Materials Sciences & Technology
Biomaterials

Figure 1: (Left) An intact bovine cornea being pressurized. The cornea appears green-blue due to illumination coming from inside the pressure chamber. Speckles on the surface of the cornea are graphite particles used to create contrast for 3D digital image correlation. At the edge of the cornea, the intact tissue is held rigidly using a custom saddle-shaped fixture that was designed and fabricated directly from a 3D image of the ocular globe.

Cornea Mechanics: Probing Bio-engineered Materials

Explaining the mechanical behavior of corneas leads to new general theory of viscous-fiber reinforced composite materials.

Technical Contact:
Brad Boyce
505-845-7525
blboyce@sandia.gov

Reese Jones
925-294-4744
rjones@sandia.gov

Science Matters Contact:
Alan Burns, Ph.D.
505-844-9642
aburns@sandia.gov

The eye is a magnificently engineered opto-electro-mechanical device. Clinicians and researchers are continuously striving to better understand the connections between the eye's anatomy and its functionality. In the case of the cornea, the transparent curved membrane at the front of the eye that refractively gathers and helps to focus light, the fixed shape is critical. Thus mechanical response of the cornea is relevant to diseases (e.g., keratoconus), surgical procedures (e.g., LASIK), prosthetics, and clinical practice. In glaucoma screening, a "tonometer" probe is used to deform the patient's cornea, thereby indirectly measuring intraocular pressure based on an assumed stiffness of the cornea. To better understand the mechanical response of cornea tissue and its relation to the underpinning structure of the cornea, Sandia is applying decades of experience in mechanical behavior of materials.

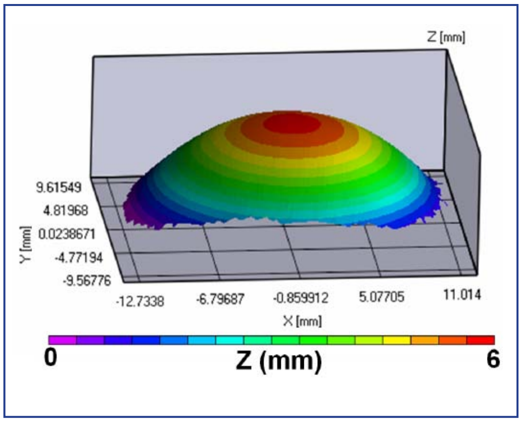

Figure 2: A 3D map of the shape of the cornea. These maps are acquired in real-time to track the pressure-driven deformation of the cornea during inflation testing.

To study the properties of this complex tissue, researchers originally used a conventional tensile test on a strip of bovine cornea. However, the tensile test fails to mimic the biaxial loading condition of real eyes. To remedy this problem, Sandia researchers developed a whole-cornea inflation test that mimics real physiologic deformation. As the entire cornea is inflated while still attached to the white sclera of the ocular globe (Figure 1), the deformation is mapped with real-time, high-resolution 3D digital image correlation (Figure 2).

These tests revealed an intricate time-dependent deformation response that could not be described with existing theory. Instead, Sandia developed a new theory based on the orientation and distribution

Sandia National Laboratories

LDRD
LABORATORY DIRECTED RESEARCH & DEVELOPMENT

of collagen fibrils, the primary structural component of the cornea. This theory, which matches experiments extraordinarily well (Figure 3), has since been generalized to describe a wide range of viscous-fiber reinforced composite materials.

One of the most interesting insights provided by Sandia's research is that the material near the center of the cornea deforms very little during pressure fluctuations: most of the necessary deformation is accommodated around the periphery. This is due to the density and orientation of collagen fibrils in the central cornea, compared to the lower density of circumferentially-oriented fibrils in the periphery. The result of this brilliantly bio-engineered tissue is that our primary vision through the central cornea is largely unaffected by pressure changes.

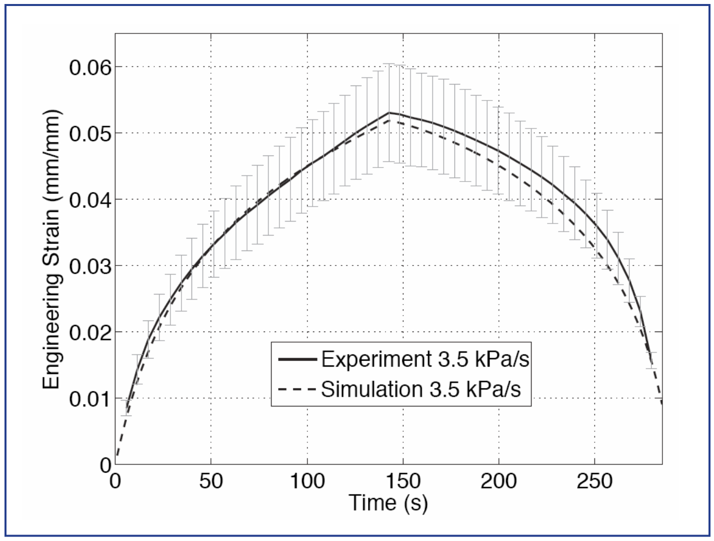

Figure 3: Agreement between experimental results (shown in dashed lines with error bars representing the standard deviation of 9 tests) and predictions using the newly developed multi-mode viscous-fiber composite theory.

Sandia National Laboratories

National Nuclear Security Administration

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. SAND 2008-0486P

01/2008