HOLOGRAPHIC CONTOURING OF NEAR CRACK TIP DISPLACEMENTS

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INTRODUCTION

In fracture mechanics studies of ductile materials, it is necessary to measure accurately the near crack tip deformation during crack advance. Assuming an analytical model which links surface displacements with internal stresses near the crack tip[1], useful information about the stress states inside the material may be determined by measuring the surface displacements near the crack tip. Experimental measurements may be correlated to the calculated displacements so that the model for crack advance may be verified. Once this has been completed, the experimental measurements of near crack tip displacements for a given material under different loading and environmental conditions may be input to the model to predict the corresponding internal stresses.

Currently, a variety of non-contact, optical techniques are used for full-field mapping of the in-plane and out-of-plane near crack tip surface deformations. They include caustics, speckle, moire, and holographic interferometry. While all of these techniques provide full-field maps of surface displacements near the crack tip, they all lack the resolution, speed, and accuracy necessary for the verification of, and use in, the micromechanical models of crack advance, especially under dynamic fracture conditions.

The goal of this study was to determine the feasibility of a using holographic technique to make an accurate, full-field map of the near crack tip surface deformation during high speed, dynamic fracture testing. The technique chosen, coherence multiplexed, two-illumination-source contouring using quasi-heterodyne holographic interferometry, made possible the full-field measurement and visualization of sub-fringe surface displacements by allowing a quantitative evaluation of the interference phase. Quasi-heterodyne holographic interferometry, shown to be accurate to better than 1/100 of a fringe[2], was used with digital image processing techniques to contour the region of interest.

BACKGROUND

Two-reference-beam holographic interferometry[3-9] holographically records an image of the front surface of an object at two instants, before and after deformation (see Figure 1). Two different reference beams are used to record the two object states on a single plate of film. Since each of the two images has its own reconstruction beam, it is possible to access each image separately while still being able to observe their mutual interference pattern. This is advantageous because the optical phase difference between the two interfering wavefields may be electronically measured when a frequency offset or series of phase shifts between the two reconstructions is introduced.

Quasi-heterodyne holographic interferometry is a technique used to provide a quantitative evaluation of the interference phase independent of fringe position and intensity variations in the reconstructed image[9]. Quasi-heterodyne holographic interferometry uses stepwise changes in the mutual phase of the two reconstructed images to compute the interference phase (from the change in measured intensity values with the applied phase steps). This technique offers moderate accuracy (up to 1/100 of a fringe) and high processing speed when using video processing.

Traditionally, quasi-heterodyne holographic interferometry has been done with a double-exposure, two-reference-beam technique in which two exposures are made -- the first with R1 and the second with R2 (see Figure 2). The interference pattern is produced by reconstructing the hologram with both beams, and the phase shift is introduced by changing the position of the reflecting mirror in one of the reference beams while the other beam remains unchanged. The mirror which moves is mounted on a piezoelectric translator (sometimes referred to as the piezo-mounted mirror). For fringe evaluation, the interfering reconstructed images are recorded by a TV-camera or CCD array and digitized. Four reconstructions are produced consecutively with three arbitrary, but equal, mutual phase shifts between them. As long as the phase shifts are the same amount each time, they need not be known quantitatively. The four images are analyzed pointwise to determine the interference phase.

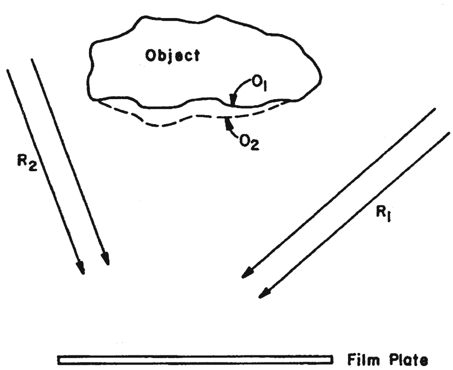

Figure 1 - A setup for recording two-reference-beam holograms.

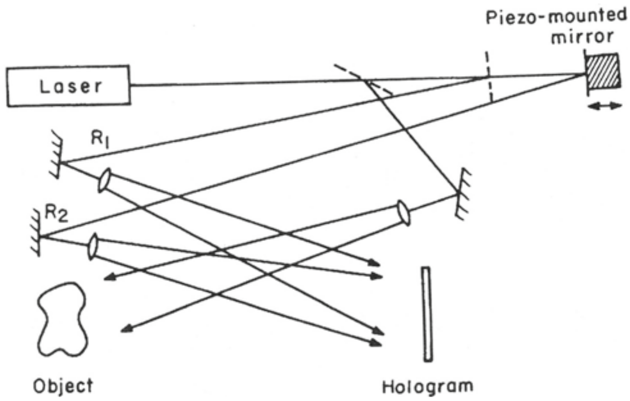

Figure 2 - Arrangement for quasi-heterodyne holographic interferometry.

Holographic contouring is a non-contact technique whereby the shape of an object's surface may be determined. Typically, to realize contours on a holographic image, two exposures are made on one piece of photographic film. Between exposures, an optical parameter is changed so that upon reconstruction of the hologram a fringe pattern, which has been modified by the surface topography of the object, is observed. There are numerous techniques used to generate contour fringes with the most common being two-wavelength contouring[10], two-index contouring[11,12], and two-illumination-source contouring [10,13,14,15]. The latter method, two-illumination-source contouring, was used in this study.

The arrangement for two-illumination-source contouring uses two angularly separated beams of the same wavelength to illuminate the object. A contour fringe pattern is generated by the interference of the two illumination sources and is projected onto the object (see Figure 3). The fringe pattern produced may be observed in real time or recorded holographically by single-exposure, using both sources simultaneously, or by double-exposure, using the two sources sequentially. Quasi-heterodyne analysis may be used with this technique to measure the interference phase.

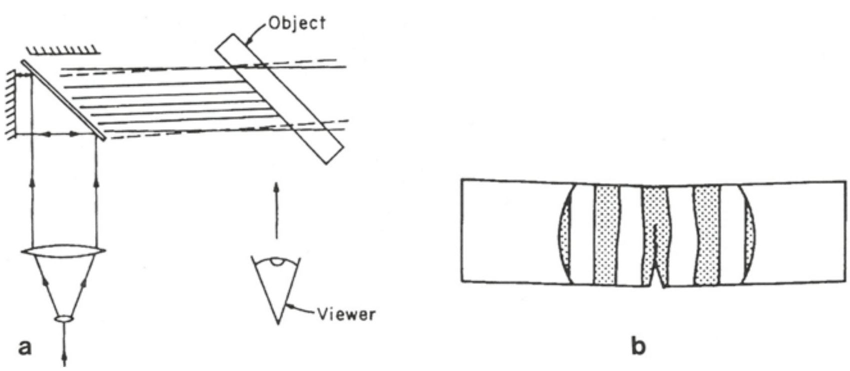

Figure 3 - (a) Michelson interferometer fringe projection setup; (b) slightly deformed contour fringes as observed on the object by the viewer.

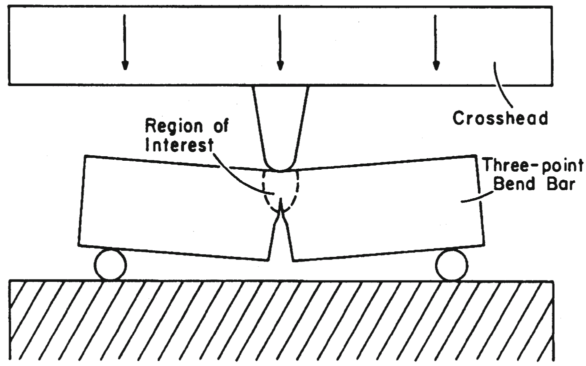

Figure 4 - Three-point bendbar loading apparatus.

Consider now the three-point bendbar fracture experiment as shown in Figure 4. At some instant during the dynamic fracture event, one may wish to map the out-of-plane surface displacements which occur near the tip of the propagating crack. This small out-of-plane displacement is accompanied by a much larger in-plane translation of the specimen surface. In such cases where significant lateral (in-plane) displacement of the object accompanies the out-of-plane deformation of interest, translation of the speckle field between holographic exposures can cause decorrelation in the reconstructed image and the associated loss of fringe visibility. One solution to this problem is to shorten the time between holographic exposures in order to limit the amount of lateral image translation. Coherence multiplexing[16] is a technique which permits the recording of a two-reference-beam hologram in one exposure, thus eliminating the problems associated with lateral image translation. Once the coherence multiplexed hologram is recorded, quasi-heterodyne holographic interferometry used with digital image processing techniques may then be used to extract the desired displacement data.

To make a coherence multiplexed hologram a setup containing two illumination and two reference sources is arranged using a laser with a limited coherence length (see Figure 5). To record the hologram, two individual pairs of object and reference beams are used. The pathlength difference between the pairs is arranged to just exceed the coherence length of the laser. An exposure is made with all four waves exposing the film at once. Because each of the two pairs is not coherent with each other, the film records the incoherent sum of the two distinct interference patterns. Once the film is processed, the hologram may be reconstructed with the same reference beams that were used to make the hologram, but interference between the two reconstructed images will not occur as the two images are not coherent. In order for interference to occur, a mirror is placed in the path of reference beam R2 to make R2′, which is the same length as reference beam R1. The reconstructed images may now interfere, and the contour fringe pattern produced by the two illumination sources when the hologram was recorded is projected onto the image of the object.

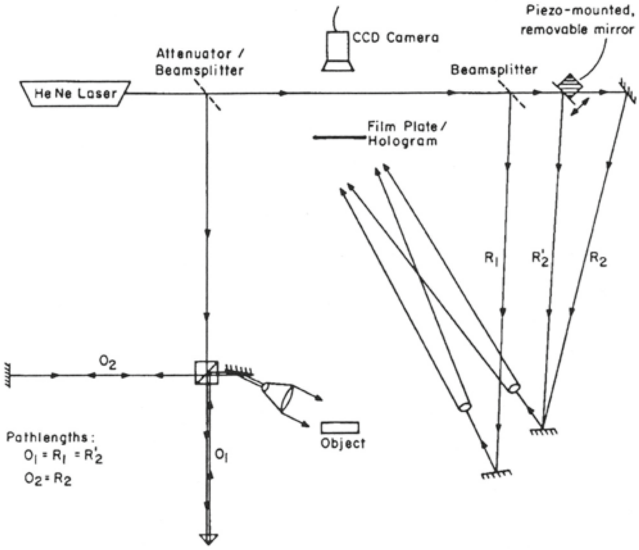

Figure 5 - Arrangement of holographic setup used to record single-exposure, dual reference beam holograms.

EXPERIMENTAL

A 70%Copper/30%Nickel three-point bendbar (9" x 2" x 0.5") was used for this study. The surface of the bendbar was lightly pellet blasted to make it diffusely reflective for holographic recording. Before optical contour measurements were made, the bendbar was bent in an Instron testing machine until a small amount of deformation was observed near the crack tip. The bendbar was placed in the holographic setup as shown in Figure 5 and the hologram recorded. Upon reconstruction of the hologram four images, each separated by a equal but unknown phase shift, were recorded by an image processor. The four images were then input into "quasi-heterodyne analysis" algorithms in order for the interference phase to be calculated.

In order to verify the optical contour measurements, mechanical measurements of the surface contour were made. A dial indicator was lowered onto the specimen and scanned over the region of interest. Comparisons were made between the optical and mechanical measurements of the surface contour.

RESULTS

The output consisted of images showing the phase information superimposed on a uniform gray background. In the images, bright regions represent deformation into the plane and darker regions represent deformation out of the plane. In Figure 6, one sees approximately a 1" x 1" area of the three-point bendbar that includes the deformed region beginning at the top of the notch. (Note: The two dark spots to either side of the notch are tapped holes for instrumentation used in other testing.) Using available image processing commands, it was possible to make

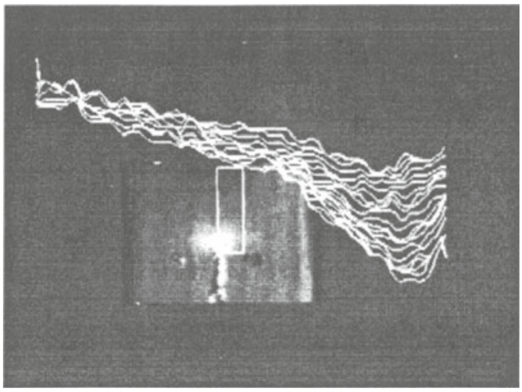

Figure 6 - Gray scale interference phase data with perspective plot showing data in box.

perspective plots of the interference phase data within a defined box. The left side of the perspective plot corresponds to the top of the bendbar and the right side of the perspective plot corresponds to the tip of the notch. The lowermost scan corresponds to the left side of the box, and the top scan corresponds to an actual position 5/32" to the right of the notch. As one can see, the deformation resulting from bending ranges from a dimple into the bar located near the tip of the notch to a bulge out of the bar at the top.

From the comparisons between the optical and mechanical measurements of surface contour, it was determined that the optical measurements showed the contour of the deformed region to approximately 2 mils.

CONCLUSIONS

The feasibility of contouring the near crack tip surface deformation on a three-point bendbar using two-illumination-source contouring with quasi-heterodyne detection was demonstrated. Due to the lateral translation of the bendbar during fracture testing, a single-exposure technique was necessary to avoid speckle decorrelation and the associated loss of fringe contrast. Coherence multiplexing provided a means by which it was possible to record single-exposure, dual reference beam holograms.

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