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Sliding Wear Behavior of UHMWPE against Novel Low Temperature Degradation-Free Zirconia/Alumina Composite

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The sliding wear behavior of ultra high molecular weight polyethylene (UHMWPE) was examined on a novel low temperature degradation-free zirconia/alumina composite material and conventional alumina and zirconia ceramics used for femoral head in total hip joint replacement. The wear of UHMWPE pins against these ceramic disks was evaluated by performing linear reciprocal sliding and repeat pass rotational sliding tests for one million cycles in bovine serum. The weight loss of polyethylene against the novel low temperature degradation-free zirconia/alumina composite disks was much less than those against conventional ceramics for all tests. The mean weight loss of the polyethylene pins was more in the linear reciprocal sliding test than in the repeat pass rotational sliding test for all kinds of disk materials. Neither the coherent transfer film nor the surface damage was observed on the surface of the novel zirconia/alumina composite disks during the test. The observed results indicated that the wear of the polyethylene was closely related to contacting materials and kinematic motions. In conclusion, the novel zirconia/alumina composite leads the least wear of polyethylene among the tested ceramics and demonstrates the potential as the alternative materials for femoral head in total hip joint replacement.

Keywords : Wear, UHMWPE, Zirconia, Alumina, Zirconia/Alumina Composite

1. INTRODUCTION

Ultra high molecular weight polyethylene (UHMWPE) has been successfully employed as an acetabular cup material articulating against hip joint femoral head. However, it has been proved that submicron sized UHMWPE wear debris caused aseptic loosening failure of total hip joint. Therefore, to minimize the polyethylene wear, ceramic femoral heads have been developed. Recently, zirconia, consisted of 97 mol% ZrO_2 and 3 mol% Y_2O_3 (3Y-TZP), has been considered one of the major ceramic materials for the hip joint heads. More than 400,000 zirconia hip joint heads have been implanted worldwide since 1985 [1]. In recent reports, however, zirconia head has been deteriorated [2, 3] in the long-term clinical usage due to the low temperature degradation of the zirconia.

A low temperature degradation (LTD)-free tetragonal zirconia polycrystal (TZP)/alumina composite was developed and showed the low temperature phase stability and good mechanical properties compared with those of 3Y-TZP. For clinical application of this zirconia/alumina composite, the characterization of UHMWPE wear behavior against novel LTD-free zirconia/alumina composite is compulsory. In the present study, the sliding wear of UHMWPE was examined on the novel low temperature degradation-free zirconia/alumina composite and compared with that on the conventional alumina and zirconia ceramics used for total hip joint heads.

2. MATERIALS AND METHODS

2.1 Specimen

Orthopaedic grade powders of alumina, zirconia and low temperature degradation-free zirconia/alumina composite were die-pressed into disks, and then isostatically pressed at 140 Mpa. The green compacts were sintered for 2 h at 1550°C in air. Sintered disks(10mm thick 55mm diameter) were grinded and polished to Ra = 0.03 ㎛.

Ram-extruded GUR 4150HP UHMWPE rod stock (70mm, Westlake Plastic, Lenni, PA, USA) was machined to right angle circular cylindrical pin specimens (8mm long 10mm diameter) for the wear tests.

2.2 Wear Test

Pin-on-disc sliding wear tests were conducted with the polyethylene pins against alumina, zirconia, LTD-free zirconia/alumina composite disks in bovine serum at room temperature. Disks moved in the two different kinematic motions of linear reciprocal sliding and repeat pass rotational sliding. A lever arrangement and a dead weight of 315N exerted a nominal contact pressure of 4 MPa, which was equivalent to average contact pressure in the hip joint for the normal gait. A frequency of 1 Hz produced a sliding velocity of 62.5 mm/s at the center of the cylinder specimen for both kinematic motions. All test were interrupted after every ten thousand cycles, the specimen was cleaned with deionized water, dried with a tissue, and weighed with a microbalance (sensitivity of 0.01mg). Wear testing was continued for one million cycles that were equivalent to a total sliding distance of 62.5km. The amount of wear was determined by weight loss of each pin specimen, which was corrected for the weight gain that was obtained from soak control tests.

3. RESULTS

The variation of mean weight loss of UHMWPE pins against alumina, zirconia and zirconia/alumina composite disks during the entire test duration was plotted in Fig. 1 as a function of number of cycles and two different kinematic motions. Fig. 1 also included the wear results of UHMWPE pins against orthopaedic grade stainless steel (SS 316L) disks from the previous work tested by the same protocol [4].

Every wear of UHMWPE pins against three kinds of ceramic disks increased almost linearly through the entire testing duration of one million cycles and showed 59-78% lower wear than that against SS 316L. The wear of UHMWPE pins against SS 316L increased rapidly in the

early period of testing and reached a steady state. In the viewpoint of two different kinematic motions, the mean weight loss of UHMWPE pins tested in a linear reciprocal motion was 2～3 times higher than that in a repeat pass rotational motion for all ceramic disks. The comparison among the three kinds of ceramic disks showed that the wear rates (wear per cycles) was in the high order of zirconia, alumina, zirconia/alumina composite in a linear reciprocal motion, and the wear rates (wear per cycles, the slope of linear wear variation) was in the high order of alumina, zirconia, zirconia/alumina composite in a repeat pass rotational motion.

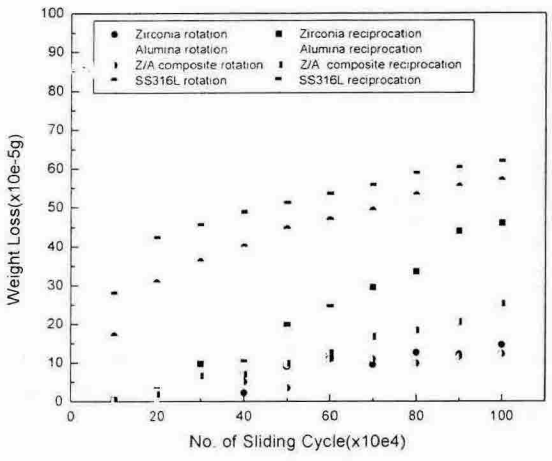

Fig. 1 Variation of mean wear of UHMWPE pins against zirconia, alumina and zirconia/alumina composite.

After one million cycles of sliding mean weight loss of UHMWPE pins against zirconia, alumina, zirconia/alumina composite, and SS 316L disks was plotted in Fig. 2 again. The wear of UHMWPE pins against the novel zirconia/alumina composite disks was 55～58% lower than that against conventional zirconia and alumina disks in a linear reciprocal motion, respectively, and it was same as that against zirconia and 54% lower than that against alumina disks in a repeat pass rotational motion.

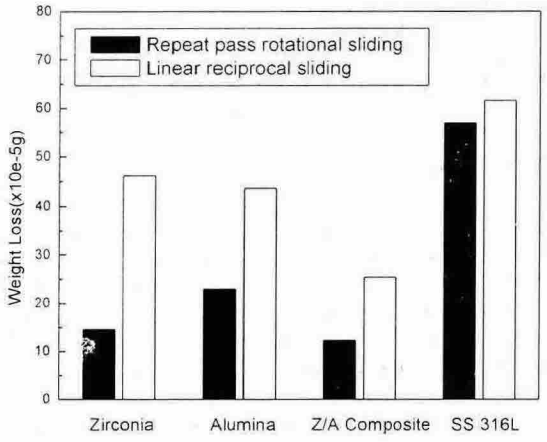

Fig. 2 Comparison of mean wear of UHMWPE pins against all tested disks after one million cycles of sliding under 4MPa.

During the tests it was observed that little amount of transfer film was formed on the sliding track of alumina and zirconia disks and the matching UHMWPE pins had finite scratches on the contact surfaces. This can be interpreted by that micro pitting wear of ceramic surface occurs through the fatigue grain boundary failure under the cyclic contact stress. On the other hand, no transfer film was observed on the sliding track of zirconia/alumina composite disks and the matching contact surfaces of pins had relatively less scratch with no surface damage of zirconia/alumina composite disks.

4. CLOSING REMARKS

From the results of present wear tests the novel low temperature degradation (LTD)-free tetragonal zirconia polycrystal (TZP)/alumina composite induced the less wear amount of contacting UHMWPE than the conventional ceramics used for the total hip joint heads. This enhanced wear resistance is due to the low temperature phase stability and good mechanical properties.

Linear reciprocal motion wore more the UHMWPE pin than did repeat pass rotational motion for all disk materials. It means that the repeated large directional change of contact stresses generates more wear in polyethylene, and thus the wear of the polyethylene is very sensitive to the relative motion between two contact surfaces. The observed results indicated that the wear of UHMWPE was closely related to the kind of contacting materials and the kinematic motions.

In conclusion, the novel zirconia/alumina composite leads the least wear of polyethylene among the tested ceramics and demonstrates the potential as the alternative materials for femoral head in total hip joint replacement.

5. ACKNOWLEDGEMENT

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