# CRACK-TIP STRAIN DISTRIBUTION MEASUREMENT IN DUCTILE MATERIAL FROM OPTICAL GRATING RECORDING ON A WHOLE FIELD

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We present an optical measurement method which allows a direct determination of the strain tensor components on a whole field from the interrogation of a crossed grating. We describe the recording device which associates the diffraction phenomenon of a laser beam and a holographic process to collect the experimental data. The restituted diffracted beams are analyzed using a phase-shifting procedure in order to improve the strain sensitivity of the method. This non-contact measurement method is applied for the determination of the strain distribution around a crack-tip on a ductile alloy loaded in an opening mode. This distribution optically obtained is compared to this issued from the classical H.R.R. formulation.

## INTRODUCTION

The optical strain determination on a full-field at the surface of a body utilizes in most cases indirect methods, like moiré interferometry, speckle or holography. The strains are then obtained from the derivation of the measured displacements. Few techniques are direct measurement methods. Let us mention the spectral analysis of a crossed grating (Sevenhuijsen (1) and Brémand et al (2)) which allows the direct determination of the components of the strain tensor, but which is yet restricted to the local measurement. The comparison of the geometry (pitch and orientation) of the grating in the deformed state with the initial one gives the magnitude and the orientation of the principal strains as well as the rigid body rotation. The grating interrogation is achieved by two ways using Fourier transform (optical or numerical procedure).

Our purpose is to extend this powerful method for the strain determination on a whole - field. We describe first the experimental apparatus for the recording

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of optical data. This device uses diffraction phenomenon and holographic process. The analysis of recorded informations utilizes a phase shifting technique to determine with accuracy the grating geometry.The developed measurement method is applied to obtain the strain distribution around a crack-tip on a ductile material.

## MEASUREMENT METHOD

The analysis of a grating to obtain the strains at the surface of a body assumes (2) that the strains are homogeneous on the measurement base. This hypothesis involves the use of high density gratings. The recording of such gratings on a whole field is impossible with the help of a C.C.D. camera because of the insufficient resolution of these equipments. The recording on a film exhibiting a high resolution is very sensible to out of plane displacement which occurs experimental difficulties. We present the recording technique we have developed and the procedure to analyze the experimental data.

### Recording device

In order to collect the experimental informations, we associate the diffraction phenomenon of a laser beam by the grating with a holographic recording process (Wang et al (3)). The crossed grating is illuminated by a expanded collimated beam under a normal incidence in a optical device (Figure 1) which realizes a double optical Fourier transform. In the first plane of Fourier, the optical figure is constituted with the diffracted orders +1 and -1 and with the reflected order. In the second plane of Fourier, the diffracted beams act as the object beam and are recorded on a holographic plate with the help of a reference beam. We record so, on the same plate, the states of the object corresponding to different steps of loading by using different orientations of the reference beam.

### Analysis device

Utilizing the wave front reconstruction processing, we can restitute the diffracted beams. The reference beam is used to reproduce the object wave.The reconstruction device (Figure 2) is chosen similar to the recording one and realizes in the second plane of Fourier the interferences of the reconstructed beams. The interferences field is significant to the diffracting one (same orientation and density two times the original one). The determination of these geometrical parameters and the comparison with those corresponding to the initial state give, point by point, the strain components and the rigid body rotation for each step of load.

The acquisition of the experimental data (i.e. the interference patterns) is realized with the help of a C.C.D. camera with an objective of microscope. The analysis can be achieved using a numerical Fourier transform (1). In order to improve this sensitivity in the strain determination, we apply a phase-shifting technique (Dupré et al (4)) by varying the phase of one of the two reconstructed beams which interfere. These shifts are obtained by placing a Bravais compensator at the first Fourier plane in the reconstruction device. With the help of three shifts, the strain sensitivity of the method reaches $0.8 \times 10^{-4}$. The spatial resolution of the measurement method depends on the density of the interference patterns (some ten fringes are sufficient for the analysis) and can be adapted to the investigated problem.

## APPLICATION TO DUCTILE FRACTURE

For a power low strain hardening material, the amplitude of the_singularity fields is given by the path independent J integral. The asymptotic crack-tip strain field is then obtained (Rice and Rosengren (5)) by the knowledge of the material constants and by the determination of the J integral. This field is compared to the strain distribution optically measured by the developed method on a single edge crack specimen of aluminium alloy Al 2017.

### Determination of the material constants

A non cracked specimen is loaded under uniaxial tension in order to determine the stress-strain curve of the material. This curve is obtained from the local interrogation of a crossed grating stamped at the surface of the specimen. The uniaxial stress-strain curve is modeled by the Ramberg-Osgood relation to determine the Young's modulus E, the Poisson's ratio $\nu$, the yield stress $\sigma_0$, the material constant $\alpha$ and the hardening exponent n (Wang et al (6)).

### Determination of the J integral

On the cracked specimen, we have reproduced a high density crossed grating (100 lines/mm) using the duplication process employed for moiré interferometry. The J integral evaluation requires the stress and the strain components knowledge. The strain tensor components are determined point by point from the grating interrogation on a whole-field. The stress components are calculated from the inverted form of the $J_2$ deformation theory. The J evaluation is realized on rectangular contours (Figure 3) surrounding the crack-tip. We find (6) that the J integral is path independent during a stable crack growth up to 0.1 mm under an opening mode loading.

### Strain distribution

The strain tensor components are determined from the proposed grating interrogation method point by point on a measurement base of small size ($0{,}15 \times 0.15$ mm$^2$). The strain distribution so obtained is compared (Wang (7)) in few angular directions from the crack tip with the distribution issued from the

H.R.R. formulation. According to these angular directions and/or to the strain components these comparisons show (Figure 4) significant differences between measurement and H.R.R. field. Similar observations have been obtained (Dadkhah and Kobayashi (8)) for the same kind of test from displacement measurements using moiré interferometry.

## CONCLUSION

Grating methods are resurging due to advances in techniques of processing the information. We propose a whole field measurement method which allows the direct strain determination from the crossed grating interrogation. This non-contact and non-disturbing metrology couples the holographic recording of diffracted beams and the analysis by quasi-heterodyne procedure of experimental data. This optical method provides a good strain sensitivity on a limited measurement area. Ductile fracture is investigated using this measurement method. This experimental way could be an efficient tool to help in the proposition of a more suitable formulation to describe the mechanical state around the crack.

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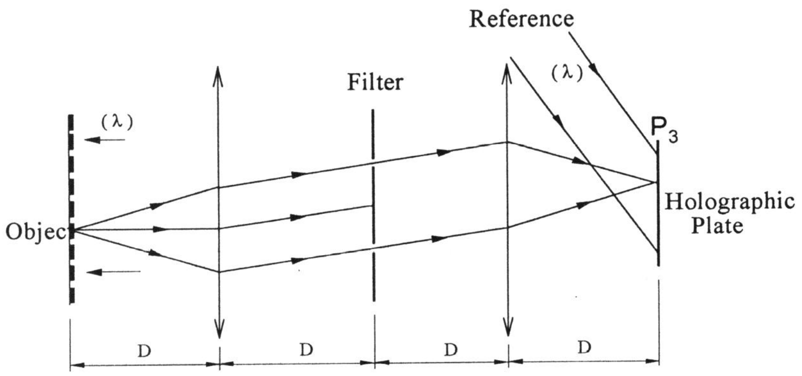


Figure 1 Optical recording device

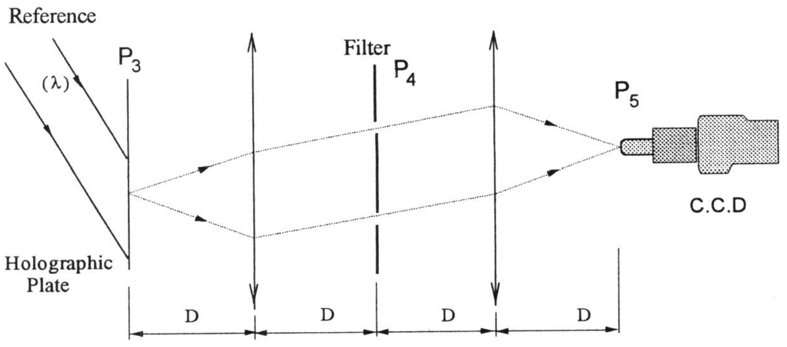


Figure 2 Optical analysis device

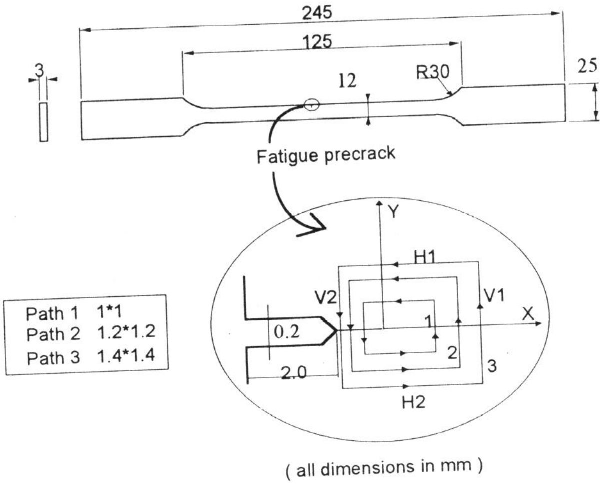
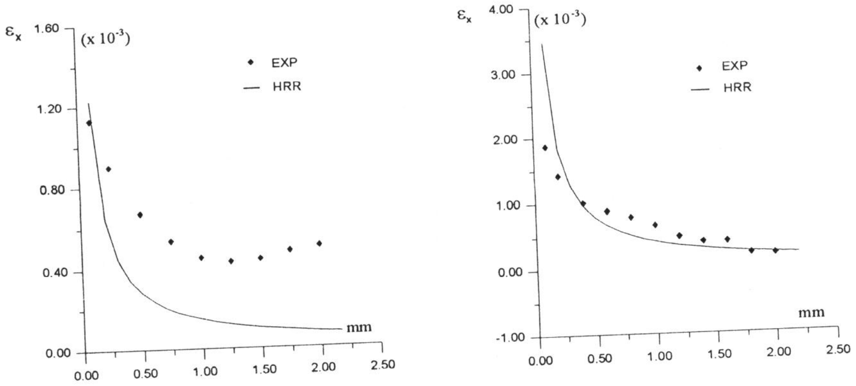


Figure 3 Geometry of the specimen



(b)

(a)

Figure 4 Comparison of $\varepsilon_x$ distributions ( in crack direction (a), in direction normal to the crack (b))