Development and Characterization of a Self-Healing/Autonomic Acrylic Bone Cement

LeRoy Jones II,[1] Gladius Lewis,[2] Patrick Biggs[1]
[1]Chicago State University, Chicago, IL, USA, [2]The University of Memphis, Memphis, TN, USA

Introduction

In cemented joint replacements, it is well recognized that the acrylic bone cement mantle often experiences fatigue fracture – due to the propagation of cracks that emanate from, for example, entrapped air bubbles, blood inclusion, etc. – which may ultimately lead to aseptic loosening of the prosthesis [1]. We present two hypotheses. The first is that it is feasible to synthesize a self-healing acrylic bone cement. The second is that the fracture behavior of this cement will be more ductile than its plain counterpart. The third was that, depending on composition, the fracture toughness of the self-healed cement would be at least 75% that of the plain cement.

A self-healing polymeric material is one that possesses the ability to autonomically heal cracks in a component fabricated from it and, hence, recover a large proportion of the initial structural function of the component. Incorporated into the matrix of such a material are the healing agent, which is enclosed in microcapsules, and the catalyst. The microcapsule shell provides a protective barrier between the two constituents, thereby preventing premature polymerization. The concept of the self-healing provided may be summarized thus: (i) cracks form in the matrix wherever damage occurs, (ii) the crack ruptures the microcapsules, releasing the healing agent into the crack plane through capillary action, and (iii) the healing agent contacts the catalyst, triggering polymerization that seals the crack closed (Figure 1).

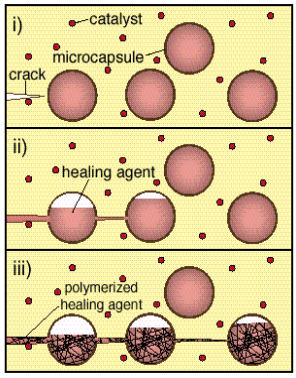

Figure 1. The self-healing concept [2].

Materials and Methods

The control cement used was Cemex® XL (Tecres SpA, Verona, Italy). The self-healing cement was synthesized by incorporating Grubbs' catalyst, $RuCl_2(=CHPh)(PCy_3)_2$, and urea-formaldehyde microcapsules containing dicyclopentadiene (DCPD) into the cement. Three variants of the self-healing cement were synthesized: 0.25 wt.% Grubbs catalyst + 1.00 wt.% DCPD (SH1 cement); 0.50 wt.% Grubbs' catalyst + 2.00 wt.% DCPD (SH2 cement); and 1.00 wt.% Grubbs' catalyst + 3.50 wt. DCPD (SH3 cement). The fracture toughness (K_{IC}) of these variants and of the control cement were determined per ASTM D 5045 (compact tension specimen; crosshead displacement rate of 10 mm/min; n = 4). The tests were conducted in ambient laboratory conditions (temperature = 21±1 °C; relative humidity = 57±2 %) 4.5 days after the fabrication of the specimens, with the specimens having been stored under the same conditions. (This time was chosen to ensure that healing was complete [3].)

Results and Discussion

All control specimens fractured in a classical brittle manner (crazes were created followed by formation of cracks form through them). In contrast, all of the self-healing variants failed in a ductile manner (extensive plastic yielding and, eventually, breakage of the bonds of the main chains). The K_{IC} values for the control, SH1, SH2, and SH3 cements were 2.01 ± 0.08, 1.70 ± 0.07, 1.70 ± 0.09, and 1.91 ± 0.08 MPa$\sqrt{m}$. The values of the healing efficiency (defined as the ratio of K_{IC} for a self-healed cement to that for the control cement) are about the same as those reported for another self-healing polymer system, in which the matrix was an epoxy mixture [3].

Future studies would include: 1) detailed characterization of the self-healed cements (especially, fatigue life and fatigue crack propagation resistance, while immersed in a clinically relevant medium, such as simulated body fluid, at 37 °C, and biocompatibility); 2) identification of other suitable catalysts and healing agents; and 3) optimization of the relative amounts of catalyst and healing agent.

Conclusion

The results support both of the hypotheses advanced. Thus, self-healing acrylic bone cement has promise for use in cemented joint replacements. With such cement, it is expected that the *in vivo* longevity of these arthroplasties will increase which, in turn, would translate to increased patient satisfaction and decreased hospital costs.

References

[1] Lewis G, J Biomed Mater Res Part B 66B:457-86; [2] White SR, et al., Nature 409:794-7 (2001); [3] Brown EN, et al., Exp Mech 42:372-9 (2002).