STUDY ON WOOD FRACTURE PROPERTIES BY HOLOGRAPHIC INTERFEROMETRY AND NUMERICAL SIMULATION

P. NAVI, J. WANG and C. HUET
Laboratoire de Matériaux de Construction
P.K. RASTOGI and L. PFLUG
Laboratoire de Mesure et d'Analyse des Contraintes
Ecole Polytechnique Fédérale de Lausanne, Switzerland

ABSTRACT

Holographic interferometry is applied to visualize the displacement fields and detect the onset of crack propagation in a number of compact tension (CT) wood specimens. The in-plane displacement maps are furnished. Each map is related to a well defined position on the force-displacement curve obtained during the experiments. These maps show the highly anisotropic and nonhomogeneous nature of wood. It is found that in the pine wood specimen the force at which the crack onsets is about two-third of the peak load. Based on the elastic linear fracture mechanics a computer program is developed to calculate the displacement fields of the specimens for the same force and boundary conditions as during the experiments. For each case the iso-values of in-plane displacement are plotted and compared with the results obtained from holographic interferometry. This program will attempt to explain the experimentally observed results.

INTRODUCTION

Holographic interferometry has proved to be a valuable tool in crack detection and its propagation for materials such as metals and concrete. The technique is noninvasive and permits a whole field visualization of the displacement fields over the object surface. Inspite of the important advantages it has to offer, holographic interferometry has not been applied until recently (Navi et al., 1991) to crack propagation in wooden structures. The wooden specimen is rendered difficult to examine by the presence of annual growth rings modulating its surface.

According to linear-elastic fracture mechanics, in a material containing a crack, fracture is assumed to occur when the stress intensity factor reaches a critical value (fracture toughness), a material property that must be determined experimentally. This critical value has been calculated from the load at which the existing crack in the specimen starts to propagate. In a wooden material the observation of the crack onset is rendered difficult by the structural inhomogeneities of the wood. In practice, the force at which the crack initiates is taken to be about the peak force (Ashby et al., 1985) obtained from the loading curve of the tested specimen. [De Baise et al., 1965] have used an acoustical emission technique to detect the flaw growth in wooden materials.

In this paper, we have applied holographic interferometry to visualize the displacement fields and detect the onset of crack propagation in a number of wood specimens. The in-plane displacement maps of notched wood specimens with a sensitivity of two fifth of a micron per fringe are furnished. These maps are obtained at different loading levels for 20 × 20 cm^2

specimens under controlled displacement tests. Each map is related to a well defined position on the force-displacement curve, plotted during the experimentation in which the specimens are subjected to testing from zero deformation till total failure. The force level at which the crack initiates is shown on the force-displacement curve. Finally, we have calculated numerically the displacement fields of these specimens for the same force and boundary conditions as during the experiments. For each case, the iso-values of in-plane displacements are plotted and compared with the results obtained from holographic interferometry.

HOLOGRAPHIC INTERFEROMETRY AND THE OPTICAL SYSTEM

Holography is a technique which permits one to duplicate the original wavefront emanating from a diffuse object illuminated by the laser beam. What really differentiates the conventional imaging from the holographic process is that whereas the former records the variations of light intensity, the latter records both the amplitude and phase information inherent in the wavefront reflected from the object surface. The phase information is thus conserved in holography.

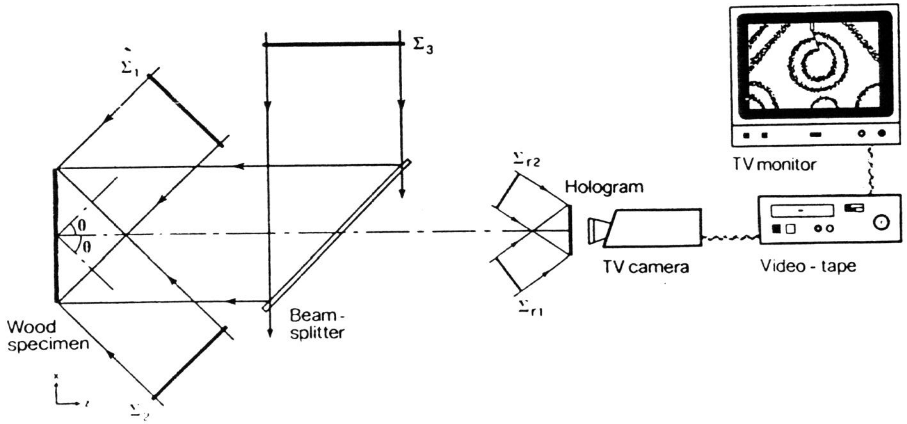


Fig. 1: Holographic arrangement.

A holographic interferogram results from an interferometric comparison of the wavefronts emanating from a laser lit object in its two neighboring states of deformation. The fringe pattern so produced is indicative of the displacement undergone by the object. Relying on its high sensitivity and the property of its interferograms to exhibit spatial and temporal continuity, real-time holographic interferometry (Rastogi et al., 1988)has developed into an enviable tool for crack detection, its onset and propagation. If a crack is present, its presence is signaled by the appearance of discontinuities in the image interference pattern. The presence of crack is detected from its very early stage and its geometrical location determined with extreme precision. The exact load at which crack initiation occurs can thus be determined very accurately.

The experimental set-up used by us is shown in Fig 1. Although the deformation perpendicular to the object surface is easiest to obtain by holographic interferometry, an effort was made to complement this information with that of deformation parallel to the object surface. The set-up provides interferograms corresponding to both the out-of-plane (w) and in-plane (u, v) components of object displacements.

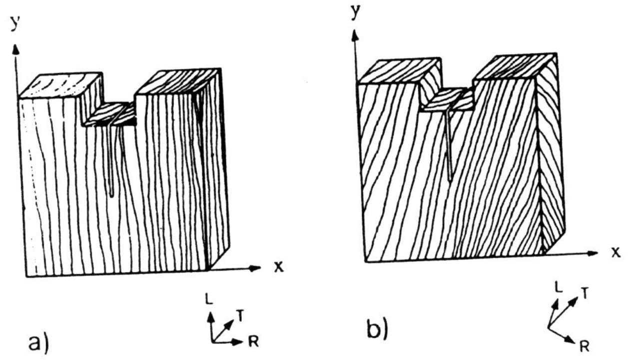


Fig. 2: Specimen types of pine wood studied by us. T, L and R correspond to the tangential, longitudinal and radial directions respectively.

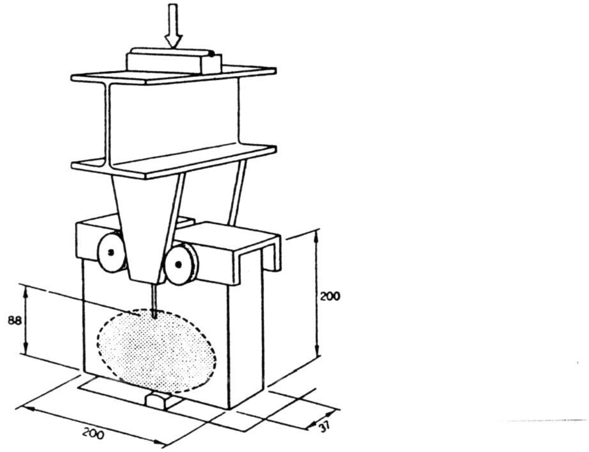


Fig. 3 Loading device.

A wood specimen mounted on the loading device is illuminated by three collimated beams Σ_1, Σ_2 and Σ_3. Σ_1 and Σ_2 make equal angles θ with the surface normal and Σ_3 is incident normal to the specimen surface. Two collimated reference beams Σ_{r1} and Σ_{r2} , one serving for the collimated beam pair (Σ_1, Σ_2) and the other for Σ_3 are made to strike the holographic plate. Two independent holograms of the object at any given initial position are recorded on the holographic plate, one each when the object is illuminated simultaneously by the beam pair (Σ_1, Σ_2) and Σ_3, by means of reference beams Σ_{r1} and Σ_{r2}, respectively. The holographic plate is processed in situ.

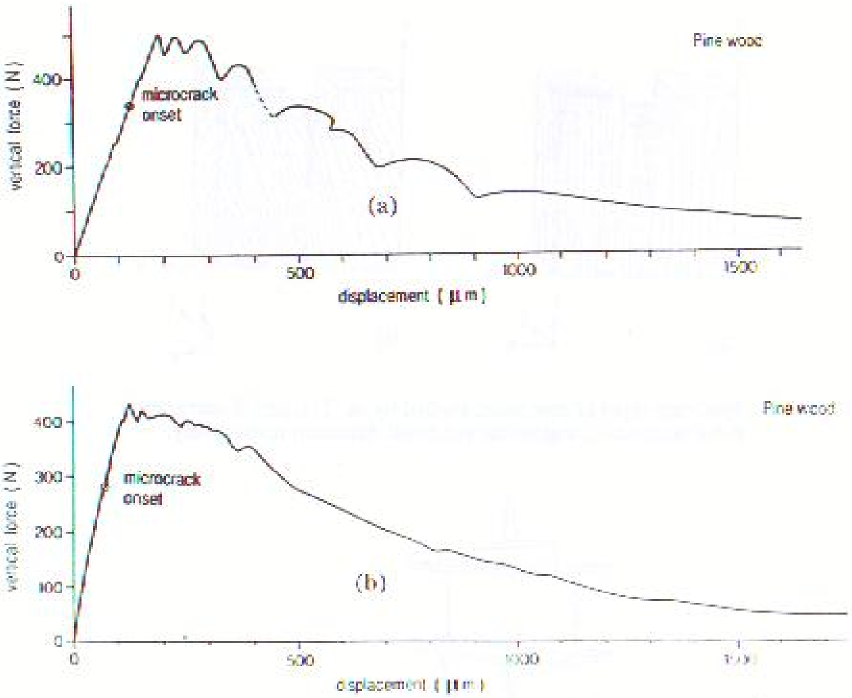


Fig. 4 : Typical loading curves corresponding to (a), (b) : pine (shown in Figs. 2(a) and (b)).

The specimen is then deformed, and the pair (Σ_1, Σ_2) and Σ_{r1} are switched off. The reconstructed image will then consist of fringes due to the interference of the wavefronts originating from the holographically reconstructed image of the object in its initially recorded state, and the deformed state of the object. The method furnishes the lines of equal out-of-plane displacement (w) according to the relation :

$$w = \frac{n\lambda}{2}$$

The increment of displacement between two successive fringes is given by one fourth of a micron. Σ_3 and Σ_{r2} are next switched off. The optical arrangement corresponding to displacements parallel to the object surface is now actioned by switching on the pair (Σ_1, Σ_2) and Σ_{r1}. The interference pattern is now composed of a system of moiré fringes. These fringes provide the lines of equal in-plane displacement (u) , along x direction, in accordance to the relation :

$$u = \frac{n\lambda}{2\sin\theta}$$

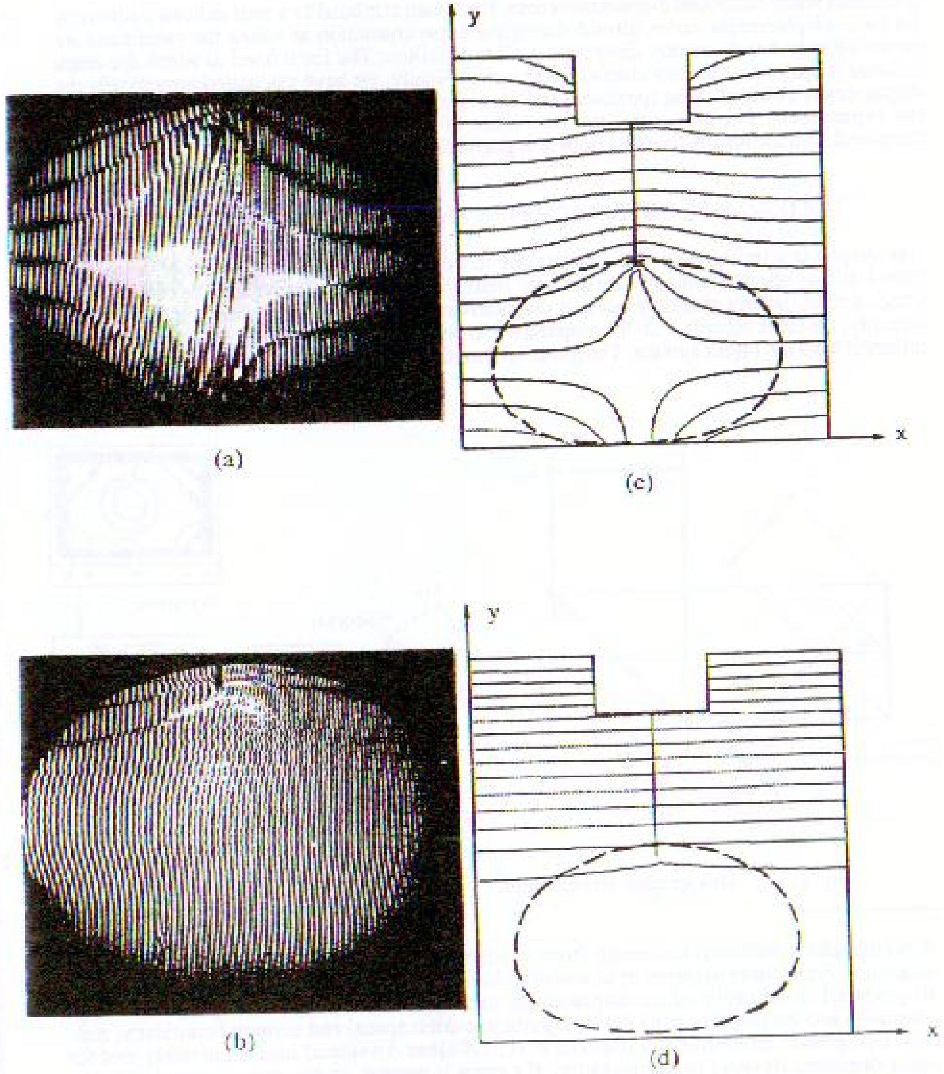
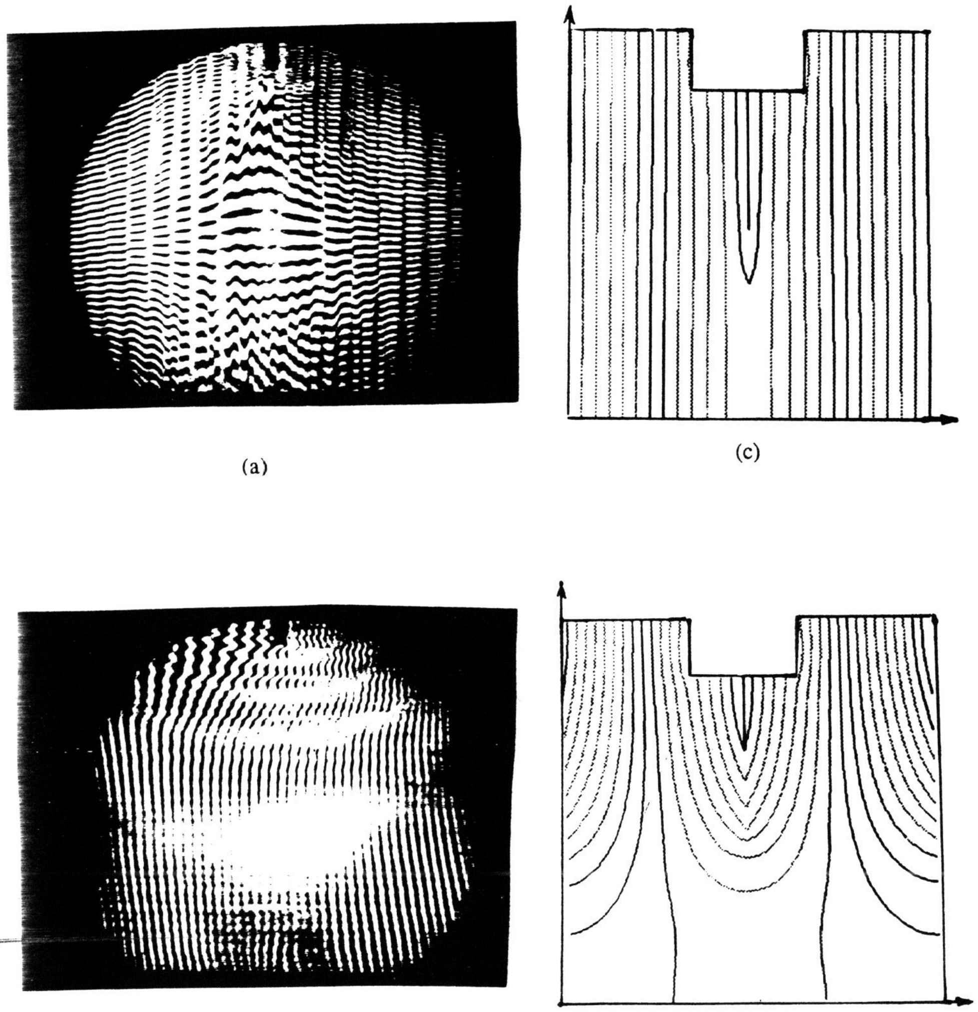


Fig. 5 (a), (b) : experimentally obtained in-plane displacement maps along x direction. (c), (d): numerically obtained maps (These results correspond to the pine specimens shown in Figs 2(a) and (b) respectively).



(a) (c)

(b) (d)

Fig. 6 (a), (b) : experimentally obtained in-plane displacement maps along y direction. (c), (d): numerically obtained maps. These results correspond to the pine specimens shown in Figs 2(a) and (b) respectively.

The increment of displacement between two successive fringes is two fifth of a micron.

EXPERIMENTAL RESULTS

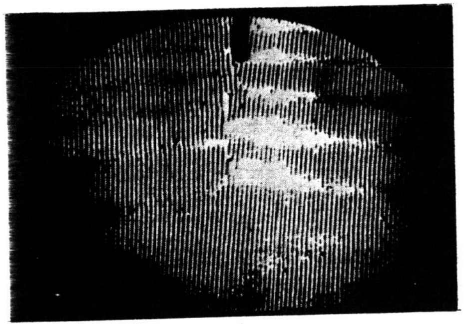
The specimens are prepared from pine (softwood) trees, such that the tangential directions are perpendicular to the specimen surfaces. The longitudinal directions make an angle of about 0^o and 15^o with respect to the direction of the notch. These specimen types for pine wood are shown in Fig. 2. The loading device used by us is shown in Fig. 3. The test consists of splitting a notched wood specimen by means of a wedge placed between rollers. The load applied to the specimen and the displacement are closely monitored and recorded during each test. Typical curves for loading corresponding to pine-wood specimens (Figs. 2 (a) and (b)) are shown in Figs 4 (a), (b) respectively. The load at which crack initiation occurs is equally shown in each figure. Figs. 5(a) and (b) represent the in-plane displacement fringes along x direction and corresponding to the specimen types shown in Figs. 2(a) and (b) respectively. The numerical examples corresponding to the same specimen types are shown in Figs. 5(c) and (d). Figs. 6(a) and 6 (b) show the in-plane displacement fringes along y direction for grains in the y and x directions respectively. The corresponding numerical examples of the same specimen types are given in Figs. 6(c) and (d).

CONCLUSION

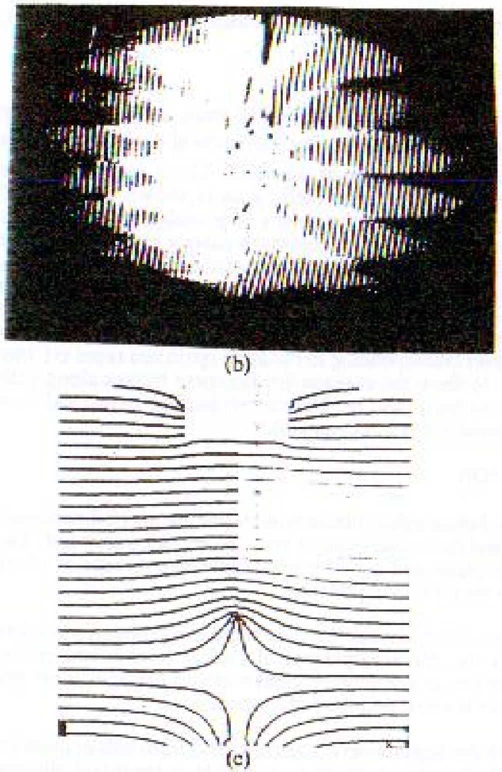
We have shown that holographic interferometry can be applied successfully to visualize the displacement fields and detect the onset of crack propagation in wood. The preliminary results obtained from the in-plane and out of-plane displacement maps of notched wood specimen draw our attention to the following problems :

1. In practice the force level in mode I at which the crack initiates is taken to be close to peak load obtained from the force displacement curve. It is found from the appearance of discontinuities in the image interference pattern that in the pine wood specimens the force at which the crack onsets is about two-third of the peak load.

2. The comparison of the displacement maps obtained from holographic interferometry and the numerical analysis of the same specimen type provide us important information about the wood fracture mechanism. These informations can be used to improve the existing fracture models for wood. From Figs. 7(a), (b) and (c) one can recognize the differences between the wood and the concrete fracture mechanism on the one hand and the limits of the LEFM method used to explain the wood fracture. For example Fig. 7(b) shows the existing of a strong bridging effect between two fracture surfaces behind the crack tip. This "bridging" effect is very small in concrete specimen (Fig. 7(a)) and inexisting in the LEFM model used in our numerical study (Fig. 7(c)).



(a)



(b)

(c)

Fig. 7 (a) : Displacement pattern obtained by holographic interferometry in a wood specimen in x direction. (b) : Displacement pattern obtained by holographic interferometry in a concrete specimen in x direction. (c) : Displacement pattern obtained by numerical method based on LEFM in a wood specimen in x direction.

REFERENCES

Ashby M.F., Eastering K.E., Harrysson R. and Maiti S.K. (1985), The fracture and Toughness of Woods, Proc. R. Soc. Lond., A 398, 261-280.

DeBaise G.R., Porter, A.W. and Pentoney R.E. (1990), Morphology and Mechanics of Wood Fracture. Material Research and Standards, vol 6, N° 10, 493-499.

Navi P., Rastogi P.K., Pflug L. and Huet C. (1991), Study of Wood Fracture by Holographic Interferometry. Proceedings of the "1991 International Timber Engineering Conference", Vol. 2, 2.258-265.

Rastogi P.K., Jacquot P. and Pflug L. (1988), Holographic Interferometry Applied at Subfreezing Temperatures : Study of Damage in Concrete Exposed to Frost Action. Optical Engineering, vol 27, 172-178.