THE EFFECT OF A THIN COATING OF A BIOADHESIVE ON THE IMPACT PERFORMANCE OF THE CEMENT – IMPLANT INTERFACE IN THR

Ashokkumar Balasubramaniam[1], David W. Nicholson[1], Larry P. Chew[1], Simon Raab[2]

[1] Department of Mechanical, Materials and Aerospace Engineering,
University of Central Florida, Orlando, FL, USA
[2] Xenon Corporation, Lake Mary, FL, USA
E-mail: ashok_balu@hotmail.com

INTRODUCTION

The aging of the world population has led to the growth of the orthopaedics market, particularly in implants. However, most implants only last about 10 to 15 years. Loosening of the femoral stem remains the major mode of long-term failure of Total Hip Arthroplasty (THA). It has been postulated that the loosening of the prosthesis is initiated by debonding of the stem-cement interface, followed by bulk failure of the cement mantle itself [Jasty et al, 1991]. Debonding is promoted by repeated subcritical impacts. Precoating the stem of the prosthesis with a thin film of Poly Methyl MethAcrylate significantly improved the strength of the cement-prosthesis interface [Ahmed et al, 1984]. But the failure then shifted to the cement-bone interface [Dowd et al, 1998].

A precoating of the prosthesis that can absorb the strain energy and impede transfer of unwanted stresses to the cement-bone interface when subjected to impact load will be an ideal candidate material for Total Hip Replacement (THR). The objective of this research is to analyze the performance of a new copolymer of 2-Hydroxy Ethyl MethAcrylate (HEMA) and Methyl MethAcrylate (MMA) as an interface material used in THR under impact, using the explicit finite element code LS-DYNA, to see if this copolymer has the potential of eliminating the long term loosening in THR.

To validate the model, a configuration for dynamic testing of the interfacial strength has been developed.

METHODS

The structure sample for testing is a simplified model of the actual artificial hip joint. Two steel rods, each coated with HEMA/MMA copolymer at the ends to be embedded, are joined together with bone cement. These samples are impacted coaxially with two spherical steel balls, causing shear at the interfaces (bone cement-copolymer and copolymer-steel rod interface). After the rods have been coated with the copolymer layer, they are soaked in 0.85 % NaCl solution for about 30 to 35 days in order to saturate the samples.

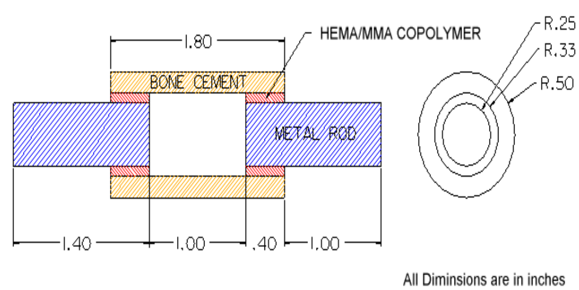

Figure 1: Structure Sample

A finite element model of the structure sample and the spherical steel balls was developed in the LS-INGRID modeling package. For the rods, the bone cement and the spherical balls, a linear elastic material model was used. The copolymer layer was modeled using piecewise linear plastic material model. LS-DYNA, an explicit nonlinear finite element code, was used for the analysis. The main reason for using LS-DYNA is its element killing capability, which few other codes do not have. When the effective plastic strain reaches the failure strain, the element loses its ability to carry tension and the deviatoric stresses are set to zero, i.e., the element behaves like a fluid.

The material properties for the copolymer layer have been obtained from experimental tensile test results of the material sample. Spherical balls delivering the impact were given an initial velocity while the structure sample was held stationary. The energy absorbed by the structure sample was noted. The composition of the copolymer was varied from 0% HEMA to 60% HEMA so as to show the effect of increase in the percentage of HEMA. Both the dry and the wet samples were analyzed. With the help of a specially designed set-up for dynamic strength testing, testing was performed on several compositions of the copolymer.

RESULTS AND DISCUSSION

Results of the validation exercises indicate satisfactory consistency between the analytical and the computational solutions.

Results of analysis without failure indicate an increase in energy absorption from 0% to 20% HEMA and a gradual drop after that till 60% HEMA. This is the same with both the wet and the dry samples. Computations with failure indicate a decrease in the energy absorbed by the structure sample at break from 0% to 20% HEMA and an increase in the same from 20% to 60% HEMA for the wet samples. However, there is not much difference between the energy absorption by 0% and 40% HEMA. On the other hand, in case of the dry samples, the energy absorbed at break is totally scattered.

Results of the experimental analysis indicate satisfactory consistency with the energy absorbed at break using finite element analysis, but for 40% dry HEMA and for 0% wet HEMA. The difference in the values of these two compositions of HEMA may be attributable to the fact that the material properties for the copolymer layer were obtained from the static results. Since four of our six finite element results matched with the experimental ones, the finite element results are believed to be reliable.

Also of importance is that the test procedure is reproducible and capable of discrimination between different adhesives, and different specimen preparations.

CONCLUSIONS

Varying the percentage of HEMA in the copolymer appears to improve the performance of the structure sample under impact loading conditions, below the breaking limit. A reliable finite element model, which can be used for further analysis, has been developed, and a discriminating experimental set-up for dynamic testing of the specimen has been designed.

REFERENCES

Ahmed A.M. et al. (1984). *Metal/cement interface strength in cemented stem fixation, J Orthop Res.* **2**, 105-118.

Jasty, M. et al. (1991). *The initiation of failure in cemented femoral components of hip arthroplasties, J Bone Joint Surg [Br],* **73,** 551-558.

Dowd, J.E. et al. (1998). *Failure of Total Hip Arthroplasty With a Precoated Prosthesis. J Clinical Orthopedics and Related Research,* 123-136.

Livermore Software Technology Co. (1993). *LS-DYNA-3D Manuals.*