The Effect of Processing Time, Temperature, and Methane Concentration on Micro-textured Ti6Al4V-carbide Surface Roughness Parameters

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Statement of Purpose: Surface morphology affects the wear performance of a surface. In the UMBC Laboratory for Implantable Materials and Biomechanics (LIMB) we developed a micro-textured, hard carbide surface grown from Ti6Al4V implant alloy [1, 2]. The purpose of the micro-textured surface is to improve wear performance, retain lubricating fluids, and entrap particles, keeping them away from the articulating surface. The effect of microwave plasma-assisted chemical vapor deposition (MPCVD) processing parameters (Table 1) on the surface morphology of the LIMB micro-textured Ti-carbide surface was investigated.

Methods: Fourteen LIMB Ti-carbide specimens were created from 0.625in diameter x 7mm Ti disks (Table 1).

Table 1. MPCVD processing parameter matrix

	1016°C	1041°C	1066°C
2 hrs	*(#1&2)*1% CH_4 *(#9)*5% CH_4	*(#3&4)*1% CH_4 *(#10)*5% CH_4	*(#5)*1% CH_4 *(#11)*5% CH_4
4 hrs	*(#6)* 1% CH_4 *(#12)*5% CH_4	*(#7)* 1% CH_4 *(#13)*5% CH_4	*(#8)* 1% CH_4 *(#14)*5% CH_4

Each surface was characterized with white light interference surface profilometry (WLISP, Zygo) using 13 designated locations on clean, dry specimens.

The number of peaks or valleys per 0.342 mm x 0.257 mm area, and the distance between peaks or valleys (peak spacing or valley spacing), R_k, R_{pk}, R_{vk}, in addition to the R_a, were recorded. The average surface roughness, R_a, is the average deviation from a plane fit to the surface area. The material that would wear away during the initial run-in period is the reduced peak height, R_{pk}, and the reduced valley depth, R_{vk}, is the lowest portion of the surface. The core roughness depth, R_k, describes the portion of the surface depth that will determine the long term wear performance of the surface. The core sum depth, (R_k+R_{pk}+R_{vk}), describes the thickness of the bearing surface prior to wear. Based on a bandwidth height (an upper and lower boundary defining the core material) determined by the software (Zygo MetroPro), the number of peaks above and valleys below the bandwidth are counted. The peak and valley spacing is then calculated by averaging the distance between the peaks (or valleys).

Results: Each specimen demonstrated a random pattern of peaks and valleys, however, 2 specimens, both of which were processed for 2 hrs at 1041°C at 1% CH_4, contained a patchwork of areas with directional preference defined by boundaries (Fig. 1). All post-MPCVD specimens had an R_a (390nm to 864 nm) of at least 10 times the pre-MPCVD R_a ($\leq$ 40 nm). For each pair of process times (2 hr and 4 hr specimens using the same CH_4 concentration and process temperature), core sum depth (R_k+R_{pk}+R_{vk}) increased with increased processing time with one exception. The pair of samples processed at 1066°C using a 1% CH_4 concentration were the only combination to show a decrease in R_k+R_{pk}+R_{vk} with an increase in process time.

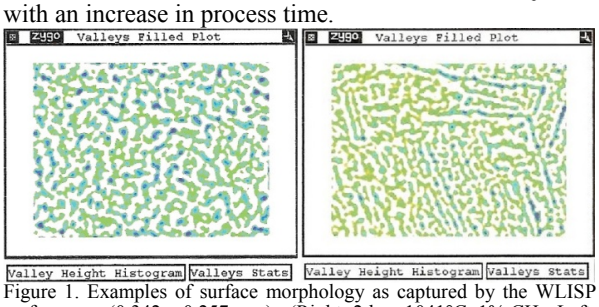

Figure 1. Examples of surface morphology as captured by the WLISP surface map (0.342 x 0.257 mm). (Right: 2 hrs, 1041°C, 1% CH_4; Left: representative surface from all other MPCVD parameter combinations)

The number of peaks/area decreased with increased CH_4 concentration, regardless of process temperature. However, the number of valleys increased in every parameter combination with the exception of the 1% CH_4/1041°C/2 hr specimens where the number of valleys decreased and the corresponding valley spacing increased.

The number of peaks/area showed either no change or increased with increased process temperature, while the peak spacing remained constant or decreased. The number of valleys remained essentially constant or decreased in every processing parameter combination while the corresponding valley spacing was also essentially constant or increased.

Discussion/Conclusions: The relationships between the CH_4 concentration, processing temperature and time, and their effect on the surface morphology and roughness parameters will be instrumental for optimizing wear performance. Understanding how the processing parameters affect surface roughness parameter outcomes may allow for 'designer' surfaces.

This study demonstrated that trends in the growth of the core sum and the number and spacing of peak and valleys is influenced by the processing parameters. For example, increasing the CH_4 concentration resulted in the greatest increase in peak spacing for the corresponding decrease in number of peaks when compared to processing temperature or time increase. This may be due to an increased availability of carbon, resulting in an increased number of TiC initiation sites which more readily coalesce due to proximity, decreasing the overall number of peaks.

The consequences of individual roughness parameters on the wear of the carbide surface are not known. Future studies should concentrate on the effects of surface morphology on the wear behavior of the surface.

References: 1. Sullivan, S.J.L., 9th World Biomaterials Conference, Chengdu, China, June, 2012.
2. Sullivan, S.J.L., SFB Annual Meeting and Exposition, Orlando, FL, April 2011.

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