Wear Analysis of UHMWPE Using a Load Sum Method

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Introduction An accelerated wear test procedure has been developed for wear screening of ultra-high molecular weight polyethylene (UHMWPE) using a new wear tester[1]. Results showed that the test procedure was able to rank wear level of samples in same order as other methods within seven days. Worn surface texture and wear debris shape were similar to those from retrieval studies.

The test procedure used a Paul-type load curve (two peaks of different magnitude) in each sliding cycle. The test was accelerated by using a periodic load spike which was designed not to change the dominant wear mechanism. For this type of loading, since the load varies with time, the effect of load on wear cannot be easily determined. Many simulation tests including joint simulators use similar load curves. Current practice is to compare mass loss of different materials at the same cycle count. This assumes that the load cycles are completely uniform throughout the test and wear and creep compensation are equal each time for different materials. For the test procedure that uses load spikes, the issue is more complicated. Therefore, a careful analysis of load history for such a test was conducted to examine the effect of load and load spikes on wear.

Experimentation UHMWPE pins with nominal dimensions of 6.35 mm in diameter and 19.1 mm in length were used in the wear experiments. The counterface was a Co-Cr plate with nominal dimensions of 50.8 mm in diameter and 6.3 mm in thickness. The pins were made from GUR1020 sheets and were sterilized by γ-irradiation at 40 kGy in vacuum. Prior to testing, the UHMWPE pins were soaked in bovine serum for a minimum of 14 d. The Co-Cr plate was polished to have a center line surface roughness of approximately 0.05 μm. Bovine serum was used as a lubricant in the wear tests. Four UHMWPE pins were used as soak control. The wear experiments were conducted on a wear tester with a multiaxial sliding pattern and programmed loading[1]. The sliding followed a 'figure-8' multiaxial motion pattern. The average sliding speed was (49±3) mm/s and the cycle frequency was 0.9 Hz. The load was controlled by geometric interference and resembled that of a Paul-type loading curve. The peak load was at 400 N ± 20 N which gave a mean contact pressure of approximately 13 MPa. Periodically, the geometric interference was raised by two PC-controlled piezo-electric actuators for 20 % of the time (2 min/10 min). This is referred to as the "spike load". The magnitude and the frequency of the spike load were the key variables under study in this paper.

During the wear test, load and friction were continuously measured by a 6-axis force transducer at a scan rate of 400 data points per second. For the purpose of this study, these data were continuously stored and numerically integrated. The sum of this load (load sum) at the end of the test was used to examine the wear level. Wear and creep compensation adjustments were also made periodically during the test to maintain the load level. The load traces immediately after adjustments were recorded and stored in a separate file. These load traces were used as typical load traces to project the average load throughout the test. This is the normal test procedure.

Two methods of analysis using "load + spike load" and "load sum" were compared in the results.

Results and Discussion A comparison between the load sum recorded continuously and the calculated sum from the typical load projected from the periodic measurements showed that the projected sum was higher by 5 % of the recorded sum. This suggested that the wear and creep adjustments were within 5 % of the intended load.

The wear data were plotted against the typical cycle count in Fig. 1. Two experimental results are compared. One experiment was conducted at a peak load of 420 N ± 20 N with a spike load of 30 N ± 5 N. The other experiment was conducted at a peak load of 400 N ± 20 N with a spike load of 80 N ± 5 N. As expected, the higher spike load produced higher wear. The relative separation of the two cases plotted this way is ≈22 %, as reflected by the two slopes. When the wear data are plotted by the recorded load sum as shown in Fig. 2, the higher spike load condition shows much higher fractional separation from the lower spike load condition by about 48 %. The worn surfaces and wear particle morphology from both cases were also examined by using scanning electron microscopy. They were quite similar in appearance to the surfaces and particles obtained from retrieval studies[2].

If we assume wear of UHMWPE is primarily from the accumulated strain, the stress profiles of each load cycle will directly influence the wear processes. For a Paul-type load curve, one can assume that below certain critical level of load, the viscoelastic/plastic characteristic of the polymer will successfully absorb the stresses. Above the critical load level, wear processes will be initiated and at a certain load level, the process will be accelerated. The introduction of the spike load is based on this concept. If the critical load dependence is weak, the differences between the two cases plotted this way will be much smaller. The fact that the difference observed is quite large, it suggests that the load dependence of wear in a Paul-type of load curve or any other variable load curve is very sensitive to the peak load level and its duration in the cycle. This raises many implications as to how simulation tests should be conducted.

Conclusions Wear comparison by using load sums represents a new way to examine variable load test results. When the loads are summed, with and without load spikes, this sum represented the total "work" being done on the UHMWPE. An increase in wear by higher load spike (20 % time) but lower peak load (80 % time) accentuated the effects of those load spikes. Such information apparently is not only useful in defining the critical influence that load has regarding wear acceleration, but may provide a better basis for comparing wear results from different test protocols.

References 1)Shen et al., 45th ORS Annual Meeting, (1999) 852; 2) Schmalzried et al., J Biomed. Mater. Res. (Appl. Biomater), 38 (1997) 203.

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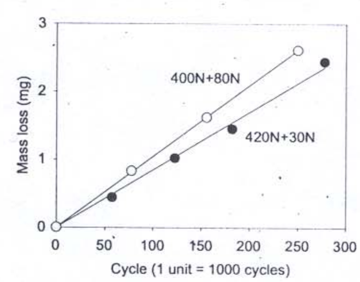
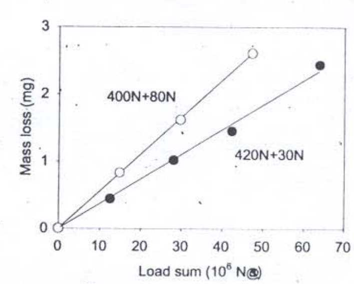


(Standard deviation of mean mass loss rate < 0.5μg/(1000 cycle); not a complete uncertainty statement)

Figure 1. Wear comparison by cycle count



(Standard deviation of mean mass loss rate < 2 μg/MN≅s; not a complete uncertainty statement)

Figure 2. Wear comparison by recorded load sum