The Influence of Machining on Micro-hardness Properties of CoCrMo Alloys

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Statement of Purpose: The inability to produce metal components with highly precise geometries may have been part of the reason for the failures of early generations of metal-on-metal artificial joints. Metal-on-metal total hip arthroplasty and hip resurfacing arthroplasty became more successful after major improvements in the manufacturing processes. Questions about unexplained differences in wear from seemingly identical devices still remain unanswered [1]. All metal-on-metal joints are made from either wrought or cast CoCrMo alloy, with or without HIPing and/or heat treatment. The final shape of the joint component is the result of precise machining, honing, and polishing. Manufacturing processes, especially heat treatments, influence the physical-mechanical properties, and hence their response to loading – i.e., fatigue and wear - of the surface layers of the machined parts [2]. The mechanical properties of the surface layers of articulating materials play a vital role for the wear of the materials. The focus of this study was to investigate how the machining process may influence the microhardness of CoCrMo artificial joint alloys.

Methods: All specimens of CoCrMo alloy were cut from the same two rod stocks. One rod was cast alloy (ASTM F75) and the other rod was wrought alloy (ASTM F1537, both from Telldyne-Allvac, Monroe, NC). Specimens with machined surfaces were disk-shaped specimens from each rod (cast – 3.8 cm dia, wrought – 4.4 cm dia, about 0.5 cm thick. The final surface finish (on the surface which was used for the hardness measurement) was machined, without cooling fluid, with either a sharp cutting tool (previously un-used, off-the-shelf cemented carbide indexable insert) (SCT), a dull cutting tool (flank wear of about 0.013 mm) (DCT), or over-dull cutting tool (flank wear greater than 0.25 mm) (ODCT). Specimens with "virgin" surfaces were prepared by slicing the machined specimens (cast alloy: 2 cm x 0.4 cm x 0.5 cm; wrought alloy: 2.54 cm x 0.25 cm x 0.5 cm) with diamond wire saw throughout their thickness of 0.5 cm. We assumed that the diamond wire saw surface preparation had a minimal influence on the properties of the newly created surface layers. Both machined and "virgin" surfaces were gently polished with 800 grit SiC paper and 1µm diamond paste before hardness measurements. One specimen from each alloy and each surface preparation (virgin, SCT, DCT, ODCT) were prepared.

The Vicker's microhardness (H_V) was measured using a Buehler I micro-hardness tester (Buhler, Lake Bluff, Ill) For each hardness measurement, we applied a 500 gram load for a 5 second exposition time. The H_V (in Kg/mm^2) was calculated in accordance with the standard formula:

$$H_V = 1.854P/d^2$$

where P is load (0.5 Kg), and d is the average indentation size measured on the diagonals of the pyramidal depression. Thirty hardness measurements were made for each specimen: ten measurements at the center of the disk, ten at the mid-radius, and ten at the perimeter. No perimeter measurements were made for the as-cast DCT and ODCT specimens because the surface at the edge was uneven surface after use of the dull tools.

Results: The results of microhardness measurements are shown in Fig. 1. In all cases (except cast-SCT) the standard deviations of the data were less than 10% of the average values taken over the entire specimen.

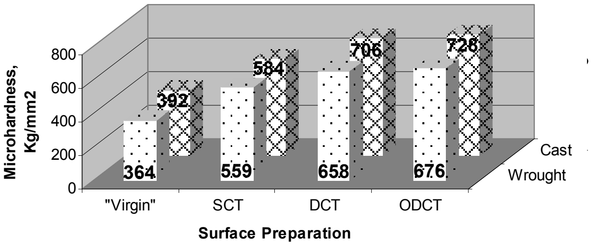

Figure 1: *Average H_V values for the different machining conditions*

Discussion: This initial investigation used a limited number of specimens for each treatment. For this first investigation, we assumed that the results for specimens from the same source rod would be similar. None-the-less, the results are consistent with fundamental principals of manufacturing and mechanics of materials. Depending on the tool condition, energy may go into material removal (cutting) or plastic deformation of the surface (cold-working), or a combination of both. The sharper the tool, the more energy goes into material removal, and the duller the tool, the more energy goes into cold-working the surface. The greater the cold-working of the surface, the greater the hardness is expected to be. This could be interpreted as the result of increase in dislocation density followed by a locally introduced plastic deformation. In addition, plastic deformation of the surface is likely to introduce residual stresses in the surface material. The initial change from the virgin to the SCT cut was an approximately 50% increase in hardness for both the cast and wrought alloys. The measured average hardness increased approximately 86% from the virgin material to that machined with the ODCT; again the increase was consistent for both the cast and wrought alloys.

The metal components of artificial hip joints normally undergo wear of the articulating surfaces, which are machined. The ordinary wear of the metal components may effectively remove or reduce the thickness of the plastically deformed surface layer, thus removing the residual stresses over time as well. The reduction of residual stresses may potentially lead to micro-deformations, or change in roundness, of the femoral head or thin-walled components of the joints, such as acetabular cups. The microdeformation can change the precisely designed conformity between the head and cup bearing surfaces, which can change local synovial fluid film lubrication, and hence the wear response of the components.

Conclusions: This initial study showed potentially dramatic differences in surfaced hardness as a function of machine tool condition. A more extensive study, including additional specimens and different machining conditions (different lubricants, different machining parameters, etc.) is currently underway based on these findings.

References: [1] Bowsher et al. J Biomed Mater Res Part B: Appl Biomater 91B (2009) 297–308.
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