Investigation of Young's modulus of elasticity in wood Using Electronic Speckle Pattern Interferometry (ESPI)

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Electronic Speckle Pattern Interferometry (ESPI) is a holographic interferometric non-contact optical technique used to measure in-plane and out-of-plane object displacements. This optical method was adopted to measure Young's modulus of elasticity in two tropical wood samples odum, kussia and steel, a reference material. The experimental results of Young's moduli of the samples compared reasonably well to the literature values obtained with mechanical methods.

1 Introduction

Electronic speckle pattern interferometry (ESPI) is a holographic interferometric non-destructive and non-contact optical technique for the measurement of in-plane and out-of-plane displacements of an object. This technique was used to measure quantitative displacements and movements in technical and biological cavities [1] and also to analyze vibrations in logs [2].

Based on the high resolution and accuracy in displacement measurement, we used ESPI to investigate the modulus of elasticity (MOE) of wood. Experimental measurements on two cantilever samples, Milicia *excelsa* (odum) and Nauclea *diderrichii* (kussia) showed comparable results to the literature values of mechanical methods. Measurement of modulus of elasticity in steel was used as our reference material.

2 Method

The schematic diagram in *Fig.1* shows the ESPI setup used in the measurements. The light from a 20 mW He-Ne laser was split into object and reference waves by a beam splitter BS1. The illuminated object was imaged onto the CCD camera. A second beam splitter superimposed the object and the reference waves onto the sensor plane of the CCD camera to generate the interferograms. The intensity of the interferograms before deformation $I_1(x, y)$ and after deformation $I_2(x, y)$ of the investigated surface were recorded by the CCD camera, transferred to a computer and saved for digital analysis. The interferogram intensities before and after deformation of the surface are described by the interferogram equation (1).

$$
\begin{aligned}
I_1(x,y) &= I_0(x,y) + I_m(x,y)\cos[\phi(x,y)] \\
I_2(x,y) &= I_0(x,y) + I_m(x,y)\cos[\phi(x,y) + \Delta\phi]
\end{aligned}
\qquad (1)
$$

$I_0(x, y)$ *and* $I_m(x, y)$ are background intensity and intensity modulation respectively, $\phi(x, y)$ is the phase and $\Delta\phi\ (x, y)$ denotes the phase difference. The relation between displacement $d(x, y)$ and phase difference $\Delta\phi\ (x, y)$ is given by equation (2) [3].

$$d(x,y) = \frac{\lambda \Delta\phi(x,y)}{4\cos\frac{\theta}{2}} \qquad (2)$$

The parameter θ is the angle between object illumination direction and object imaging direction, λ represents wavelength of the light source, and d denotes the displacement.

The phase distribution of each interferogram was determined by a spatial phase shifting technique [4]. Calculation of the phase difference $\Delta\phi(x, y)$, and the displacement $d(x, y)$, of the deformed cantilever was performed digitally. The bending equation (3) was fitted with the cantilever displacement $d(x, y)$ in order to obtain the modulus of elasticity of the samples under investigation.

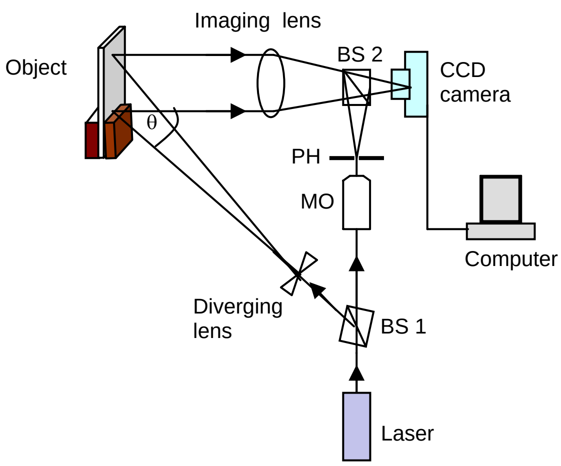

Fig. 1 Schematic diagram of the ESPI setup used in the measurements. PH is the pin-hole, BS 1 and BS 2 are beam splitters and MO is a microscope objective.

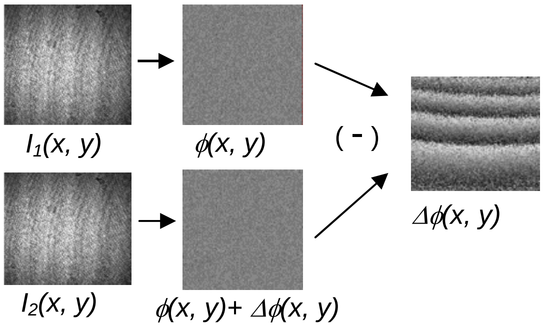

Fig. 2 The phase distributions $\phi(x, y)$ and $\phi(x, y) + \Delta\phi(x, y)$ were calculated from the interferograms $I_1(x, y)$ and $I_2(x, y)$ respectively. The difference between the two phase distributions $\Delta\phi(x, y)$ was computed for the analysis.

Experimental Results

The coefficient a of $W(x)$ in equation (3) was determined from the curve fitting of $d(x, y)$ and was used to calculate the modulus of elasticity of the samples. The modulus of elasticity of steel, a homogeneous material, was also measured to be compared with the inhomogeneous wood samples.

$$W(x) = a[(\frac{x}{L})^3 - 3(\frac{x}{L})^2]$$
$$a = \frac{FL^3}{EI}, I = \frac{bt^3}{12}, E = \frac{12FL^3}{abt^3} \qquad (3)$$

W(x) represents the curvature of the deformed object, *F* is the applied force, *I* denote the moment of inertia, *L* is the length of the imaged area, *t* represents the thickness, and *b* is the width of cantilever beam.

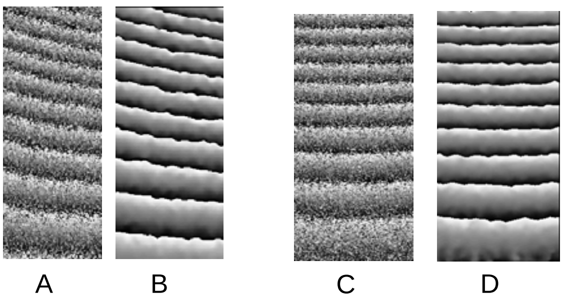

Fig. 3 : A and C are the unfiltered phase difference distributions for kussia and steel and B and D the corresponding filtered phase difference distribution of kussia and steel. Force applied was 0.10 N for steel and 0.12 N for kussia.

Table 1: Measured values and literature values for MOE of samples investigated.

	Steel	Odum	Kussia
Literature MOE/GPa	207	9.4	11.4
Measured MOE/GPa	190 ± 10	11.2 ± 0.2	13.6 ± 0.3

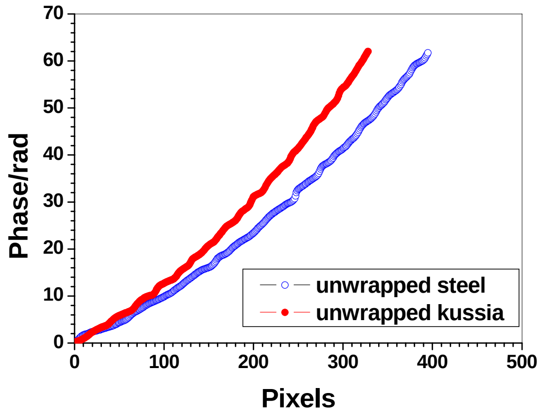

Figure 4: Graphs of unwrapped phase difference distributions along the bending curvature for kussia and steel.

CONCLUSION

The experimental results on the determination of modulus of elasticity for steel, odum and kussia presented here are evident to the fact that ESPI optical technique has a great potential to measure mechanical properties of materials. This initial setup of the ESPI gave results within 10% error for steel and 20% error for wood samples. This can be improved by using a very stable clamping system and increasing the resolution in our future investigation.

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