Evaluation of Fracture Concepts by Means of Micro Moire Method and Laser Interferometry

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ABSTRACT

A new hybrid method is described which allowes to obtain fracture quantities such as generalized J integral by means of scanning electron microscopy using the micro moire effect. A similar approach has been applied for the evaluation of fracture quantities by means of laser interferometry. A three-dimensional analysis for obtaining generalized integral fracture terms is presented which is based on holographic as well as speckle metrology.

KEYWORDS

Scanning micro moire method; J-integral; holographic fracture test; electron microscopic J testing; hybrid fracture models.

INTRODUCTION

A new hybrid method is presented to obtain fracture mechanical quantities such as conventional and generalized integral parameters or energetic quantities within the region surrounding the crack tip using a scanning electron microscope in connection with a modern image processing unit (Kuehnert and Michel, 1985, Kuehnert et al., 1987, Michel et al., 1987a, Michel et al., 1987b). The path-independency of fracture parameters (such as generalized J etc.) in real materials has been dealt with as a special case of application. Other criteria (Sih, Watanabe, Ouyang etc. (Michel and Will, 1986a)) also will be considered. The method is based on a combined model taking into account a more precise experimental determination of deformation field quantities in the microscope around the crack tip as well as special calculation methods based on fracture theory. A similar approach has been used applying laser interferometric technique (Will, 1987, Michel and Will 1986b).

Here a three-dimensional analysis will be presented which leads to a quantitative method for evaluation of fracture parameters through application of holographic and speckle interferometry combined with numerical analysis of deformation fields around cracks.

CRACK TIP DEFORMATION ANALYSIS BY MEANS OF MICRO MOIRE METHOD

The operating mode of a scanning electron microscope (SEM) permits the generation of displacement or topography-caused moire interference patterns if suitable imaging parameters have been choosen (Kuehnert and Michel, 1985, Robinson, 1981, Gold-stein, 1981).

By satisfying special conditions in the process of image forma-tion a quantitative evaluation of these patterns is possible with a sufficient accuracy for the application introduced. The use of image processing computer hardware combined with an appropriate handling of image generation enables a widely auto-matic operating pattern recognition and processing (Durelli and Parks, 1970, Kuehnert *et al.*, 1987).

Preparation.

For the test CT-specimens with W=20mm and different thickness values orientated on ASTM-standard E813 have been employed. By means of lithographic techniques the surface in the notched region has to be structured by an orthogonal crossed line grid mask with spacings of about 2.E-03...E-02mm. After preparation these specimens have to be positioned in the secondary or backscattered electron contrast with magnifications of about 100x...1000x.

Pattern Formation.

The discrete distribution of surface positions where the prima-ry probe ejects secondary (or backscattered) electrons realizes the superposition of an active and a reference structure, if suitable magnifications and scanning frequencies have been used. This leads to an intensity distribution on the detector which generates a moire interference pattern on the SEM-CRT. In its positiondependent spatial frequency such a pattern con-tains the information about the relative displacement of the superimposed structures as it is well-known from classical moire analysis. So this technique first of all can be used to record the plane displacement components of every choosen ana-lysing increment as interference pattern. For on-line proces-sing the CRT-signal has to be digitized and stored in the image memory of the processing system.

Pattern Recoginition and Processing

The first task of pattern processing is the superposition of the components of every analysing step to generate a so-called second order moire pattern if this has not yet happened by a special primary probe or digitizing regime. Then only the spot-like extrema have to be detected and stored as distribution of position vectors in a data file so that the number of needed image memory units does not exeed 2.

The plane displacement vector pertinent to the interference nodal points can directly be determined as quasilinear function of their nodal displacement. This can be done with an accuracy of about 2.E-04mm for every component so that the problem of quantitative displacement analysis can be handled as one of pattern sequential analysis where neither phase sampling nor any interference order identification is necessary.

Application of Micro Moire Method in Fracture Mechanics

The accuracy of displacement measurements employing the presen-ted technique contrary to macroscopical moire analysis (Kockel-mann and Kraegeloh, 1981) permits its use for quantitative fracture mechanics testing. In principle for this use there are two different possibilities:

On the one hand assuming a special material law, stress-fields and fracture quantities can be derived directly from the dis-placements measured in the analysed region and compared with the results of numerical computations for the same specimen. Thereby additional inaccuracies resulting from the derivation of the displacement values can arise. On the other hand there is the possibility to fit the displacement measurements in the analysed region to a special type of material law.

Both variants have been investigated. The paper deals with special field quantities and derived fracture criteria in the surroundings of a notch (0.8x0.8 mmxmm, SEN-CT-specimens) and their comparision with FEM-results. It is shown, how the dis-placement measurements are used to test the assumption of K- or J-dominant crack behaviour. It should be possible to genera-lize the method for the study of deformation fields due to crack tip temperature rise too (Hennig *et al.*, 1984).

LASER INTERFEROMETRIC FRACTURE EVALUATION

Holographic Interferometry and Speckle Pattern Interferometry (HI and SPI) have become powerful tools in scientific and engineering investigations of deformations and vibrations in solid mechanics or diffusion and fluid mechanics as well. One of the most important problems to be solved in this field is the data reduction from interferograms. It is one aim of this paper, to show how this problem has been solved and a tool has been provided for applications in the field of fracture mecha-nics (Will, 1987, Michel *et al.*, 1987b, Hoefling 1988).

There are a number of problems, where a quantitative analysis of strength parameters by means of optical methods is presented. Among the modern fracture criteria the J integral and its modifications have been investigated (Will, 1987).

In order to reveal the mechanical behaviour of cracks under complex loading the combinations of traditional, experimental techniques with basic mechanical equations has been becoming an increasingly popular approach to solve a variety of stress analysis problems (Balas et al., 1983, Will et al., 1987) With that holographic interferometry as a hybrid method becomes an essential tool in the fracture characterization, including identification of fracture mechanisms, modes, initiation and propagation.

Electronic Speckle Pattern Inferferometry (ESPI) has also found many applications in the field of solid mechanics e. g. for vibration amplitude mapping as well as deformation analysis. ESPI provides rapid information about mechanical and fracture properties of engineering components.

Generalized J and Strain Energy Density Evaluation by Means of Holographic Interferometric Testing

The relevant information about the three-dimensional surface displacement is derived from the interference pattern by determining the locations and order of fringes which are related to the wavelength, the directions of observation as well as illumination and the mechanical displacement at the point of observation on the surface by simple vector expressions. Holographic interferometry determines the full displacement field on a surface of a solid under load. The extent of data which have to be processed is considerable. Fortunately, recent developments in digital image analysers raise the potential for automatic data processing. Usually the resulting set of interferograms is transferred to an image analyser through a vidicon camera. The varying light intensities then are digitized into one of discrete gray level at the pixels of a display. The limited, local pixel resolution in digital image analysers seriously hampers the task of determining fringe maxima or minima. In order to reconstruct an actual three-dimensional displacement field least-square fitting of the experimental data from an overdetermined set of equations is regarded as being favourable. Local parametric estimations satisfying balance of linear momentum (Lame-Navier-equation) and bearing in mind as well boundary conditions due to a plane stress state on the lateral, unloaded, plane specimen surface form handy, suitable models of the experimental, discretely distributed data. Local and piecewice, truncated power series defined on a finite region are useful in fitting a three-dimensional displacement field (Will et al., 1988).

An advantage of the proposed, hybrid technique is based on the feature that theoretical solutions required for constructing interpolation or extrapolation curves are not needed. Connected with this fact the authors refer to recent experimental results (Rosakis and Ravi-Chandar, 1986) which also indicate that the two-dimensional analysis basing on a SIF-dominant field leaves

out certain three-dimensional features of the near crack front behaviour.

Our data reduction program involves three steps. Firstly, the optical distortion in the reconstructed image due to perspective effects is considered. Because of the oblique angle of observation with respect to the normal of the surface the surface of the object appears to be shortened and distorted because of the oblique angle of observation with respect to the normal of the surface. Secondly, before the regression problem concerning the parametric estimation is solved obtaining reliable local derivatives of displacements up to the second order, it is desirable to process the actual data by a precursory, smoothing of the fringe isolines. The problem of fringe pattern interpretation is supported by numerical modelling.

It is useful to include FEM-results for the interpretation of artificial interferometric patterns (Sommer et al., 1985). Finally, upon supplementing the mentioned parametric estimation with a presumed, linear elastic material behaviour the J integral vector (Miyamoto and Kikuchi, 1980) as well as other interesting fracture quantities are calculated. Thus, the evaluation of displacements, stresses and mechanical energies is also allowed (Will, 1987, Will et al., 1988).

Tests concerning the present holographic method showed that satisfactory reconstruction of strains is restricted to absolute values greater than about 2.E-05. The local resolution amounts to about 0.2 mm. Reviewing the path independence of the J integral yields an accuracy of about 2.E-08mm for the J value related to Young's modulus. The high accuracy has been demonstrated in several experiments for different kinds of materials. The method is part of a more general concept for computer aided fracture testing which has been investigated for years at The Institute of Mechanics. It is expected that further development of the introduced, hybrid method will lead to an effective tool in mixed-mode crack problems too. The authors have also successfully applied the method to study SIH's strain energy density criterion in more detail (Will et al., 1988).

Digital Speckle Pattern Interferometry

The development of highly integrated digital frame stores and processors has provided the possibility to substitute the videoprocessing units in ESPI by special digital equipment (Nakadate et al., 1980) or commercial computer systems. Such technique is called Digital Speckle Pattern Interferometry (DSPI) and some effort has been spent in order to evaluate DSPI-fringes automatically. To this aim, different approaches are available, e. g. phase-shifting methods (Oreb et al, 1984, Nakadate et al., 1980) or automatic fringe centre detection (Hoefling, 1988). The digital extension of ESPI has some advantage because of high flexibility, software implementation and on-line computer aided evaluation. However, an important property of ESPI - its real time operation - may be lost, if an all-purpose processor is used for image operations.

In order to maintain real-time fringe formation in DSPI, we use the digital image processing system ROBOTRON A 6472 E configured with an image processor K 2027 (Schulze and Rebel, 1983). This pipeline-type image processor performes image operations at video rates (40 ms) on the data area of eight digital TV frames formated to 512x512x8 bit each.

The processor is programmed to run DSPI software for mapping out correlation fringes, suppressing electronic noise, reducing speckle noise and detecting fringe centres. Different interferometer heads have been used to get in-plane and out-of-plane displacement vector components independently. A TV camera with vidicon pick up tube is sufficient for DSPI if only small areas (up to 50 mm in diameter) are to be inspected. Electronic noise has been suppressed very efficiently by TV frame-averaging. We used to accumulate 20 images for at least the reference speckle pattern in about 2 s. The live fringes appear instantaneously by image subtraction "on the flight". For further processing of DSPI fringes, the final object state image is frame-averaged again (Hoefling, 1988).

Speckle reduction may be achieved with very simple and fast mean filters (window size 2x2...27x27) after less than 1 s. For narrow fringes, a geometric filter algorithm compares favourably with the mean filter application.

The image content of DSPI-fringes is very close to that of holographic interferograms and software available for the latter could be applied to DSPI successfully.

The paper will give some examples how DSPI can be successfully applied for the study of deformation behaviour at the near crack tip region similar to holographic interferometry.

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