

Poly(vinyl alcohol)-poly(2-acrylamido-2-methyl-1-propane sulfonic acid) hydrogels as a synthetic cartilage material

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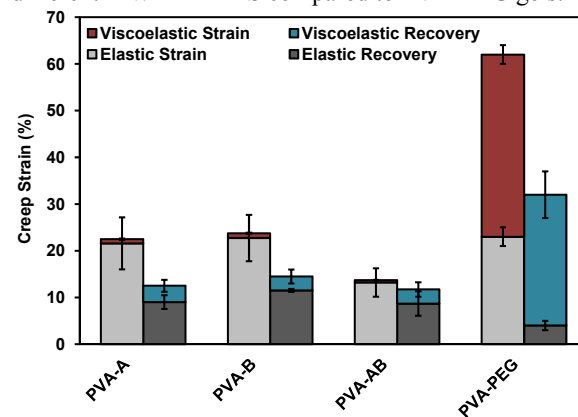
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Statement of Purpose: Poly(vinyl alcohol) (PVA) hydrogels are a strong candidate for synthetic cartilage replacements due to their lubricity, viscoelasticity, and biocompatibility. Previously, our lab has shown that PVA hydrogels can be enhanced by poly(ethylene glycol) (PEG) immersion, which protects pores from collapsing during subsequent thermal annealing [1]. To compensate for the loss of equilibrium water content that results from the annealing process, a secondary polymer can be blended into the primary polymer matrix to improve lubricity and strength [2]. Poly(2-acrylamido-2-methyl-1-propanesulfonic acid) (PAAMPS) is a potentially useful secondary polymer because PAAMPS hydrogels demonstrate high strength, low surface friction, and even potential for cartilage regeneration [3]. Thus, we propose that the addition of PAAMPS to a PVA hydrogel matrix will produce a highly lubricous, creep resistant, and tough cartilage-like hydrogel. We examine the effects of varying the molecular weight (MW) of PAAMPS and immersion in different MW PEG blends on the physical and mechanical properties of the resultant gels. We compare these results to previously reported PVA-PEG theta gels.

Methods: PVA-PAAMPS hydrogels were prepared by dissolving PVA (MW=115,000g/mol) and PAAMPS at a ratio of 19:1 in DI water (25% polymer, 75% water) at 90°C and mixing for at least 6 hours. Three gels with different MW PAAMPS solutions were made: (i) 1,300,000 g/mol (PVA-A), (ii) 800,000 g/mol (PVA-B), and (iii) equal amounts of PVA-A and PVA-B (PVA-AB). The hydrogel solutions were poured into molds and immediately placed into the freezer at -20°C for 16 hours and then removed to thaw at room temperature for 8 hours. The gels were dehydrated in different PEG blends (i) 100%-MW400 (PEG-1), (ii) 60%-MW600/40%-MW400 (PEG-2), or (iii) 80%-MW400/20%-MW200 (PEG-3) for 40 hours at 55°C and then, still immersed in PEG, the gels were dehydrated at 80°C for at least 20 hours and annealed for 1 hour at 160°C in air. Subsequent to annealing, gels were rehydrated in DI water at 40°C until equilibrium. The **equilibrium water content (EWC)** was measured using a thermogravimetric analyzer. The **elastic modulus (EM)** and other tensile properties were measured with an MTS mechanical tester. **Total creep strain (TCS)** was determined under 0.1 MPa compression for 1 hour using 17mm diameter samples. **Relative coefficient of friction (rCOF)** was determined using a stress controlled rheometer to measure torque, normal force, and angular velocity and applying the Kavehpour and McKinley method to calculate rCOF [4]. **Results:** PVA-PAAMPS gels displayed a high EWC of 66%-67% due to the hydrophilic nature of PAAMPS. The rCOF of PVA-PAAMPS gels was 0.03-0.04, an order of magnitude less than PVA-PEG (Table 1). The enhanced lubricity is likely due to the water uptake ability of PVA-PAAMPS and the ionic nature of PAAMPS. Varying the

MW of PAAMPS in the PVA-PAAMPS gels had little effect on the EWC and rCOF. Changing the MW of PAAMPS from 800,000 to 1,300,000 increased the modulus from 3 MPa for PVA-B to 4 MPa for PVA-A (Table 1). While PVA-AB displayed the lowest creep strain of 14%, all PVA-PAAMPS gels were much more creep resistant than PVA-PEG (Figure 1, Table 1).

Figure 1. Creep strain of PVA-PAAMPS gels with different MW PAAMPS compared to PVA-PEG gels.



Immersion in different PEG blends resulted in minimal variation of TCS and EWC (Table 1). The PEG-1 mixture was the best, as it yielded the most lubricous PVA-PAAMPS gel with an rCOF of 0.03, with an EM of 4 MPa. The PEG-2 mixture yielded a 1.5 times higher EM, accompanied with nearly an order of magnitude increase of rCOF. The PEG-3 mixture also displayed a similar increase in rCOF (Table 1).

Table 1. Equilibrium water content, relative coefficient of friction, elastic modulus, and total creep strain for different MW PVA-PAAMPS gels and PEG mixtures.

Sample	EWC (%)	rCOF	EM (MPa)	TCS (%)
PVA-A	66 ± 0.6	0.04 ± 0.007	4 ± 1	23 ± 5
PVA-B	67 ± 0.5	0.03 ± 0.004	3 ± 0.1	24 ± 5
PVA-AB	66 ± 0.3	0.03 ± 0.008	4 ± 0.8	14 ± 3
PVA-PEG	79 ± 0.6	0.4 ± 0.06	2 ± 0.1	62 ± 1
PEG-1	66 ± 0.3	0.03 ± 0.008	4 ± 0.8	14 ± 3
PEG-2	59 ± 3	0.2 ± 0.03	6 ± 0.1	15 ± 3
PEG-3	63 ± 1	0.1 ± 0.002	4 ± 0.1	17 ± 4

Conclusions: Current treatment options for early stage cartilage injuries are few and have limited success. By adding PAAMPS into a PVA hydrogel matrix, we have successfully formed a highly lubricous, creep resistant, and strong gel. Such cartilage-like properties make PVA-PAAMPS gels a potential candidate for synthetic cartilage replacement to treat early stage cartilage injuries.

References: [1] Bodugoz-Senturk H. Biomaterials 2008; 29:141-149. [2] Bodugoz-Senturk H. Biomaterials 2009; 30:589-596. [3] Gong J. Soft Matter 2010;6:2583-2590. [4] Kavehpour HP. Tribology Letters. 2004;17:327-335.