Surface Micromechanical Testing Methods for Contact Lenses: Indentation, Friction and Dehydration

Gilbert, JL, Lewis, E,
Syracuse Biomaterials Institute, Department of Biomedical and Chemical Engineering, Syracuse University

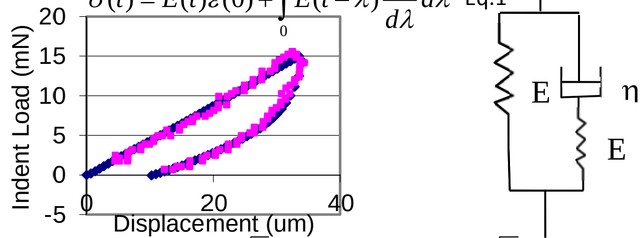
Introduction: A major focus of hydrogel-based contact lenses are their surface properties like modulus, hardness and friction, and the effect of storage solutions on behavior. Comfort is a primary concern. The underlying hypothesis of this study is that comfort and surface mechanical behavior are dependent on the hydration state of the lens. This study presents methods to investigate the surface micromechanical properties of contact lenses to study issues related to the comfort of the lens. This study explores specific micromechanical test methods of indentation and friction to explore surface mechanical properties. The effect of short-term dehydration on the coefficient of friction is presented. This work is meant to demonstrate methods that will be used to explore comfort-related parameters in subsequent studies.

Materials and Methods: Two basic measurement methods are presented: Indentation testing and friction measurements during dehydration. Indentation test methods utilize a custom built micromechanical test system that allows x, y, z positioning and depth sensing indentation testing. A 50 um alumina tip is indented to various depths and the load-deflection behavior is captured. From these data the hardness (H), modulus (E) and energy dissipation factor (EDF) can be calculated. Additionally, the load-deflection behavior can be modeled with both an elastic-based method using Sneddon's equation for modulus, or with a standard linear viscoelastic heredity integral approach. Analysis of results includes standard methods for modulus but also Eq. 2 can be integrated numerically to find the modulus, based on the F vs δ plots. All contact lenses are cross-linked viscoelastic materials which exhibit time and frequency dependent behavior. The standard-linear viscoelastic model parameters were found by fitting the load-deflection curves with a heredity integral based equation (Eq. 1). Indentation tests were performed as a function of frequency, indent depth and location on two commercially available lenses (Acuvue Oasys^{TM}, and CIBA AirOptix^{TM}). Because lenses are only in the 100 um thickness range, the effect of indent depth during testing is important. Indentation tests can be repeated across the lens surface to obtain a profile of mechanical properties.

The second test method explored is the frictional interaction between contact lenses and an opposing surface (polished titanium surface). In these experiments, the whole contact lens was mounted in a holder and driven into the opposing surface to a fixed load (10 mN to 300 mN) and slid 3 mm back and forth. The opposing surface was mounted on a flexible cantilever platform instrumented to measure lateral friction loads with sliding. The coefficient of friction was measured both in a fully hydrated state as a function of normal load, and as the lenses dehydrated over 20 min at a fixed load.

Results: Indentation tests can be modeled using both the heredity integral approach and the integrated Sneddon Eqn approach. Fig. 1 shows a typical contact lens indent test with the SLM fit of the data.

$$\sigma(t)=E(t)\varepsilon(0)+\int_0^t E(t-\lambda)\frac{d\varepsilon}{d\lambda}d\lambda \quad \text{Eq.1}$$



$$E=\frac{(1-\nu^2)}{2}\frac{\sqrt{\pi}}{\sqrt{A}}\frac{dF}{d\delta} \qquad \frac{dF}{d\delta}=\frac{2E}{1-\nu^2}\frac{\sqrt{A}}{\sqrt{\pi}} \quad \text{Eq.2}$$

Fig 1: Contact lens indentation test, viscoelastic model and equations.

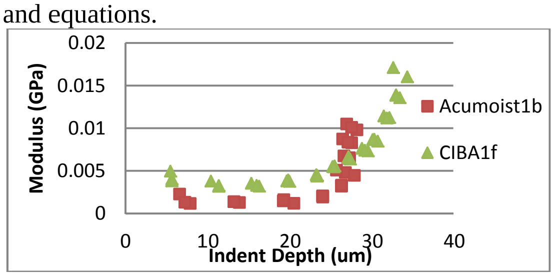


Fig. 2 shows results of contact modulus versus indent depth for CIBA and Acuvue.

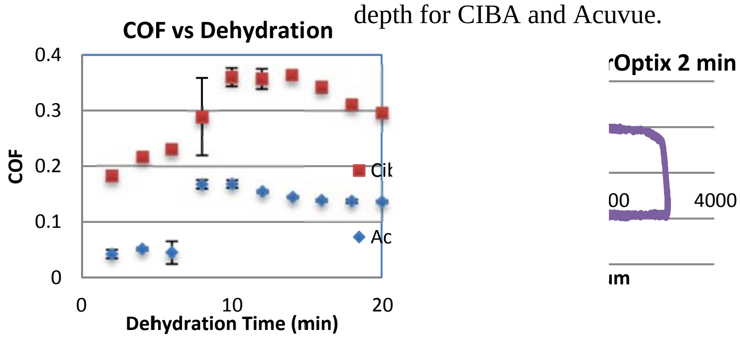


Fig 3: COF as a function of dehydration.

Fig. 2 shows how modulus varies with the depth of indentation with optimal testing at between 10 and 20 um. The COF (Fig. 3) of both lenses show increases with dehydration but also differences in behavior.

Discussion and Conclusions: The combination of test methods described allow for an integrated multiple test approach to the study of contact lens performance. Indentation profiling across a lens and dehydration, along with friction and adhesion tests will provide insight into contact lens compositions, solution chemistry, and dehydration state and their role in the surface properties related to comfort. **Acknowledgements:** Bausch and Lomb