Mechanical properties of micro-textured carbide surfaces on a CoCrMo substrate using nanoindentation

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Statement of Purpose: Micro-textured surfaces have the potential to reduce wear in orthopaedic implants. A micro-textured carbide surface (the “Brain Coral" surface) has been developed using a microwave plasma-assisted chemical vapor deposition (MPVCD) process [1]. The mechanical properties and surface morphology play an important role in the wear mechanisms and wear rates. In this study, the elastic modulus, hardness and contact stiffness of the Brain Coral surface were determined by nanoindentation. Surface profile parameters (Ra, rms and PV and peak area) were measured using a white light profilometer and atomic force microscopy (AFM).

Methods: CoCrMo alloy (ASTM F1537) specimens with 16 mm diameter and 7 mm thickness were polished to a mirror finish. The Cr-carbide micro-textured Brain Coral surface was created on one-half of the specimens by a MPCVD process [1]. The surface morphology of the micro-textured surface was investigated using a white light interference surface profilometer (NewView 100, Zygo Corp) and AFM (Auto Probe CP, Park Scientific Instruments). The overall surface roughness and the surface roughness of the upper 1.5µm of the carbides (approximating the contact surface during articulation) were measured. The mechanical properties of the surface were investigated using a nanoindentor (Hysitron Inc TriboIndenter). Load controlled indentations (9 for each specimen) were conducted at 5mN for the micro-textured surface and mirror finished CoCrMo alloy.

Results/Discussion: The AFM image of the micro-textured carbide layer surface profile exhibited the same “Brain Coral” like pattern presented by previous investigators (Figure 1). The upper 1.5µm, which represents the potential contacting areas during articulation, have an average roughness (Ra) of 0.224 µm, compared to the Ra of the overall surface of 0.4 µm. The relatively rough overall surface, together with the reduced contact area and the ability of the micro-textured surface to retain lubrication, may reduce wear in implant systems. The measured mechanical properties, hardness (H) and reduce elastic modulus (Er), depended on the indent depth. The geometric variation of the Brain Coral surface contributed to the variation in the load-depth plot profiles (Figure 2). Unlike the CoCrMo alloy, the micro-textured carbide layer had no visible indent marks after the indentation tests. For the micro-textured surfaces, at an indent depth of 150 nm, the average values of H and Er were 9.8 GPa and 300 GPa, respectively. For the polished CoCrMo alloy, the average values of H and Er were 7.8 GPa and 159 GPa, respectively. Differences between H for the carbide layer and the substrate may effect the mechanical integrity of the layer [2]. The contact stiffness, dp/dh (p-load, h-depth) of the initial unloading segment of the load-depth plot, demonstrated minimal depth-related variation and, at 250 µN/nm, was statistically indistinguishable for both the carbide and the CoCrMo surfaces.

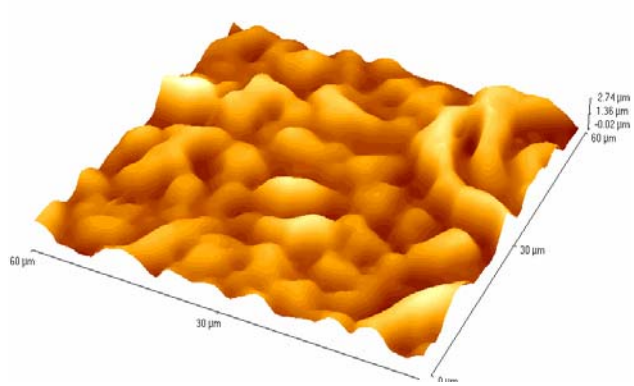

Figure 1 : The 3-D surface profile imaged using AFM illustrates the contact surface of the carbide surface.

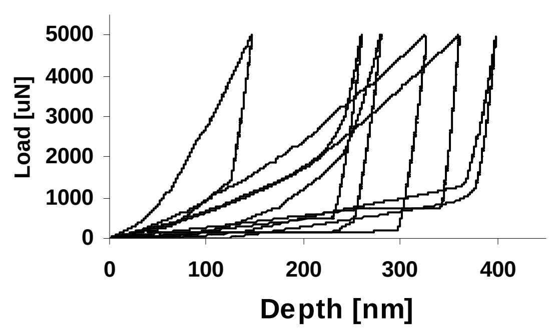

Figure 2: Differences in load-depth plots of the micro-textured surface from geometric variation of the surface.

Conclusions: Nanoindentation and AFM provide valuable information on the local properties of the micro-textured surfaces. The mechanical properties and morphological advantages micro-textured surfaces, in addition to the lubricant and debris trapping ability, may provide a significant improvement in wear resistance for metal joint replacement components. Our on-going investigations focus on determining the coefficients of friction and wear behavior of the micro-textured carbide surfaces on UHMWPE, metal, and itself.

References:

[1] Vandamme NS. Journal of Materials Science. 2005; 16: 647-654.
[2] Fujisawa N. Wear. 2006; 260: 62-74