SPECKLE PHOTOGRAPHIC STRAIN FIELD MEASUREMENTS - A HELPFUL AID IN FRACTURE MODELLING AND ANALYSIS OF MICROSTRUCTURES

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Speckle photographic contactfree strain field measurement on crack specimen surfaces has been used to support numerical modelling of fracture and fatigue processes.

Digital image processing facilities for displacement and strain extraction from specklegrams are described briefly. Two basically different approaches are reported and compared with each other.

Measurement examples for static and dynamic load conditions are represented.

INTRODUCTION

Advanced modelling of fracture and fatigue processes demands in addition to appropriate mechanical approaches and FE simulation tools also experimental means for theory verification. One group of powerful methods makes use of the unique natural or an artificial surface structure of specimens in order to study spatially resolved object deformation (see Dadkhah et al (1)). In speckle photography artificial surface structure is produced by coherent object illumination. Comparison of the so caused speckle pattern between an object reference state and a deformed state of interest results in the surface displacement field (e.g. Vogel et al (2)).

SPECKLE PHOTOGRAPHIC DISPLACEMENT AND STRAIN MEASUREMENTS

Spatially resolved displacement extraction from moved speckle pattern is accomplished in two different ways. In the first case the speckled object is photo-

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graphed on high resolution photo material. A classical speckle photographic point-by-point laser scanning of the specklegram is used to find displacement values. In the second case different object states with the speckle noise over the object surface are snapped directly in a frame grabber by a CCD-camera. Subsequent local cross correlation analysis of picked up images results in the speckle pattern, i.e. object displacement field.

Read-out of specklegrams by laser scanning

In-plane displacement components for a specklegram image point illuminated by a narrow laser beam are obtained from the far field halo intensity captured by a screen (see fig. 1). The halo intensity

$$I(x,y) = I_o \cdot I_{Sp}(x,y) \cdot I_H(\sqrt{x^2+y^2}) \cdot \cos^2\left[\pi \frac{M}{F\lambda}(u_x x + u_y y)\right] \qquad (1)$$

is modulated by the so called Young's fringes, which spatial frequencies $Mu_x/F\lambda$ and $Mu_y/F\lambda$ are directly proportional to the displacement components u_x and u_y between the recorded states of the double exposure specklegram. A sophisticated image processing algorithm has been implemented on a PC-AT host computer with a simple OFG frame grabber board to evaluate u_x and u_y from the rather complex Young's fringes. It has been described in more detail by Vogel and Kaulfersch (3). The two-directional specklegram scanning is carried out completely automatically within an equidistant data grid. A cubic spline smoothing of the displacement field results additionally in in-plane strain and shear values of the surface area under investigation.

Interfaces to graphic programs (pseudo-3D-plots, isoline-maps, vector-plot images), to FE postprocessors and to special software (i.e. for J-integral evaluation from in-plane displacement values) allow to use the experimental data in an efficient way. During software development special effort has made to tackle displacement fields typically for near crack tip regions characterised by rapidly changing displacement gradients and displacement discontinuities.

Cross correlation analysis of speckle pattern

A more recently established software allows the determination of displacement fields from single shot specklegrams. Local displacement values are obtained from the location of the cross correlation function maximum for small object areas. The algorithm includes subpixel analysis and is set up for an equidistant point grid. It seems to be favourable especially to small scale objects, e.g. to microstructural investigations, where the measurement resolution is sufficient. Nevertheless, the algorithm needs further improvement regarding the subpixel measurement and it has more potential of measurement rapidity, than achieved recently.

Measurement capabilities

Some of the measurement capabilities of the reported methods are summarised in the following table:

TABLE 1 - Speckle photographic measurement capabilities

	Young's fringes analysis	Cross correlation algorithm
Measurement accuracy	0.2 µm/M M = 0.5 ... 5.0	d/10^4 maximum ≈ 50 nm
Lateral spatial resolution	500 µm/M	d/10^2 maximum ≈ 5µm
Evaluation speed (66 MHz CPU)	maximum 1s/point	strongly depends on search radius, 1/10 s possible

STRAIN FIELD MEASUREMENTS ON CRACK SPECIMENS

Crack opening process on high ductile steels

Crack opening of high ductile materials can be connected with a close interaction between thermal and mechanical strain/stress fields, if only the crack opening is realised fast enough. So significant temperature rise occurs because of the energy dissipation in the crack tip region. On the other hand, a strong temperature feedback influences the mechanical stress state. Fracture mechanics studies of that materials must include coupled field approaches. Owing to such complex behaviour experimental verification of numerical results is desirable.

The example of a measured incremental strain field in a 10 mm by 10 mm area around the crack tip of a stressed X2CrNi1911 steel is shown in fig. 3. Strain values have an accuracy of $1 \cdot 10^{-4}$. A slightly asymmetric crack opening of the CT-specimen can be recognised. The demonstrated data presentation is carried out with the help of FE post processing tools (APOSTL), making sure an appropriate comparison between experiment and theory.

Fracture mechanics investigations in a Hopkinson equipment

The use of pulsed lasers for specklegram registration permits to freeze particular states of the interaction of running stress pulses and cracks. If the first exposure is taken without stress pulse, then the momentary dynamic stress state can be determined. Measurements on steel and ceramics have been aimed at

- the comparison between numerical and experimental results
- the control of the pulse coupling conditions from the Hopkinson bar into the test specimen
- the determination of the strain filed around the crack tip and the calculation of the crack parameters from the strain field.

Fig. 2 illustrates the strain behaviour of a rectangular unnotched Al_2O_3 ceramic specimen with a dynamic three-point-bending load, coupled in by a bridge-like distance piece. The presented shear field shows, that the load is performed nearly symmetrically, i.e. on the line, where the future crack notch will be placed to, the shear equals roughly zero, so that a mode-I crack opening in the crack occurs.

The financial support from the Deutsche Forschungsgemeinschaft is gratefully acknowledged.

SYMBOLS USED

u_i = in-plane displacement values (m)

x, y = screen co-ordinates of Young's halo fringes (m)

M = magnification factor for specklegram recording

F = distance: halo screen - specklegram (m)

λ = laser wave length (m)

I_H = main halo intensity of Young's fringes

I_{Sp} = secondary speckle noise in Young's fringes halo

d = image size captured by the camera-chip for correlation analysis (m)

REFERENCES

(1) Dadkhah M.S. et al, Proc. of SPIE, Vol. 1554A, 1991, pp.164-175

(2) Vogel D. et al, Proc. of SPIE, Vol. 1554A, 1991, pp. 262-274

(3) Vogel D. and Kaulfersch E., Jahrbuch Laser, 3rd ed., edited by H.Kohler, Vulkan-Verlag, Essen, in print

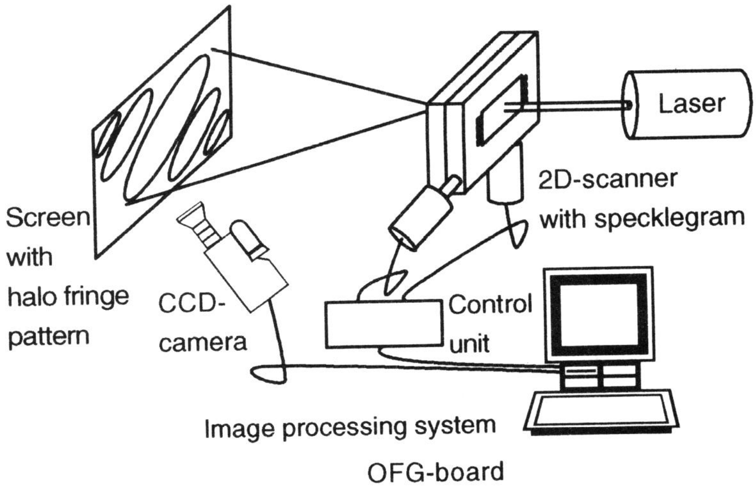

Figure 1 Displacement evaluation by specklegram scanning

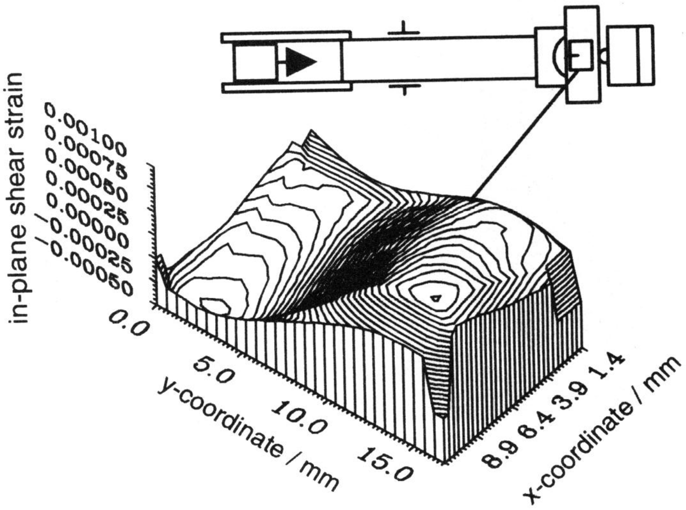

Figure 2 Shear strain field for an unnotched specimen under dynamic load in a Hopkinson equipment

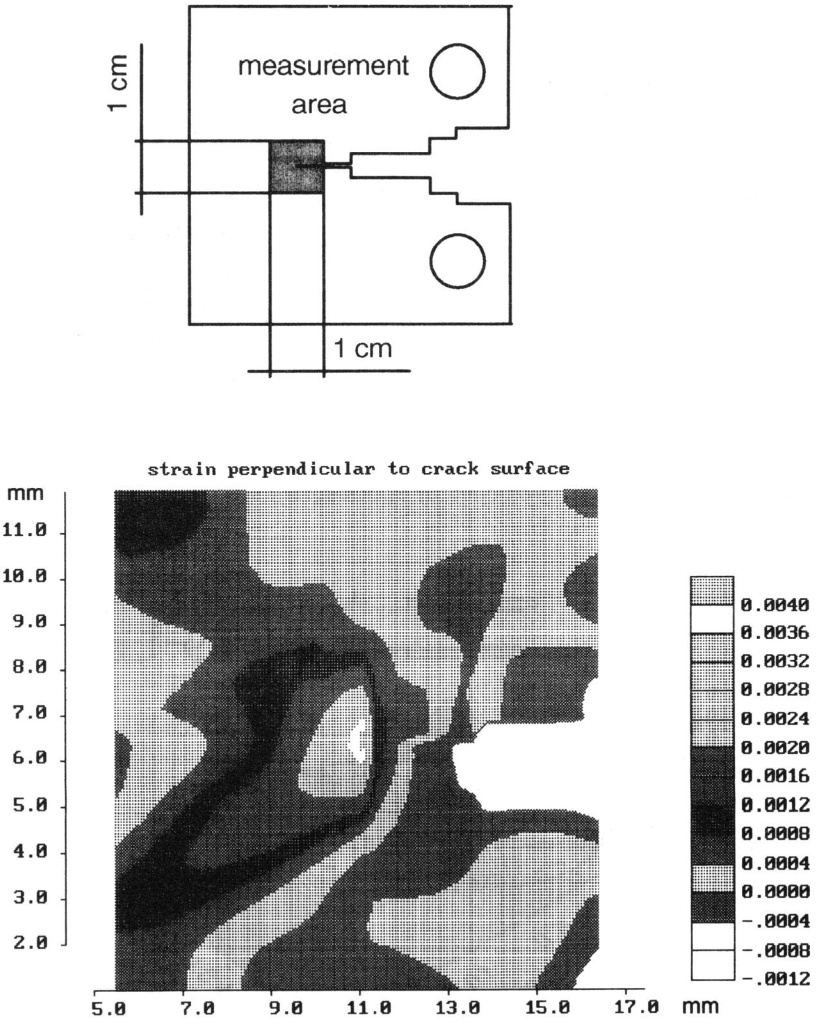

Figure 3 Measurement area and resultant strain field on a loaded CT specimen of X2CrNi1911