Surface roughness properties of a micro-textured carbide-coated CoCrMo implant alloy during wear

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Statement of Purpose: Polymers and metals commonly used as articulating materials in artificial joints are subject to wear, and wear can lead to failure of the artificial joint. For example, wear particles are believed to induce localized osteolysis and resorption of the bone around the joint, which are now thought to be two of the main factors contributing to aseptic loosening of total hip replacements [1-2]. Metal surface wear mechanisms are critical to understanding the failure of artificial joint materials and improving their performance [3].

Modifying articulating surfaces is one potential method to increase wear resistance in materials used in artificial joints. Surface modifications are attractive because the bulk properties and the non-modified surfaces thatinteract with bone, for example, can remain the same, while the articulating surface is engineered to provide optimum tribological properties. This study investigated the surface roughness of the micro-texture, carbide-coated (MTCC) CoCrMo surface wear using non-contact while light profilometry.

Methods: The specimen preparation for one hundred and thirty-six CoCrMo alloy (ASTM F1537, Teledyne Allvac) CoCrMo and forty-one UHMWPE (GUR 415 medical grade round rod , E.I. Dupont de Nemours and Company, Inc. DE specimens were machined to 16-mm diameter, 7-mm thick disks and 44-mm diameter, 7-mm thick plates, respectively. The CoCrMo alloy disks were polished with SiC abrasive paper and 3μm diamond suspension and prepared for film deposition in the microwave-assisted plasma chemical vapor deposition (MPCVD) system to create the carbide coated specimens. Thirty measurements for each of the surface profile parameters (R_a, PV and rms) were made along the diameter of the 177 specimens to compare the changes in surface roughness for UHWMPE material on the CoCrMo alloy and MTCC-CoCrMo surfaces. Wear tests were conducted using the standard CoCrMo-on-UHMWPE, and the novel (MTCC-on-UHMWPE) [4]. The UHWMPE, CoCrMo alloy and MTCC-CoCrMo specimens were weight, thickness and diameter using digital balance and ultrasonically cleaned according to standard test method [4]. The surface roughness values were measured using the method developed by Que and Topoleski [5]. Data were analyzed by ANOVA with post-hoc Tukey tests for multiple comparisons and linear regression. The wear factor was determined from the wear rate and the applied load during wear testing using the following equation:

Wear factor ($mm^3N^{-1}m^{-1}$)= Wear rate (mm^3m^{-1})/Load (N).

Results: The three surface roughness parameters (R_a, PV and rms) for each of the MTCC surfaces (both 2h and 4h processing times) were larger than surface roughnesses of the UHMWPE and mirror-finished CoCrMo specimen surfaces (Table 1). The 2h and 4h MTCC specimens' mean average surface roughness (R_a), increased significantly over the mean average surface roughness of the polished CoCrMo specimen ($p < 0.001$) (Fig. 1). Similar results were found for the mean peak to valley height (PV), and average root mean square (rms), ($p < 0.001$). The surface roughness parameters (R_a, PV and rms) and summation roughness ($R_k+R_{pk}+R_{vk}$) increased with an increase in processing time for the MTCC specimens (p=0.0001), (Figs. 2 a-c). The R_a of the 2h and 4h MTCC decreased after 10^6 wear cycles (Fig. 3).

Table 1 Mean Surface Roughness Property for UHMWPE, CoCrMo, 2h and 4h MTCC specimens

Specimen No.	Average roughness (Ra), μm	Mean peak-to-valley height, (PV), μm	Average Root Mean Square (rms), μm	Number of specimens
Mirror finish CoCrMo	0.036 (±0.031)	1.456 (±2.162)	0.059 (±0.064)	N=136
CoCrMo plate	0.051 (±0.011)	1.099 (±0.420)	0.066 (±0.016)	N=34
2h-MTCC-CoCrMo	0.274 (±0.133)	7.940 (±2.907)	0.374 (±0.169)	N=94
4h-MTCC-CoCrMo	0.376 (±0.047)	9.032 (±2.032)	0.393 (±0.224)	N=42
UHMWPE plate	0.070 (±0.057)	4.198 (±1.656)	0.078 (±0.566)	N=41

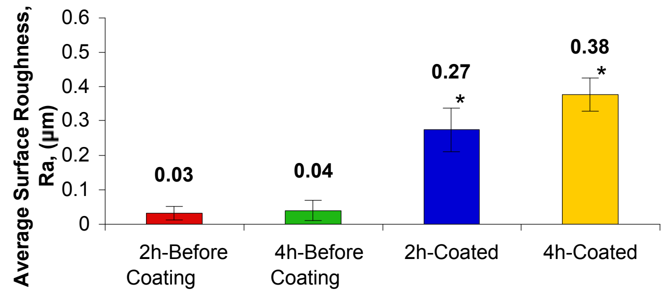

Figure 1. Average surface roughness (R_a) for the CoCrMo (N=136), the 2h (N=94) and 4h MTCC (N=42) specimens. (*) represents significant statistical difference with $p < 0.05$.

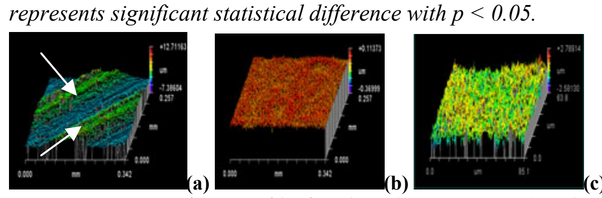

Figure 2. 3-D surface profile for the (a) UHMPWE (machine marks- white arrows), R_a=0.08μm, (b) mirror finished CoCrMo disks, R_a=0.03μm and (c) the 2h MTCC specimens, R_a=0.27 μm.

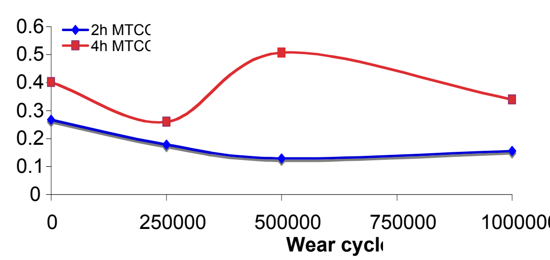

Figure 3. 2h and 4h MTCC wear couple systems

Conclusions: The surface roughness of the MTCC specimens increased as the result of processing time. Because the peaks of the MTCC surfaces were at different heights, it may be that an additional processing step, where additional polishing would create a smooth peak profile, would be necessary to improve wear performance.

References: [1] Wolfarth DL, et al. *J Biomed Mater Res* 1997;34(1):57-61. [2] Schmidt M, et al. *Clin Orthop* 1996; 329 Suppl:S35-47. [3] Schmalzried TP, et al, J Bone Jt Surg 1992;74-A:p849-863. [4] Vandamme,NS;Topoleski, LDT *J Mater Sci* 2005:16(7). [5] Que L, et al. *J Biomed Mater Res* 1999;48(5):705-711.