2017 International Bionic Innovation Competition

Designing bionic articular cartilage on UHMWPE as a promising material for joint lubrication

Abstract

Lubrication is key for the efficient function of ultra high molecular weight polyethylene (UHMWPE) bearing material in artificial joint applications. The natural articular cartilage (AC) system, containing the porous collagenous network and the bio-macromolecule brushes, provide the efficient lubrication and extraordinarily low friction. Here, we prepared a bionic articular cartilage on UHMWPE with two steps: employing the sodium chloride leaching technique to form an interconnected porous UHMWPE, and then the modification of 2-methacryloyloxyethyl phosphorylcholine (MPC). The porous structure and molecular brushes of AC were mimicked. The wettability was improved, at 0 ° contact angle. The bionic articular cartilage exhibited excellent lubricity, a low friction coefficient, about 0.03, and the value was stable in a long-term test (60 h), essentially duplicating the key features of cartilage in order to prepare the cartilage mimetic lubrication system.

Methods

First step, preparation of porous UHMWPE. The mixture of UHMWPE-sodium chloride granules were hot pressed, and then the sodium chloride in the composite disk were removed by extraction using water. Second, graft modification of the porous UHMWPE. The porous plates coated with benzophenone were immersed in aqueous MPC solution. Photo-induced graft polymerization was conducted for 30 min under a 500 w high pressure mercury lamp. After that, the modified specimens were rinsed in ethanol and dried in vacuum.

Results

An interconnected porous UHMWPE was successfully created and the SEM images in Figure 1A revealed a well-defined highly dense porous structure with interconnected porescreated through overlapping of large single crystal formations. The sodium chloride content has a great influenceon the porosity and weight loss ratio.

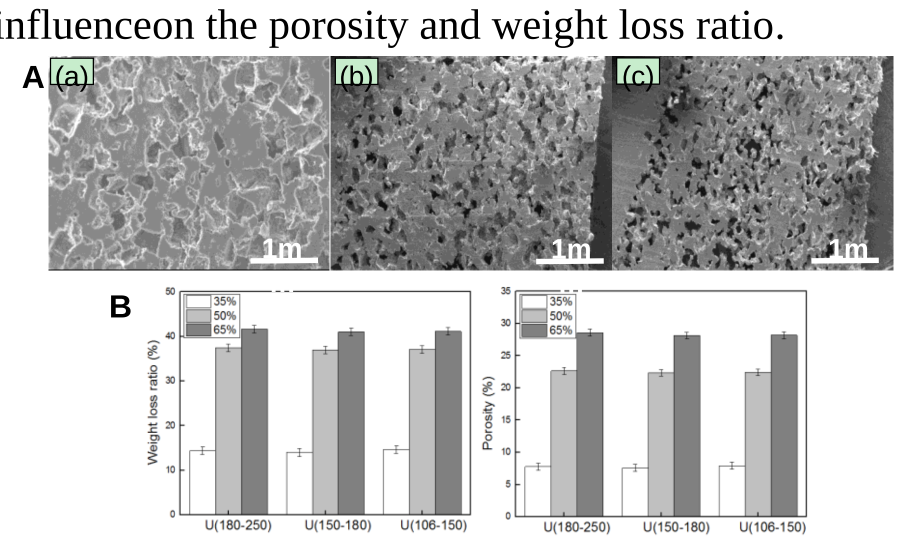

Figure 1. Cross-sectional analysis of porous sample. A) Cross-sectional SEM images of porous UHMWPE. U(180-250). b) U(150-180). c) U(106-150). B) The weight loss ratio and porosity of porous UHMWPE.

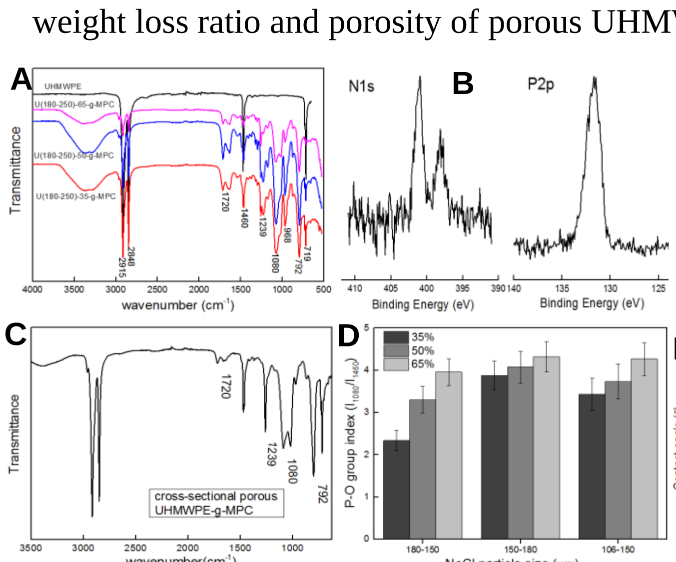

Figure 2. Characterizations of porous UHMWPE-g-MPC. A) FT-IR/ATR spectra of UHMWPE and PMPC-grafted UHMWPE. B) XPS spectra of UHMWPE-g-MPC. C) FT-IR/ATR spectra of the cross-sectional porous UHMWPE-g-MPC. D) P-O group index as a function of NaCl content.

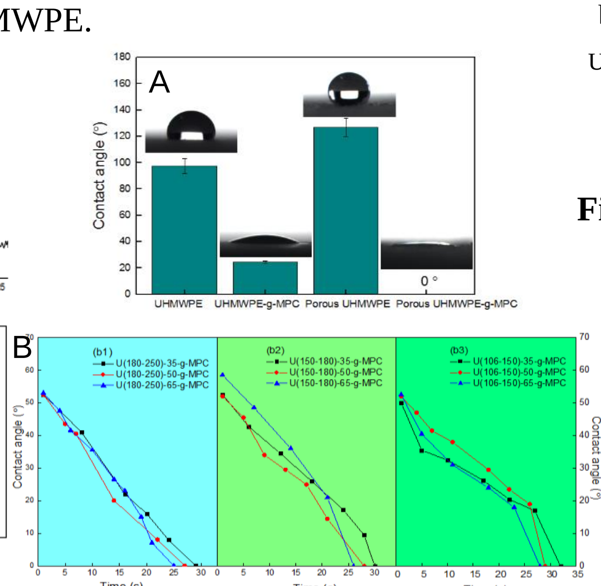

Figure 3. Water-contact angle. A) The contact angle with final steady state of a water droplet on different sample. B) Water contact angle of porous UHMWPE-g-MPC as a function of the time.

MPC polymer chains were grafted on the interconnected porous UHMWPE to mimic the charged proteoglycans brushes within the collagen network of AC. These results of FT-IR/ATR and XPS spectra indicate clearly that MPC was successfully grafted on the UHMWPE. The samples were sliced in half and the transmittance absorption peaks of phosphate group were observed (Figure 2C), which indicated that MPC was grafted onto the interior of the pore. The P-O group index which is proportional to the fixed MPC polymer chains on the porous UHMWPE increases with the increase of NaCl content.

The hydrophilicity of MPC modified UHMWPE were improved significantly. When the water droplet on the surface of porous UHMWPE-g-MPC reached a steady state, it spread out completely and the contact angle was 0 ° .

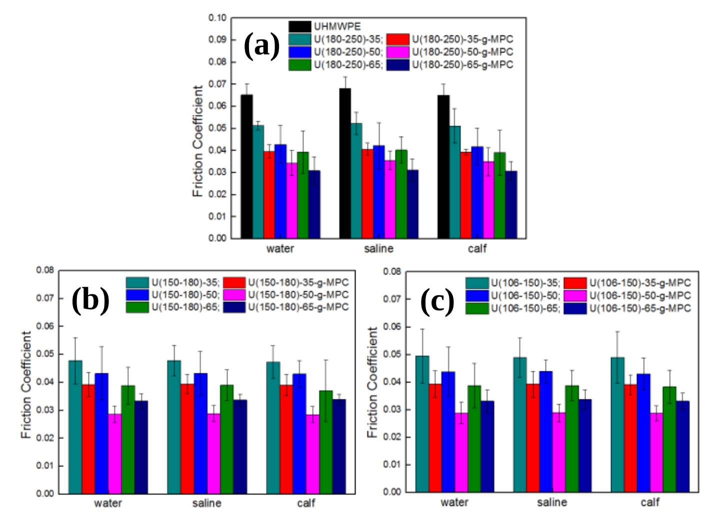

Figure 4. The average friction coefficient of porous UHMWPE and porous UHMWPE-g-MPC with different contents and sizes sodium chloride.

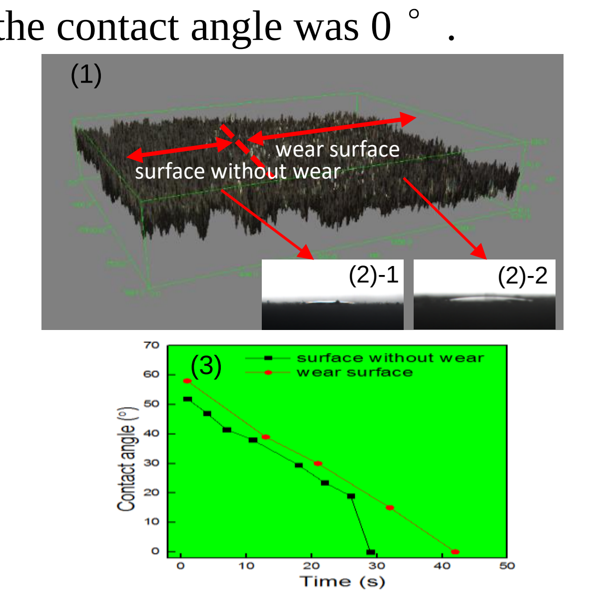

Figure 5. Wear morphology and contact angle of porous UHMWPE-g-MPC after friction test. (1) the wear morphology; (2) the contact angle after friction test. (2)-1 the contact angle of sample surface without friction test; (2)-2 the contact angle of wear surface. (3) The water contact angle as a function of time.

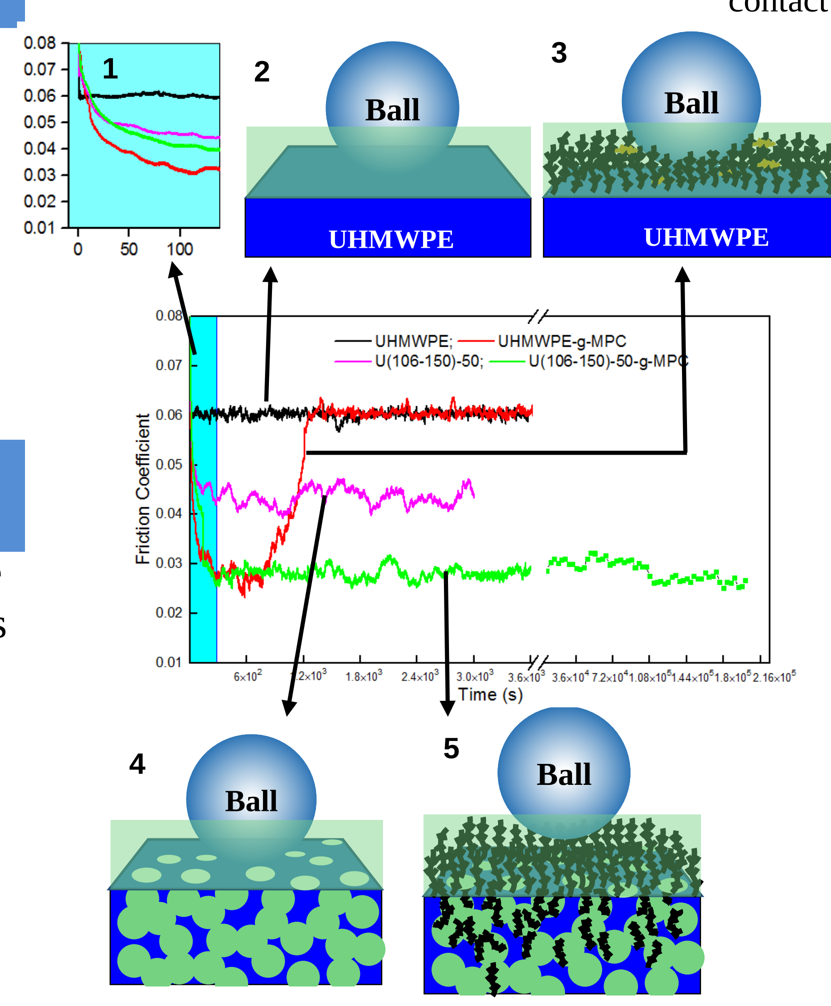

Figure 6. Friction properties and schematic diagram of pristine and modified UHMWPE

The porous UHMWPE -g-MPC has the lowest average friction coefficient. After the long term testing (about 60 h), it still has excellent tribological performance. The contact angle of wear surface was still 0° , however the time at which contact angle become zero increased (Figure 5). The UHMWPE-g-MPC plate sample had the lowest friction coefficient at initial stage due to the rigid and dense UHMWPE substrate (Figure 6(1)). With the increase of time, the polymer brushes were gradually cut off and eventually worn out leading to direct contact of friction pair. Therefore, the friction coefficient was approximately equal to pristine UHMWPE at last. The bionic articular cartilage of porous UHMWPE-g-MPC has the structure of porous and polymer brushes, that is similar to the structure of articular cartilage (Figure 7). The porous structure could store and release the lubricants, leading to hydrodynamic lubrication. The MPC polymer brushes absorb the water molecules and form the hydration layers which provided the extreme boundary lubrication via the hydration lubrication mechanism.

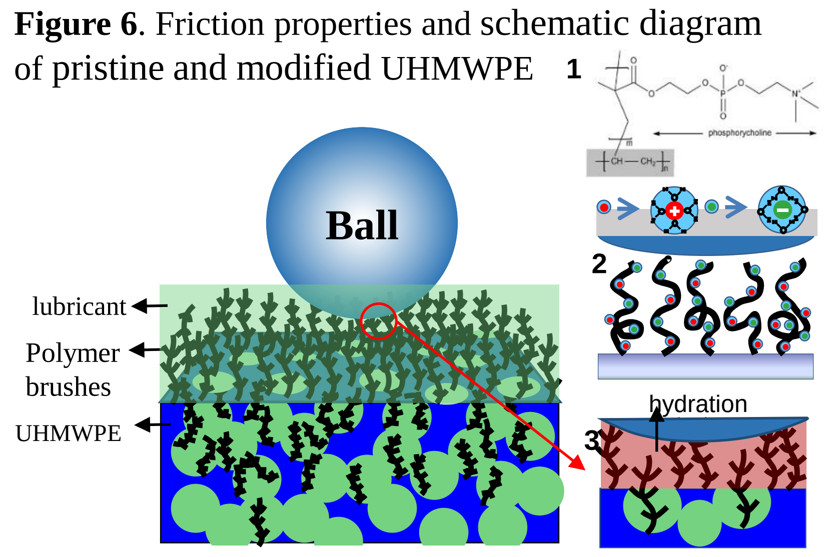

Figure 7. Schematic diagram of porous UHMWPE-g-MPC

Conclusions

A bionic articular cartilage on UHMWPE by mimicking central features of articular cartilage system were created successfully. The bearing interface showed good wettability with 0° contact angle and the material still contained super-wettability after the long term testing. The friction coefficient decreased significantly (about 0.03). The lubricity was achieved by the hydrodynamic lubrication of porous structure and boundary lubrication of MPC polymer brushes. The key features of cartilage have been duplicated.

Publications/patents or Rewards

Study on tribological properties of UHMWPE grafted with MPDSAH. *Materials Science & Engineering C*, 2013, 33(3): 1339-1343.

The mechanical properties of the ultra high molecular weight polyethylene grafted with 3-dimethy (3-(N-methacryamido) propyl) ammonium propane sulfonate. *Journal of the mechanical behavior of biomedical materials*, 2014, 35:18-26.