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Journal

INVESTIGATIVE OPHTHALMOLOGY & VISUAL SCIENCE, 56(7)

ISSN

0146-0404

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Publication Date

2015

Peer reviewed

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Investigative Ophthalmology & Visual Science June 2015, Vol.56, 6111. doi:

Abstract

Purpose

Minimal sliding friction of soft contact lenses (SCLs) is now considered critical to wear comfort. Recently, SCLs (DAILIES TOTAL1, DT1) have been introduced to reduce sliding friction by coating a silicone-hydrogel core with a 10- μm thick hydrophilic surface gel of high water content (ARVO 2014 E-6071). At this thickness, the surface gels exhibit bulk gel properties. To ascertain whether softness (i.e., low modulus) of high-water-content surface gels leads to low sliding friction, we synthesized high-water-content bulk gels and determined their moduli and sliding-friction coefficients.

Methods

Bulk gels were synthesized by thermally reacting hydrophilic azetidinium-functionalized polymer (polyamidoamine epichlorohydrin, PAE) with random hydrophilic copolymer (poly(acrylamide-co-acrylic acid), 500 kDa, 80/20, pAAM/AA) in aqueous solution at 85 $^{\circ}\text{C}$ for 2 h. Solutions consisted of varying PAE:pAAM/AA mass ratios and 80 wt% phosphate buffer saline (PBS). Following equilibration in PBS for 2 d, equilibrium water contents (w), zero-frequency storage and loss moduli (and $\tan \delta$), and critical coefficients of sliding friction (CCOF) were obtained from gravimetric analysis, oscillatory shear rheology, and the inclined-plane method of Peng et al. (ARVO 2014 E-4062), respectively.

Results

Table 1 reports water contents, storage/loss moduli, and CCOFs for the synthesized gels. The last two rows report corresponding values for DT1 surface coatings and a PHEMA gel. All PAE:pAAM/AA gels have high water content greater than 90%. Storage moduli are larger than loss moduli. PAE:pAAM/AA gels are “soft” with storage moduli 100 times smaller than PHEMA. Storage moduli decrease with increasing water content, although small changes in water content lead to large changes in storage moduli. For all gels studied, CCOF is low and basically unchanged.

Conclusions

For high-water-content gels, large changes in storage modulus occur with minor changes in water content. Hence, gel chemistry/structure is more important in determining gel softness than is water content. CCOF, although low, is insensitive to water content. Two possible explanations are: (1) at low CCOF values, the sensitivity limit of the inclined-plane method is reached; (2) CCOF is determined by gel surface properties not reflected in the storage moduli, such as dangling polymer ends (ARVO E-Abstract 500).

Table 1.
Water Contents, Storage/Loss Moduli, and Friction Coefficients of PAE:pAAM/AA Bulk Gels

Bulk-Gel Mass Ratio, PAE:pAAM/AA	Water Content, w	Storage/Loss Modulus, $G'(0)/G''(0)$ [Pa]	Friction Coefficient, CCOF
1:0	0.89	$2,090 \pm 69 / 91 \pm 13$	0.08 ± 0.01
1:1	0.92	$1,452 \pm 63 / 4 \pm 2$	0.05 ± 0.01
1:2	0.91	$13,300 \pm 58 / 132 \pm 9$	0.06 ± 0.01
3:1	0.95	$518 \pm 81 / 27 \pm 2$	0.05 ± 0.01
6:1	0.96	$541 \pm 75 / 22 \pm 3$	0.04 ± 0.01
DT1 (surface layers)	0.91 ^a	$G'(0) \sim 8,300$ ^b	0.04 ± 0.01 ^{c,d}
pHEMA	0.38	$220,000 \pm 59 / 10,000 \pm 7$	0.07 ± 0.01

^a from Liu et al. (ARVO 2014 E-6071)
^b from Dunn et al. (Tribol. Lett. 2013)
^c from Peng et al. (ARVO 2014 E-4062)
^d Dunn et al. (Tribol. Lett. 2013) report 0.02

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