A NEW IN-PLANE SHEAR TEST FOR MIXED-MODE FRACTURE OF THE STEM-CEMENT INTERFACE

*+Mann, K.A., *Bhashyam, S., **Davidson, B.D.
*Department of Biomedical Engineering,
University of Alabama at Birmingham, Birmingham, AL 35294-4440
(205)-975-4920, FAX:(205)-975-4919,kmann@eng.uab.edu

Introduction: Interfacial failure of the stem-cement bond is an important mechanism for loosening of cemented total hip replacements. However, the mechanics of how this interface fails is poorly understood. Recent advances in bimaterial fracture mechanics provides a method to relate the fracture toughness of the stem-cement interface with the stress field at the crack tip. With this approach the interface fracture toughness can be completely described, but requires a full range of loading phase angles from Mode I (0°) to Mode II (90°). Unfortunately, to date, there has not been a convenient set of fracture mechanics tests which could provide a wide range of loading 'phase' angles for this interface. The purpose of this study was to 1) develop a new set of test geometries that would provide a wide range of phase angles for testing of the stem-cement interface., and 2) determine if the characteristic responses for the stem-cement interface were substantially different for a smooth stem surface versus a roughened stem surface.

Materials and Methods: A new in-plane shear test geometry (Fig 1A) was developed and was characterized using the finite element method to determine energy release rate (G_c) and crack tip phase angle (ψ). The two variables controlled with the test specimens were crack length (a) and position of bottom support (d). By adjusting these two parameters, a wide range of phase angles (ψ) could be determined (Table 1). Crack tip phase angles were determined using the method of Matos (1). An additional clamped cantilever beam test geometry was used to provide one additional phase angle (2).

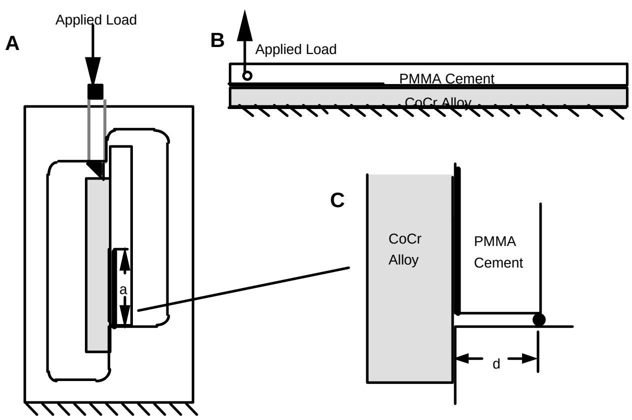

Figure 1: Experimental in-plane shear (IPS) fixture (A) and clamped cantilever beam (CCB) fixture (B). Enlarged view (C) of specimen support for the IPS test.

Table 1: Test parameters for the in-plane shear (IPS) and clamped cantilever beam (CCB) geometries. The overall width of the cement mantle was 6 mm.

Geo Type	'a' (mm)	'd' (mm)	Phase angle, ψ°
IPS	10	6	-51
IPS	5	3	-34
IPS	20	6	-30
IPS	10	0	7
IPS	20	0	24
CCB	n.a.	n.a.	74

CoCr bars (n=60) were coated with either a plasma sprayed surface (Ra = 13.64 μm) or a PMMA precoat (Ra = 1.27 μm), thus providing two very different surface roughnesses. A mold was used to apply the PMMA cement to the CoCr bars and the specimens were allowed to cure for 24 hours before testing. Testing was conducted with a materials testing machine under displacement control at 5 mm/min. Specimens were divided into six groups according to Table 1. The peak load at the prescribed crack length was determined and the corresponding critical energy release rate (G_c) was calculated.

Results: The in-plane shear geometry provided a range of crack tip phase angles from –51 to + 24°. The clamped cantilever beam resulted in the largest phase angle (74°). The critical energy release rates (G_c) were significantly ($p < 0.001$) larger for the plasma sprayed surface when compared to the PMMA precoated surface (Fig 2). However, the G_c was not a function of phase angle for the plasma sprayed specimens ($p > 0.3$, $r^2 = 0.21$). The critical energy release rate was a strong function of phase angle for the precoated surface ($p < 0.01$, $r^2 = 0.72$).

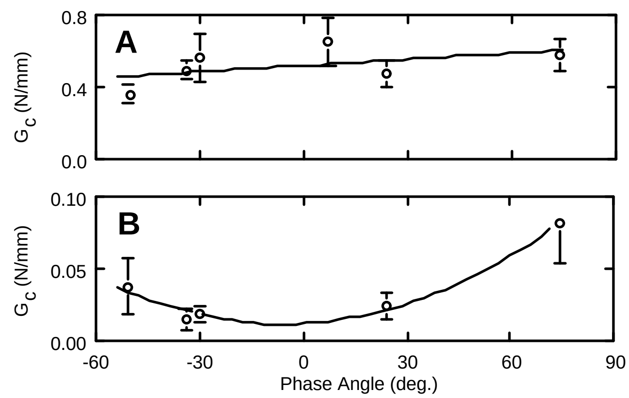

Figure 2: Critical energy release rate as a function of crack tip phase angle for the plasma sprayed (A) and precoated test specimens (B).

Discussion: This study presents a new test methodology to determine fracture toughness of the stem-cement interface over a wide range of phase angles using a convenient test geometry. Through change of position of the base support and by adjusting crack length, a wide range of phase angles can be realized. The crack tip phase angle changes because the combination of bending moments and compression at the crack tip is a function of position 'd'.

A full fracture response, over a wide range of phase angles was developed for both a smooth and roughened stem-cement interface. The response determined for the smooth precoated surface was similar to that found for other smooth bimaterial interfaces (3); the fracture toughness increases substantially with increasing phase angle. However, this response was not found for the plasma-sprayed surface. This could be explained by the rough undulating surface of the plasma-sprayed surface over which the crack must pass, resulting in a wide variety of local phase angles across the crack front. Thus, each point along the crack front would have a different fracture toughness and would result in a composite toughness that was independent of the presumed crack tip phase angle.

These data can now be applied to finite element models of cemented femoral hip components to determine how the stem-cement interface debonds during in-vivo loading.

This work was supported by NIH AR42017. **Dept. Mech Engr, Syracuse University, Syracuse, N.Y.

References 1. Matos, et al. Int J Fracture 40:235-254, 1989. 2. Mann et al, J Biomed Mater Res 38:211-219,1997., 3. Hutchinson, et al., Adv. Appl. Mech, 64-191, 1991.

☐ One or more of the authors have received something of value from a commercial or other party related directly or indirectly to the subject of my presentation.

☒ The authors have not received anything of value from a commercial or other party related directly or indirectly to the subject of my presentation.