HOLOGRAPHIC INTERFEROMETRY USED IN BIOMECHANICAL TESTING OF BONES

By

Z. FÜZESSY, J. ANTAL, E. BAKAY* and A. VAJDA*

Department of Physics, Institute of Physics, Technical University, Budapest

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1. Introduction

One of the most significant applications of GABOR's wavefront reconstruction technique [1] is the holographic interferometry introduced by Horman [2] and by POWELL and STETSON [3]. A very important technological contribution from holography has been in the field of experimental deformation analysis, where the holographic interferometry has led to a new and highly sensitive technique for visualizing small displacements of the surface of an object. The applications of these techniques are mostly connected with problems of machine industry, but more and more applications in medical diagnostics have been published recently [4, 5, 6, 7, 8, 9]. In our work double-exposed interferograms were made on rabbit bones under increasing static load and resulting displacement of surface points was determined. The method can be used for judging over the structure and regeneration of bones after fractures and operative discontinuities. This technique is a more sensitive tool in determining the displacement values than are traditional ones and provides simultaneous information about every point of the surface.

2. Experimental procedure

Thigh-bones were taken from 2—3 months old healthy rabbits and immediately rigidly fixed at distal end in a proper holder by "Dentacryl" cement. In this way the distal end was reliably clamped. On the proximal end the thigh-bones were loaded by a perpendicular static force possibly with the same orientation relative to the bone axis and geometry in every experiment as indicated in Fig. 1.

The experimental setup is shown in Fig. 2. The light from cw He—Ne laser of 30 mW was split into two beams by a beam splitter. One of them reached the photographic plate (Agfa Gevaert 10 E 75) as reference beam and the second one carried informations from the surface of bones.

*Clinic of Orthopaedics, Semmelweis University of Medical Sciences.

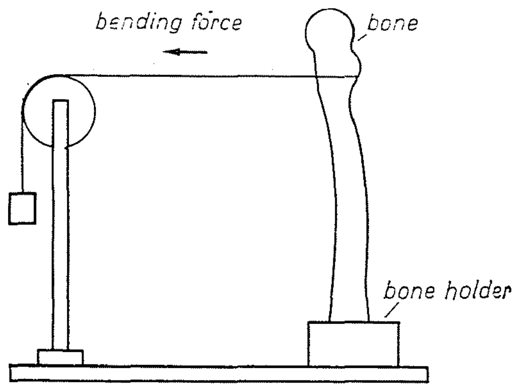

Fig. 1. Schematic representation of the loading equipment

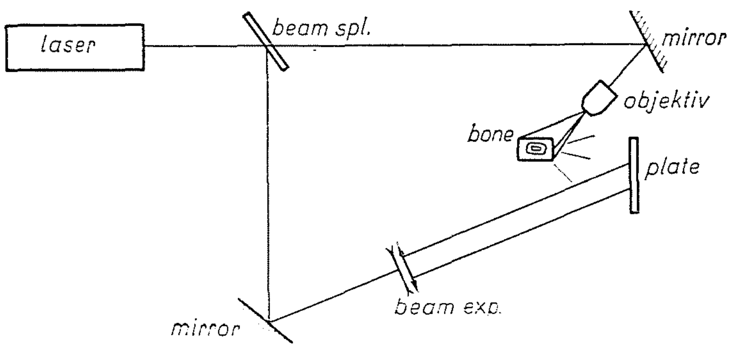

Fig. 2. Experimental setup

Before deforming the surface, the plate was first exposed to object and reference beams. The surface was then deformed and the second exposure was made on the photographic plate. The loads between two exposure differed by 0.1 N. After processing the plate formed a double-exposure hologram, which was reconstructed by a reference beam and then the reconstruction was photographed.

Desiccation of the bone surface markedly affects the visibility of fringes. In order to avoid the desiccation, the bones were kept in physiological NaCl solution until the measurements. Some experiments were made inside the solution.

Figure 3 shows the interference pattern of two thigh-bones of the same rabbit. A hole was drilled into one of the bones and then both were loaded by bending moment of the same value. The difference in the number of the fringes on the two bones indicates well the weakened area and the consequences.

One of the interferograms of the bent bones in physiological solution is shown in Fig. 4. Interference pattern on Plexiglas indicates the change in the stress state due to creep.

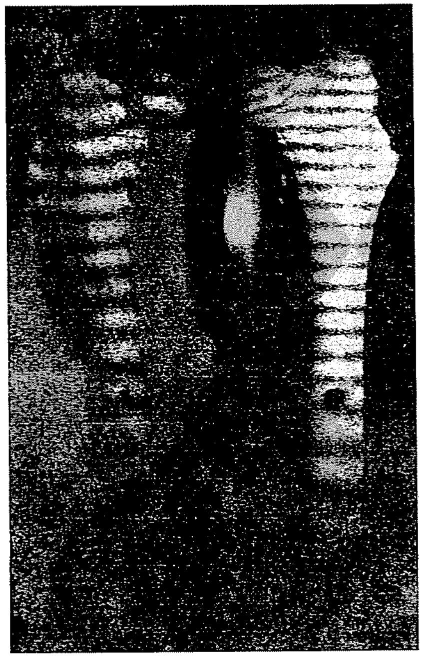

Fig. 3. Holographic fringes on two femurs of a rabbit

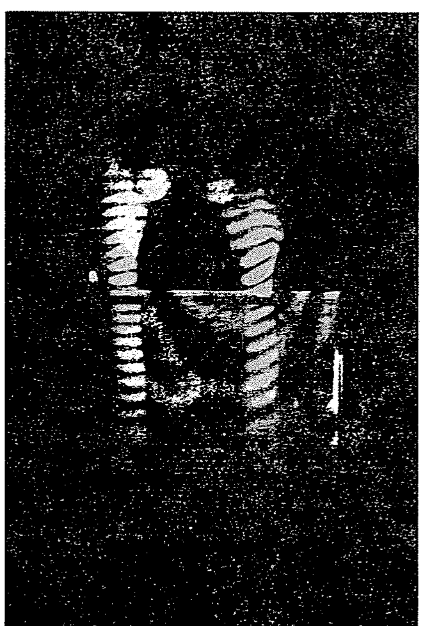

Fig. 4. Interferometric pattern on bones in NaCl solution

3. Analysis of fringe pattern

The fringes observed on the bone surface locate points along which equal changes of optical paths between the source and the observer arise due to bending. The change in optical path is related to the fringe order by the following equation:

$$\Delta s = N\lambda\,, \tag{1}$$

where Δs is the change in optical path, N the fringe order, and λ the wavelength of the light. Considering that the distal end of bones was clamped rigidly the zero-order fringe was in the field of view in every experiment. So Eq. (1) gives the change in optical path for each point. The problem then becomes one of pure geometry, relating the change in optical path for each point to the actual displacement of that point.

The displacement component measured by this technique is that along the bisector of the illumination and viewing direction. In our case the direction of the actual displacement was known and the illumination and viewing directions were arranged so that the sensitivity vector lied approximately along this direction. Now the value of actual displacement of the point under consideration can be calculated simply by

$$d = \frac{N\lambda}{2}\,. \tag{2}$$

The displacements of the bone surface points *vs.* distance from the clamped end are shown in Fig. 5.

4. Discussion and perspectives

From the measured displacement under given load condition the proper strain component can be obtained along the bone surface. On the other hand, the maximum stress can be calculated approximating the bone by a tube of properly varying cross section. Closeness of suggested approximation is illustrated in Fig. 6, where 22 measurement results are shown: the inner and outer diameters of each femur bone were measured along the bone length in two perpendicular directions and the mean diameters were determined as a function of the bone length.

The stress and strain tensors are related via moduli of elasticity, so the above procedure allows the local determination of the proper modulus in the elastic range. Measurements are possible in the inelastic range, too, where also irreversible deformations occur. The mechanical strength of the bone can be measured and the detailed process of fracture observed.

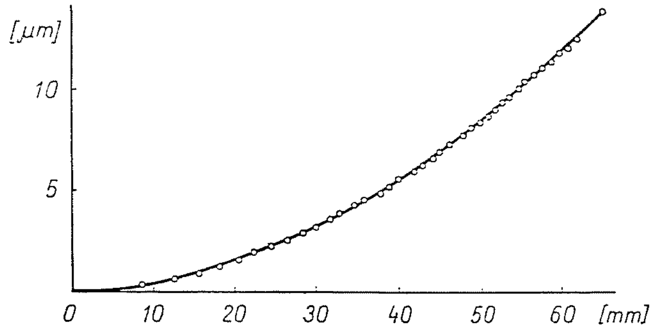

Fig. 5. Displacements of bone points *vs.* distance from the clamped end

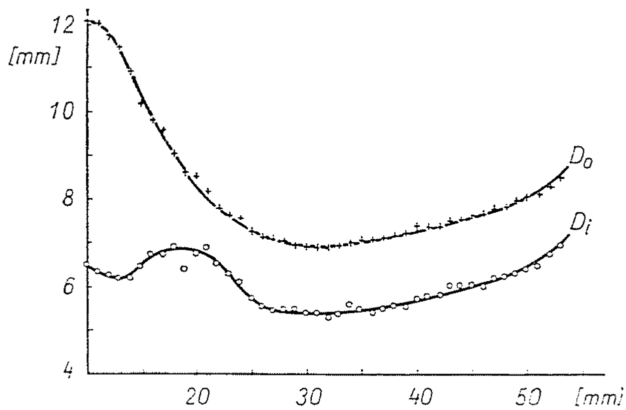

Fig. 6. Inner and outer diameters D_i and D_0 of a thigh-bone *vs.* the bone length

Summary

Double exposure holographic interferometry was used to determine the deformation of bones under static load. Displacement yields further information on the local strain and other mechanical characteristics of the bones.

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Dr. Zoltán FÜZESSY
Prof. Dr. János ANTAL
Dr. Endre BAKAY
Dr. András VAJDA

H-1521 Budapest