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Wholefield NDT of Porous Materials Using Digital Holography

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Abstract

NDT of porous material using conventional methods is difficult due to signal attenuation, low sensitivity, problems due to surface irregularities etc. In this paper the feasibility of using digital holographic interferometry to detect defects in porous materials is investigated and discussed. The basic methodology of digital holographic interferometry for defect detection is presented. Proper excitation should be applied on the test object to detect the defect from the anomalous holographic fringe pattern. Extensive experiments have been carried out with different types and magnitudes of excitation to obtain the most suited one. Application of the method to detect defects in porous materials like silica and ceramic material is presented with experimental results.

Keywords: *Holographic Interferometry, Reconstruction, CCD, Exposure, Fringe, Transient thermal stressing*

1. Introduction

Holographic interferometry is a whole-field optical method that allows non-contact measurement of surface displacement in the micron to sub-micron range. This being a non-contact optical technique has high potentiality in NDT. Because of its high sensitivity, surface, subsurface and interior details of the object can be obtained [1].

The basic methodology of holographic interferometry for defect detection is as follows. Initially a hologram is recorded when the object is at rest or in its first state and afterwards the object is excited and another hologram of the object in its new state is recorded over the first hologram. The resulting interferogram upon reconstruction shows fringes representing the deformation undergone by the object under excitation. The defect is visible as anomalies or discontinuities in the fringe pattern where a local differential deformation occurs owing to the different behaviour of the defect under the stimulation. Hence holographic non-destructive testing (HNDT) can be used wherever the presence of a defect results in change of local deformation of the stressed component.

Conventional holographic NDT which uses high resolution photographic films for recording has a few drawbacks: The developing process of the recorded hologram is time consuming. Optical reconstruction requires special setup. The developed photographic plate needs to be illuminated with an expanded laser beam and the image can be viewed only in a particular direction, which has to be photographed for further analysis. Finally the fringe pattern represents the deformation field only qualitatively. Phase shifting methods are necessary for quantitative measurements.

In this paper the advantage of digital holography [2] and its application to non-destructive testing is described. Specimens of different porous materials with known and unknown cracks were tested through digital holographic interferometry technique and the results obtained from the analysis is presented. The results shows that digital holography is able to identify cracks in these materials with great ease because of its high sensitivity and whole field nature.

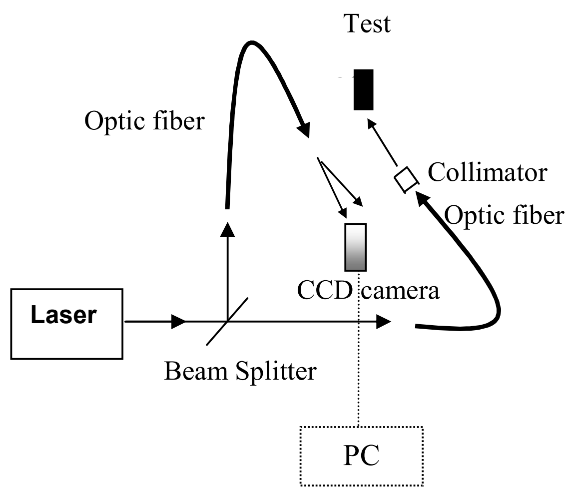
2. Digital Holography

With the developments in imaging sensor technology and fast algorithms in image processing, digital holography has emerged. Digital holography is an advanced technique in which hologram is recorded digitally and reconstructed numerically in a computer.

In digital holography, a digital camera replaces the photographic film/ plate used in conventional holography. The holograms are generated directly on a charge coupled device (CCD) target and stored electronically. This eliminates the need of time consuming wet processing of photographic plates. The reconstruction is performed by numerical methods from the digitally stored holograms. In the numerical reconstruction process not only the intensity, but also the phase of a holographically stored wave front can be obtained.

2.1 Digital Hologram Recording Setup

The optical setup for recording digital hologram is shown in Fig. 1. The laser beam is split into two using a beam splitter. One beam guided by an optic fiber and collimated by a collimator is used to illuminate the object. The other beam is guided through another fiber and is made to fall directly on the CCD sensor of the digital camera without lens. The object and reference waves interfere directly at the surface of the CCD sensor, which is the hologram plane.



2.2 Digital Hologram Reconstruction

Digital holograms are reconstructed numerically in a computer [3]. Digital hologram is created as a result of the interference between the object wave and reference wave at the CCD plane. Complex amplitude of the diffracted wave field at the real image plane is given by Fresnel-Kirchoff integral and can be obtained by the Fourier transform of the product of the transmittance and the quadratic phase factor. Intensity of the real image is given by the modulus of complex amplitude. HDigital©, numerical reconstruction software developed in-house was used for reconstruction.

2.3 Digital Holographic Interferometry

Two digital holograms are captured at different states of stress of the object, on separate frames of the CCD camera. Intensity and phase maps of each hologram are calculated through digital reconstruction of the recorded holograms. Intensity of the double exposure fringe patterns and corresponding interference phase are obtained through subtraction of the reconstructed intensity and phases respectively of the undeformed and the deformed object waves as shown in Fig. 2. Interference phase represents the deformation field quantitatively.

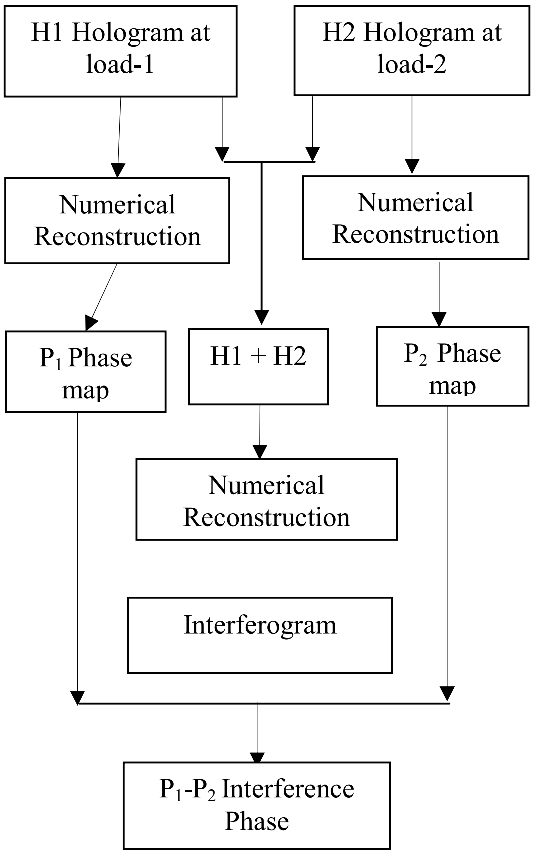


Fig. 2: Procedure for generation of intensity and phase maps

3. Test Specimens

Specimens of two different types of non-metallic porous materials were tested using digital holography. Defects like cracks, voids and density variation are generally occurring in porous materials. The following are the details of the specimens tested.

3.1 Silica Tile

Two samples of silica tiles were taken for this study. One is having a very tight crack compared to the other. The sample is of dimension 100 mm × 100 mm as shown in Fig. 3a. The thickness of both the samples is 12 mm.

3.2 Ceramic Sample

A sample made of ceramic material with suspected micro cracks is shown in Fig. 3b. The specimen is of 70 mm length and 10 mm width and having a thickness of 5 mm.

Fig. 3a: Silica tile

Fig. 3b: Ceramic sample

4. Modes of Stressing

Holographic interferograms were recorded under two different modes of stressing viz., mechanical loading (compression) and thermal loading. Holograms were recorded separately for both the stressing.

4.1 Mechanical Loading

Compressive load was applied by keeping a few grams of weight in the range 50g to 100g on the top of sample.

4.2 Transient Thermal Loading

The most effective stressing to obtain the information along the thickness of a component is established as transient thermal stressing. The method and extent of stressing depends on the material property, geometry, and dimensions of the test article.

Uniformity in stressing is very important during heating. Spceimens of smaller sizes are heated with single IR lamp so that the temperature on the surface will be approximately uniform. Fig. 4 shows the schematic of the loading setup with IR lamp. For larger objects an array of IR lamps may be used. One surface of the test article is first heated using the IR lamp and after switching off and removal of IR lamp the holograms of the test object are recorded continuously at its different state while cooling.

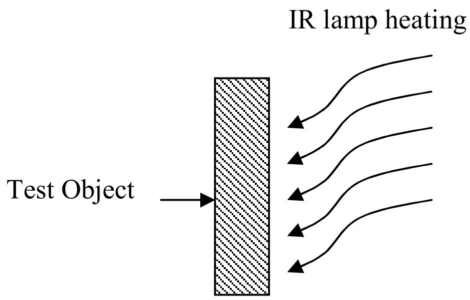


Fig. 4: Thermal loading setup with IR lamp

Objects can also be heated using a vertical hotplate by keeping the objects near or in touch with the hot plate as shown in Fig. 5. Here hologram can be continuously recorded at different state of the object while heating.

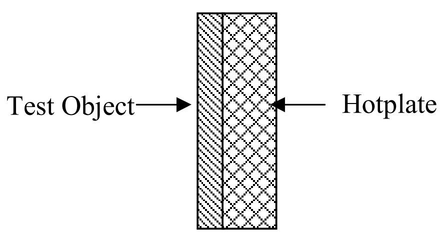


Fig. 5: Thermal loading setup with hot plate

To get the effect of surface and subsurface cracks holograms at different stressing magnitude corresponding to different time instants are to be taken. In digital holography the first hologram (1^{st} frame) is recorded at t = 0 seconds from removal of IR lamp or at the time of placement of specimen on hotplate. Successive holograms are taken for timing $t+\Delta t$, $t+2\Delta t$, $t+3\Delta t$ etc. where Δt is the delay between two exposures.

5. Experimental Results and Discussion

The type, method and magnitude of stressing were evolved through experiments using digital holography.

5.1 Silica Tile

5.1.1 Compressive Load

A small weight of 40g was kept over the silica tile and the corresponding holographic interferogram is shown in Fig. 6. This tile was having a known crack on its surface along the vertical direction. The tile was kept with its cracked surface facing towards the camera. Fringe discontinuity was observed in the holographic fringe pattern along crack.

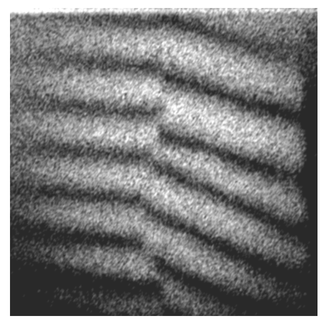


Fig. 6: Interferogram showing fringe discontinuity along crack

The silica tile was kept reversed with crack surface at the backside and hologram of defect free front face with compressive load was recorded. Fig. 7 shows the hologram with fringe anomaly along the crack.

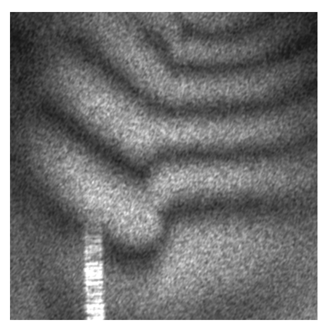


Fig. 7: Interferogram showing fringe discontinuity along crack

Even though mechanical stressing is capable of producing fringe anomalies corresponding to cracks it is observed that in some cases this type of stressing does not reveal the defect. This depends on the size and orientation of the crack and also on the magnitude of stressing. Fig. 8 shows interferogram of another silica tile with a tight crack and no anomaly was observed in the fringe pattern under mechanical stressing.

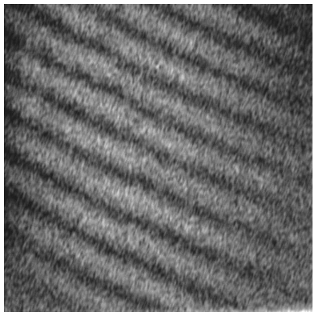


Fig. 8: Interferogram of region with tight crack

5.1.2 Heating with Hotplate

The silica tile with tight crack was stressed thermally using a hotplate. The temperature of the hotplate was 60^{o} C. Holograms were continuously recorded at video frame rate while heating and interferograms were generated using different combinations of holograms. One of the interferogram with fringe anomaly corresponding to surface crack is shown in Fig. 9.

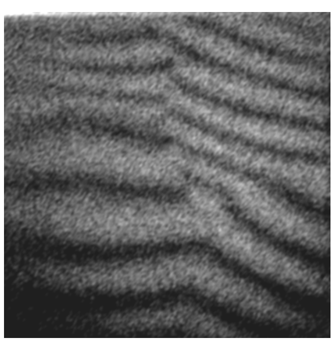


Fig. 9: Interferogram with thermal stressing of region with tight crack

5.1.3 IR Lamp Heating

The double exposure holographic fringe pattern for thermal stressing with IR lamp is as shown in Fig. 10. Here tile was kept with its cracked surface on the reverse of the side facing the camera. The tile was heated for a few seconds and the hologram was taken with a delay of less than one second. The fringe pattern has globally changed but along the crack the fringe anomaly was repeated as sudden change in the slope of the fringes. This shows that cracks on the silica tile produce local changes in the surface deformation within one second after heating of the silica tile. Also it is observed that the material attains thermal stability within a few seconds with this thermal load and the holographic fringe pattern become regular showing no effect on the crack.

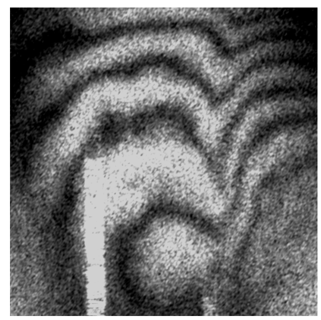
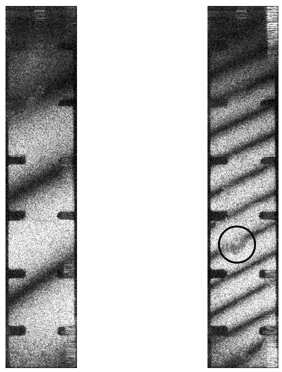


Fig. 10: Interferogram of region with crack under IR lamp heating

Conventional hologram recording media needs an exposure time much more than the high sensitive CCD camera [3]. In digital holography holograms are recorded in milliseconds exposure time, hence the transient changes during the thermal stressing will not be missed. Hence holography technique is sensitive enough to map the surface deformations of 80% porous silica tile. Also the IR lamp heating is very easy and practical for stressing the tile.

5.2 Ceramic Filter

The ceramic filter was heated with the IR lamp for a few seconds. Then holograms were recorded continuously at different timings and stored in separate frames. Fig. 11a and 11b show two interferograms generated with holograms stored in the initial time frame and at the final time frame respectively. Hologram at first frame is used as reference for both interferograms. Fringe anomaly is observed in Fig. 11b as marked in circle. Regular fringe patterns were observed at all the remaining regions of the specimen.



a b

Fig. 11a and 11b: Interferogram of ceramic specimen

6. Conclusion

In this paper applications of digital holography in the field of nondestructive testing are described. The results demonstrate the solution through digital holography for detecting and locating the defects in highly porous materials. Digital holography is a practical tool to measure defect induced deformation fields. The recording of hologram using a highly sensitive digital camera minimizes the exposure time to milliseconds, which eliminates the requirement of the vibration isolation. This also helps to register the fast varying states of porous material at a high frame rate during stressing. This increases the detectability of defect through holography technique.

The result shows that the quality of digital interferograms is better than conventional holograms and less noisy compared to speckle interferograms. The importance of the stressing type and magnitude is also demonstrated through the results.

The test results show that the cracks in the silica tile under thermal and mechanical stressing induce discontinuities in the surface deformation, which are sufficient to generate a local change in the holographic fringe pattern. The test results present the nature of the fringe anomaly due to a crack on silica tile under compressive load and thermal load. Stressing through IR lamp is an easier and practically viable method for stressing, which gives fringe anomaly near the crack location. The extent of thermal load and the exposure timings are established for the two cases.

7. References

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