Changing the Mechanical Properties of PMMA Bone Cement with Nano and Micro Particles

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Statement of Purpose: Total joint arthroplasty is a highly successful way to restore pain free function to patients afflicted with arthritis. Polymethylmethacrylate (PMMA) bone cement is commonly used as a grouting and stress transfer agent in artificial joints. The historical success rate on patients over 60 years exceeds 90% (in a ten year time frame)[1], however the failure rates for total knee implants and hip implants for younger patients are much higher. Loosening is often preceded by the fracture of the bone cement[2], and this inevitably leads to a revision surgery[2,3]. The objective of this research is to increase the fracture resistance of bone cement to improve artificial joints. Changing the fundamental microstructure may lead to increased fracture and fatigue resistance. Using novel particles on the micro and nano size scale, we hope to change the microstructure by implementing these particles within the matrix of the bone cement specimens. Overall, we seek to improve both the fracture toughness and the fatigue resistance. Longer fatigue life will ultimately result in longer operational life of cemented prosthetic joints.

Methods: Specimens were prepared using commercial bone cement (DePuy®). Bone cement was mixed in standard vacuum mixing bowls (Stryker®). Four types of particles were mixed into the bone cement and tested. Three different versions of a liquid rubber; Paraloid TS-7100, 7300, and 7300(180), the last one cross-linked irregular-shaped PMMA particles (Rohm and Haas Co.). The rubber modifiers were presented in the liquid state and then mixed into the liquid monomer component of the bone cement before mixing all the components in the vacuum mixer. During the exothermic polymerization of the bone cement, the liquid rubber should precipitate and form solid rubber particles. The amount of additive added to each sample group was 10%. In preliminary results, samples with this amount of additive showed an average increase on the fracture toughness value, this was common throughout all the different additive types. The material was then injected into rectangular molds (10mm x 10mm x 60mm rectangular) using clinical cement delivery tools. Once the bone cement polymerized, the specimens were retrieved from the molds. A Dremel® tool was used to create a notch in all specimens using also a fixture to hold them in place, this helped keeping consistency throughout the samples. The notch was further sharpened with a razor to provide the samples with a stress concentration area. The specimens were placed in physiologic saline solution at 37ºC for at least 24 hours before testing. Specimens were retrieved and subject to fatigue cycling (60% maximum failure load at a ratio of 0.2) until a crack started developing. They were then tested individually in three point bending quasi-static loading until failure. The maximum load at failure was recorded and fracture toughness was calculated using the equation for 3 point bending tests[5]:

$$K_I = \frac{PS}{BW^{3/2}}\left[2.9\alpha^{1/2} - 4.6\alpha^{3/2} + 21.8\alpha^{5/2} - 37.6\alpha^{7/2} + 38.7\alpha^{9/2}\right]$$

where α is a/W (a is the initial crack length, and W is the specimen width, in this case 10mm), B is the specimen depth (also 10mm), S is the span between the lower supports (45mm), and P is the load at failure.

Results: *Figure 1* summarizes the fracture toughness results for all specimens. The error bars represent one standard deviation above and below the average. We believed that the liquid rubber solidified into micron-sized particles. The amount of each type of particle added was 10%. The amount used was based on a percentage of the mass of the powder component. Thus the additive replaced some of original powder component.

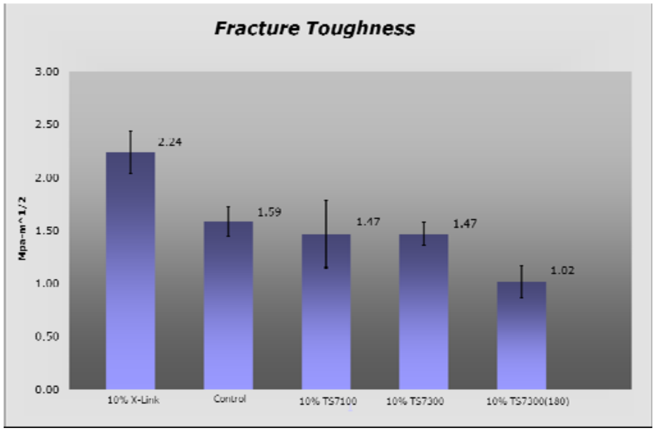

Figure 1

Figure 2 shows the microstructure observed using SEM imaging on a specimen containing the cross-linked PMMA particles.

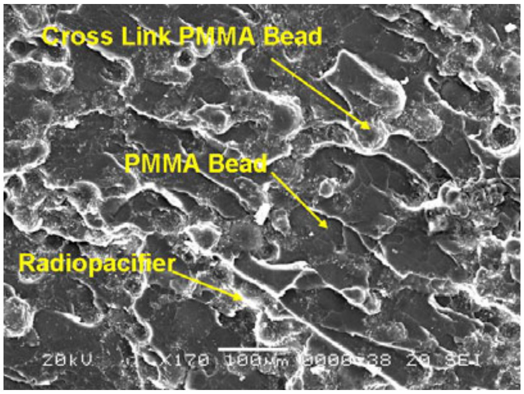

Figure 2

Conclusions: There is a need to increase the longevity of artificial joints, and one contribution toward this goal is by increasing the fatigue life of bone cement in cemented joints. Irregular micro- and nano-particles incorporated into the microstructure of the bone cement to absorb energy and slow crack propagation will increase the life of the material. Specimens with the cross-linked additive revealed the best results, with increase in value of about 41% when compared to the control samples (2.24·MPa $m^{1/2}$ versus 1.59 MPa·$m^{1/2}$ in the control group). Fracture toughness results are very promising, nano indentation, fatigue tests until failure and tensile tests are in progress, they will provide us with a better understanding of the fracture mechanics, crack propagation, and overall changes in mechanical properties due to the new additives.

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