# Comparison of Bone Cement Abrasion Resistance of Various Surface Hardening Technologies

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INTRODUCTION: Although titanium (Ti) alloys have been used in total joint arthroplasties as hip stems, acetabular shells and tibial trays, their use as a bearing surface, either as a knee femoral or femoral head, is not recommended without surface hardening.[1].Without surface hardening, third-body debris such as bone cement or bone particles can scratch the titanium surface and may increase wear of polyethylene that can lead to loosening and early revision.[2] Unlike zirconium alloys, Ti alloys cannot be oxidized to form a well-adhered hard ceramic surface that resists scratching. Shetty et al. proposed solid-solution hardening of Ti6Al4V by diffusing nitrogen to a depth of approximately 0.2 µm and showed acceptable performance in several in-vitro tests.[3] The purpose of this study was to compare the durability of a nitrogen diffusion hardened (NDH) Ti alloy to that of oxidized zirconium-2.5 wt% niobium (OxZr) in a bone cement abrasion test. This bench test evaluates the ability of a surface to resist scratching due to third-body debris such as bone cement. Untreated Ti6Al4V, titanium niobium nitride coated (TiNbN) CoCrMo, and untreated CoCrMo were also tested for comparison.

METHODS: Bone cement abrasion resistance of various materials was evaluated on a bespoke bone cement abrasion tester (Figure 1). Surfaces were tested in lactated ringer's solution for a duration of 1 million cycles (1 Mc). Disks were approximately 35.4 mm in diameter x 6 mm thickness. Bone cement pins were made from polymethylmethacrylate containing zirconia as a radiopaque material. Zr-2.5Nb disks (ASTM F2384) were oxidized to form a well-adhered ceramic oxide (5 µm thick) as described previously[4]. Ti6Al4V disks (ASTM F1472) were nitrogen diffusion hardened at 593°C for 8 hrs as described in US Patent 5,192,323 with the exception of a reduced nitrogen pressure in this study instead of atmospheric pressure. The depth of nitrogen penetration and the concentration profile were measured using x-ray photoelectron spectroscopy (XPS), and results were compared to that reported previously.[3,5] Disks of TiNbN-coated (5 µm thick) CoCrMo, available from a commercial vendor, untreated Ti6Al4V, and CoCrMo disks were also obtained or fabricated. All the samples (n=3) were tested with a mirror-finished surface ($R_a$<0.05 micron). After the bone cement abrasion test, wear depth and wear volume were measured using a contact profilometer.[6] Student's t-test was performed (Minitab) to compare the results with a level of significance ($\alpha$) of 0.05.

RESULTS: XPS analysis showed nitrogen reached a peak concentration of 7 at% at ~ 25 nm below the surface and reached a maximum depth of ~165 nm (Figure 2). Shetty et al. reported a peak nitrogen concentration of 32 at% at 40 nm below the surface[3], whereas, a second study reported 8 at% at 7 nm below the surface.[5] Figure 3 shows a representative profile of each material abrasion tested with the average maximum wear depth (Pt) and average wear volume. Maximum wear depth of NDH was ~1.9× greater than that of OxZr (p=0.02). The wear volume of the NDH surface was ~2.3× higher than that of OxZr (p=0.071). Except for OxZr, the hardened surfaces of the rest of the technologies were worn through by the end of the abrasion test.

DISCUSSION: Comparing the nitrogen profiles in the literature to those in this study suggests that were in the correct approximate range. The nitrogen diffusion hardened Ti6Al4V showed a similar nitrogen depth profile as one of the previously reported works.[5] The NDH and OxZr samples performed better in terms of abrasion resistance than the TiNbN and untreated samples. However, unlike OxZr, the hardened layer of NDH was completely worn through by 1 Mc exposing the softer underlying Ti6Al4V substrate.

SIGNIFICANCE/CLINICAL RELEVANCE: Durability of the bearing surface is important for wear reduction and associated biological response from the wear debris. Although nitrogen diffusion hardening of Ti6Al4V showed better durability compared to untreated Ti6Al4V, the hardened layer was worn within 1 million cycles and thus may not be optimal for long-term usage.

REFERENCES: 1. ISO 21536:2009+A1:2014; 2. Lombardi, et al., JBJS-AM, 71(9), 1989; 3. Shetty RH, ASTM STP 1272, 1996; 4. Hunter et.al., JASTM Intl, 2(7), 2005; 5. Venugopalan R et al., Trans ORS #507, 1999; 6. Hunter et al., Proc. MPMD, ASM Intl, 91-97, 2004.

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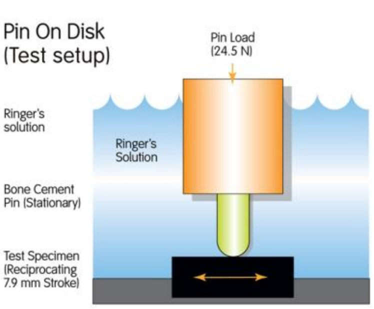


**Figure 1:** Schematic of bone cement abrasion test setup

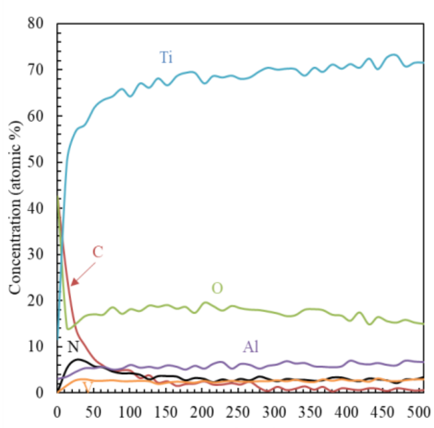


**Figure 2:** Nitrogen profile for NDH sample

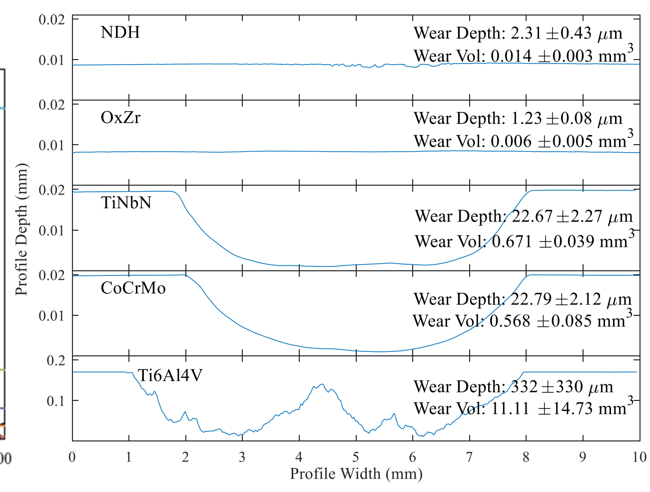


**Figure 3:** Representative profile tracings of each surface with the mean ± SD wear depth and wear volume. *Ti6Al4V y-axis is at a different scale.