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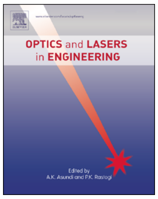

Review

Measurement of electrostriction in bone using digital image correlation

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ABSTRACT

The electromechanical properties of bone may play roles in the growth of bone tissue. The electrostriction effect of bone, which is one of the electromechanical properties of bone, was investigated using the digital image correlation technique (DIC). The advantage of using DIC is that the light beam used for the displacement measurement does not interfere with the electric field exerted on the bone specimen. To measure the bending deflections of a bone cantilever in an electric field, the displacement of the free end surface of the cantilever was measured using the image correlation technique. The experimental results show that the bending direction of the bone cantilevers is independent of the electric field direction and that the bending deflections are proportional to the square of the applied voltages. The attractive force between the charges on the electrode and the unlike charges in the specimen can be equivalent to a uniform distribution load regardless of the thickness of the bone specimen.

Contents

1. Introduction

Bone has electromechanical properties (stress-generated potentials SGPs) that may be related to whether the electric potential has an influence on the growth of bone cells. According to Wolff's law [1–4], bone can change its mass, shape and density to adapt to its external environment, and this process is called bone remodeling. A hypothesis is that the electric potentials produced by stress may also influence the remodeling of bone.

The piezoelectric property of bone was found in 1950s [5–7], and this was one of the origins of SGPs. In the early studies, bone was considered a typical piezoelectric material similar to quartz crystals [8–10], and most studies focused on determining its piezoelectric matrix. However, as a type of inhomogeneous and anisotropic biomaterial, the piezoelectric behaviors of bone are very complicated. To date, its electromechanical properties have not yet been fully understood. Accordingly, it is appropriate to study this problem from various aspects. With the progress of technology, piezoelectric force microscopy and atom force microscopy were employed to study the piezoelectric properties of bone based on its converse piezoelectric effect [11,12], which measures the deformation of bone induced by an external electric field.

Our original goal was to measure the converse piezoelectric properties of bovine bone using the digital image correlation (DIC) because the light beam from a microscope did not disturb the

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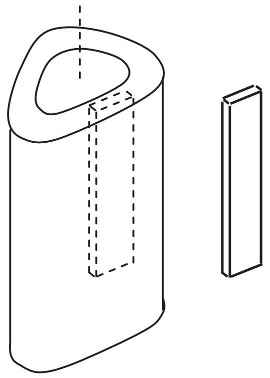

Fig. 1. Thin plate-like specimens and location in the diaphysis of bovine tibia.

electric field around the bone specimen. However, the results showed that the measured deformation arose from electrostriction instead of piezoelectricity. The difference between the electrostriction and the piezoelectric effects is that the former is a quadratic effect and the latter is a linear effect [13,14].

Electrostriction is a property of dielectric materials [15], and the measurements of the deformation of dielectric films caused by an electric field are useful methods to study their electrostrictive properties. Watanabe et al. [16,17] measured the bending deformation of polyurethane films in an electric field. A strip-like film was coated with gold on both surfaces as electrodes and vertically suspended in air. As a voltage of 40 V (corresponding to an electric field strength of 200 V/mm) was applied between the electrodes, a laser displacement meter was used to measure the deflection of the free end of the film. Kunanuruksapong et al. [18] studied the electrostriction of elastomer using another method. An elastomer cantilever with a length of 23 mm was immersed vertically into silicone oil between two parallel copper electrode plates. The electric field, which ranged from 0 to 400 V/mm between the electrodes, induced the cantilever to bend. The deflections of the cantilever were measured by a CCD video camera, and the displacements were obtained directly from the digital image due to the large deflections, which ranged from 2 to 12 mm.

In this study, the electrostrictive effect of bone was investigated. The deflections of the free end of bone cantilevers with different thicknesses were measured using digital image correlation as an external electric field was applied to them. It was found that the bending deflection is proportional to the square of the applied voltage or electric field intensity.

2. Materials and methods

The bone specimens were harvested from mid diaphysis of dry bovine tibias and machined into thin beams with a rectangle cross section (length of 50 mm, thickness of 1 mm and width in the range of 5–8 mm), as shown in Fig. 1.

The experimental setup is illustrated in Fig. 2. A cantilever specimen with a span of 35 mm was fixed vertically at its bottom end. Two copper plate electrodes with a width of 12 mm were placed on the two sides of the specimen parallel to its surfaces. A high-voltage amplifier (Trek 610D-k-CE H.V. Supply Amplifier/controller, Trek Inc.) was employed to apply both positive and negative voltages to the electrodes, which produced a uniform electric field in the gap between them. The left electrode was connected to the grounding terminal of the amplifier and grounded to the earth. The right electrode was connected to the voltage output terminal, and the sign of the voltage applied could be changed by a switch on the amplifier panel.

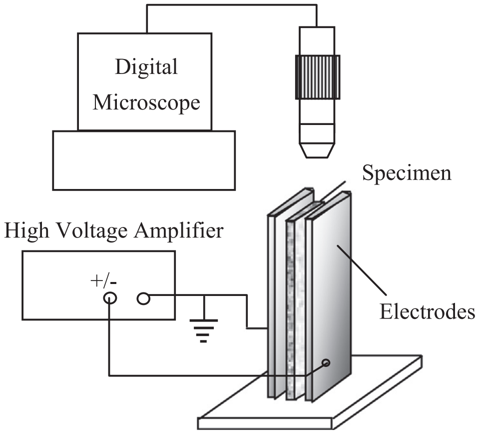

Fig. 2. Setup of the measurement system.

Fig. 3. Image of the microstructure texture of bone.

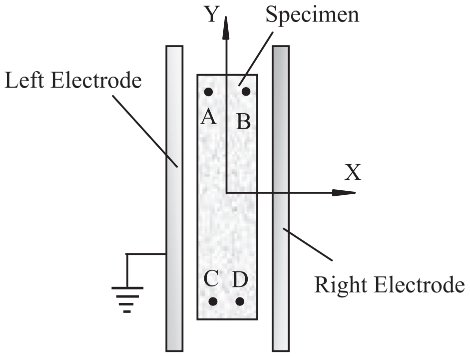

Fig. 4. Top view of the specimen and electrodes.

The commonly used contact-type displacement sensors were unsuitable to measure the deflections because their probe tips might disturb the electric field when they are placed near the bone specimen. Because the two electrode plates interrupted the beam of light, the laser displacement meter used in the literature [16,17] was also unsuitable for the deflection measurement.

The digital image correlation technique (DIC) [19–22] provided an approach to overcome the challenges faced in this study. The object distance of the microscope used was greater than 14 mm, which implies that the distance between the objective lens and the specimen top end surface or the electrode top ends was