Nanoindentation of microstructural elements in bone cement

L.D. Timmie Topoleski, Jamie Gurganis
Department of Mechanical Engineering, UMBC, Baltimore, MD,

INTRODUCTION: Poly(methyl methacrylate), or PMMA, bone cements have been important materials for total joint replacement for over four decades. Previous modifications to the standard polymer powder-methacylate monomer system have included the addition of fiber reinforcing phases, bioactive ceramics, antibiotic agents, etc. The microstructural phases in a PMMA bone cement can affect its fracture and fatigue behavior [1]. Bone cements originally designed and used for artificial joints are now being used in, for example, vertebroplasty, with increased amounts of radiopacifier [2]. It is important to understand the macro-mechanical behavior of bone cements. Understanding the microstructural contributions to mechanical performance, however, may be an effective approach to designing or improving bone cements for different applications. In this study we report on using nanoindentation to investigate local properties of microstructural elements of bone cement.

METHODS: Commercially available PMMA bone cement (Simplex P, Stryker, Inc.) was cured following standard clinical procedures, including vacuum mixing. Beam bending specimens were sectioned into approximately 5mm thick wafers (cross sectional dimensions = 10mm x 10mm). Each wafer was polished with sequentially smaller alumina or diamond grit polishing powder, with a final polishing treatment using 0.5 µm powder. The specimens were indented using a nanoindentor (Hysitron Inc., TriboIndenter). Load controlled indentations were conducted to approximately 1,500 µN. Indents were attempted on both the polymer bead and inter-bead matrix phases of the bone cement.

RESULTS AND DISCUSSION: We were able to place distinct indentations on the bead phase and in the inter-bead matrix of the bone cement specimens (Figure 1). The nanoindentor, with careful operation, was able to distinguishing between, and hence determine the local properties of, different microstructural phases based on load-depth data (Figure 2).

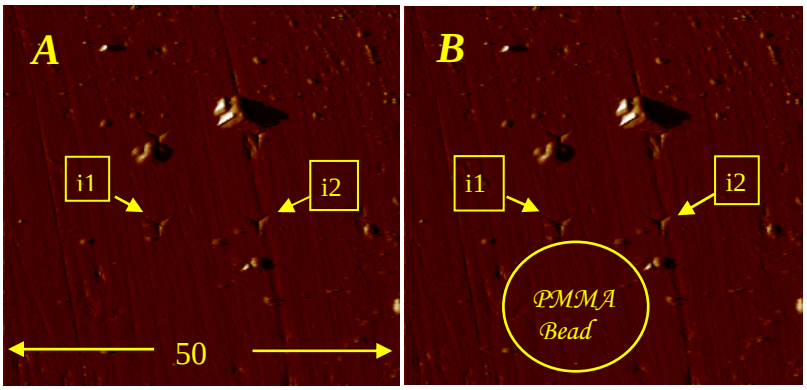
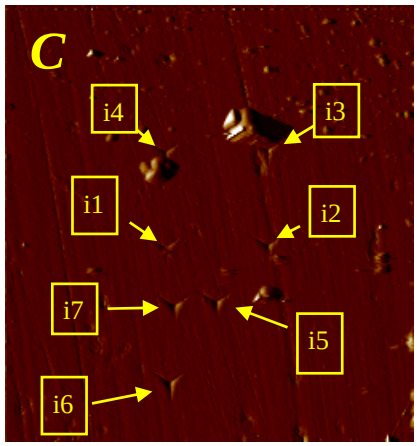


Figure 1: *A, B, and C show sequential indentations on the same PMMA surface.* ***(A)*** *Indentations i1 and i2 show the characteristic three-pointed shape of the indentor.* ***(B)****The PMMA bead is identified by its boundary of radiopacifier particles ($BaSO_4$) and surface depressions from the radiopacifier.*



(C) *Indents i5-i7 are placed within the PMMA bead; indents i1 and i2 appear to be in the interbead matrix. Particles near I3 and I4 are likely diamond polishing particles.*

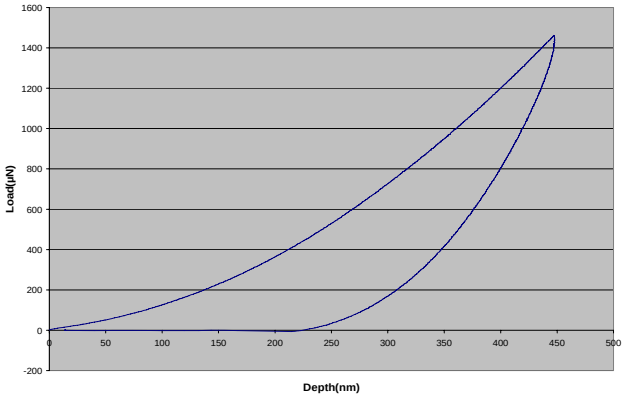


Figure 2: *Load-Depth plot for Indent #7*

The local properties for different areas showed slight differences. For example, the hardness and Young's Modulus for indent #1 (in the inter-bead matrix) were 5.86 MPa and 335 MPa, respectively, and for indent #7 (within a PMMA bead), 5.68 MPa and 318 MPa, respectively. This work was not designed to test for differences between indentation areas. Indeed, we recognize that more work is needed to positively identify specific areas of the bone cement microstructure for testing, and to determine the most appropriate nanoindentation testing conditions. However, the potential to investigate contributions of microstructural elements, additives, etc. to the mechanical behavior of bone cement may lead to an effective method for improving bone cements.

CONCLUSIONS: This work demonstrates that we are able to determine properties in bone cements from local microstructural elements using nanoindentation.

References: [1] Molino, LN, Topoleski, LDT, *J Biomed Mater Res*, **31(1):** 131-137 1996.
[2] Kurtz, SM, Villarraga, ML, Zhao, K, Edidin, AA, *Biomaterials* 26 (17):3699-712, 2005.