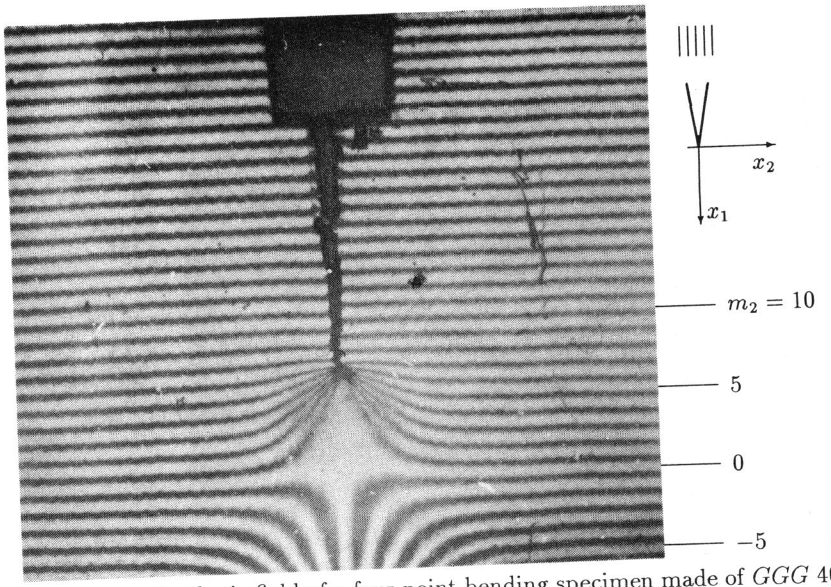


Figure 3 $u_2$–isothetic field of a four point bending specimen made of $GGG$ 40 (pitch: $p = 20\,\mu m$, deflection: $u_d = 1.22\,mm$, load: $M_b = 38.02\,Nm$)

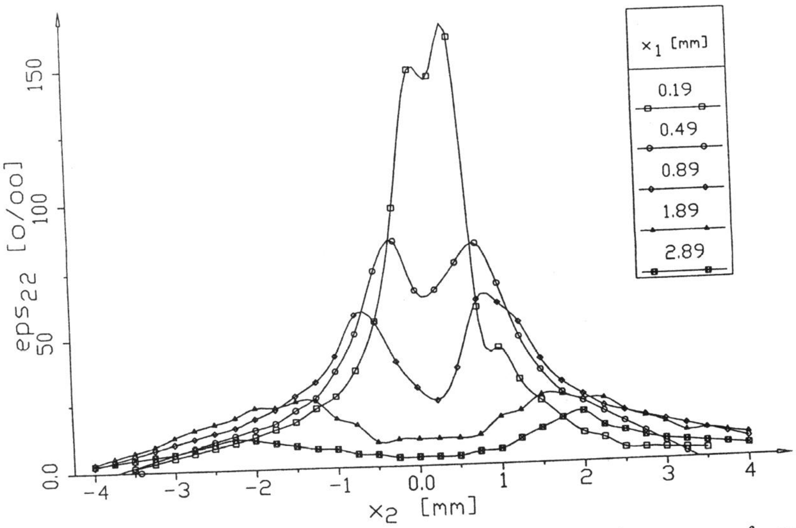


Figure 4 Strain distribution $\epsilon_{22}(x_2)$ determined in discrete distances $x_1$ from the crack tip

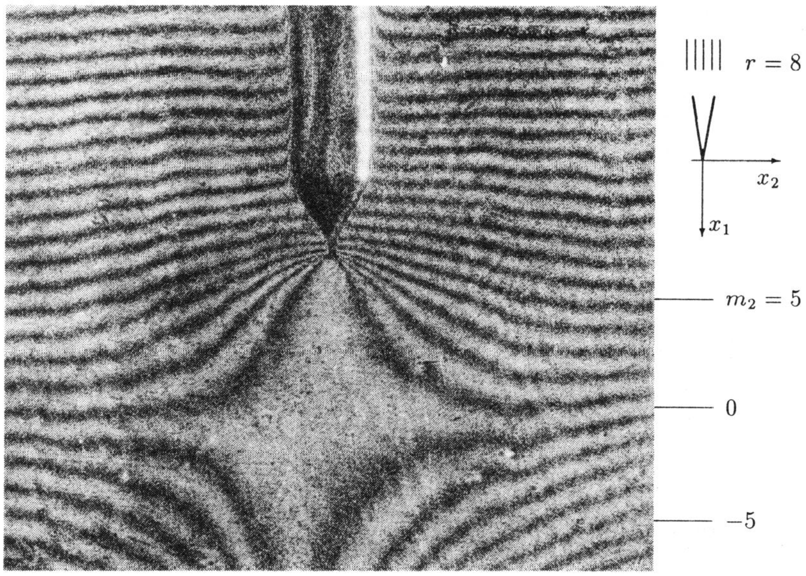


Figure 5 $u_2$–isothetic field of a three point bending specimen made of $X6\,CrNiTi\,1810$ (effective pitch: $p_{eff} = 2.5\,\mu m$, load: $F = 5287\,N$,)

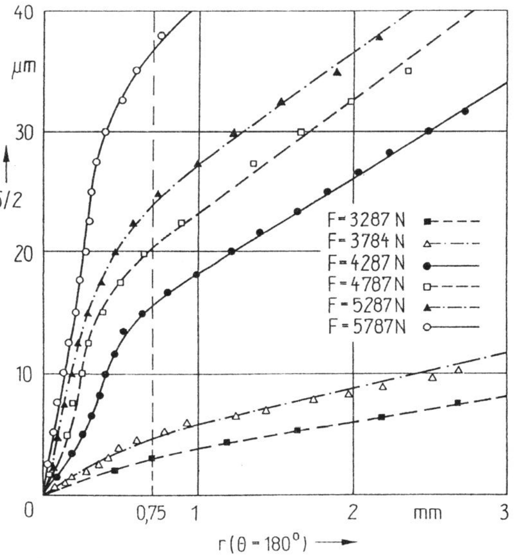


Figure 6 Measured COD along a crack flank for a short fatigue crack as a function of the applied load