• TWO-SOLUTION ACRYLIC BONE CEMENTS: EFFECT OF POLYMER TO MONOMER RATIO AND MOLECULAR WEIGHT ON MECHANICAL PROPERTIES

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INTRODUCTION

High viscosity solution bone cements have been developed using the same chemical components as commercial powder/liquid cements. Previous work has shown that these solution cements have setting characteristics and mechanical properties similar or superior to those of commercial formulations.[1] These studies have investigated the effects of varying concentrations of initiator chemicals[2], but have yet to study varying polymer to monomer ratios or molecular weights of the polymer constituent. The objective of this study was to determine the effect of polymer molecular weight and polymer to monomer ratio on both the static mechanical and fatigue properties of the two-solution cements.

MATERIALS AND METHODS

Poly(methyl methacrylate) (PMMA) powder was obtained in three different average molecular weights (M_w = 120,000, 80,000 and 40,000 g/mol) and was used as received (Ineos Acrylics, Cleveland, England). Benzoyl peroxide (BPO), N,N-dimethyl-p-toluidine (DMPT), barium sulfate ($BaSO_4$) and methyl methacrylate monomer (MMA) stabilized with hydroquinone were used as received (Aldrich, Milwaukee, WI). Four different sets of compositions were made with constant initiator chemical concentrations of 1.25 g BPO and 0.87 ml DMPT per 100 ml MMA. These compositions had polymer to monomer (P:M) ratios ranging from 0.8:1 to 1.2:1 (g PMMA/ml MMA). All compositions were mixed on a rotary drum for 18 hours at 0.5 Hz and then stored upright at 4° C for a minimum of 24 hours. Polymerization was initiated by mixing the two solutions through a static mixing nozzle (Ellsworth Adhesives, Germantown, WI).

Flexural testing was conducted using a three-point bend test in accordance with ASTM Standard D 790-86. Samples of the solution compositions and Palacos® R-40 bone cement (Schering-Plough Europe, Brussels, Belgium) were polymerized in a PTFE mold. All samples were polished to 600 grit by hand. The samples had an average width of 10.81 mm and an average thickness of 3.36 mm. Six samples of each composition were tested in air at room temperature on a Sintech 2/G test frame (MTS Corp., Research Triangle Park, NC), using a constant loading rate of 2.54 mm/min and a span length of 40 mm. The flexural strength (σ_{max}), modulus (E_b) and maximum strain (ε_{max}) were calculated for each group according to ASTM standards.[3]

Three-point flexural fatigue testing was performed using an Instron Model 1350 electrohydraulic mechanical testing system. Samples of solution compositions and Palacos® R-40 were made in the same manner described above, and were then polished on one side with a 1.0 µm alumina micropolish (Buehler, Lake Bluff, IL). Samples were fatigue cycled in air at room temperature under load control at a frequency of 5 Hz. A stress ratio ($\sigma_{min}/\sigma_{max}$) of R = 0.1 was used for all samples. Tests were run until failure or 10^6 cycles were reached, and stress versus cycles to failure curves (S-N curves) were generated for each composition tested.

The flexural testing data were statistically analyzed using a one-way ANOVA and Newman-Keuls *post hoc* comparison tests. Sample fractography was performed using a scanning electron microscope (JEOL, Peabody, MA) to assess microstructural differences between groups.

RESULTS AND DISCUSSION

The results of the flexural testing are summarized in Table 1. Statistical analysis revealed that the 40k molecular weight samples had a significantly lower flexural strength and modulus than all of the other cements tested ($p < 0.001$). They also had a significantly lower maximum strain than two of the other two-solution compositions. There was also a significant difference in maximum strain between the two 80k molecular weight compositions. The Palacos® R-40 samples had a significantly higher modulus than all other compositions, but did not show a significant difference in strength in comparison with the two-solution compositions. It also showed a significantly lower maximum strain than two of the two-solution compositions. All compositions tested performed comparably or superior to reported values for commercially available cements.[4]

Table 1 – Summary of Mechanical Testing Properties

Cement Type	P:M Ratio	σ_{max} (MPa)	ε_{max} (%)	E_b (GPa)
2-sol. 40k	1.2	73.19 ± 7.14	3.82 ± 0.67	2.33 ± 0.08
2-sol. 80k	0.95	102.44 ± 4.13	5.26 ± 0.71	2.66 ± 0.06
2-sol. 80k	0.9	102.12 ± 3.54	7.40 ± 1.26	2.56 ± 0.05
2-sol. 120k	0.8	100.15 ± 3.92	6.34 ± 1.58	2.60 ± 0.07
Palacos® R-40	1.7*	94.45 ± 7.31	4.38 ± 0.60	2.98 ± 0.06

* Cement was mixed in a 2:1 powder to liquid ratio

Fatigue testing yielded S-N curves as shown below in Figure 1. The 120k molecular weight composition exhibited the best fatigue performance out of the two-solution cements. Preliminary results indicate that cements containing the 40k molecular weight polymer do not perform as well as those that contain the 120k polymer or Palacos® R-40.

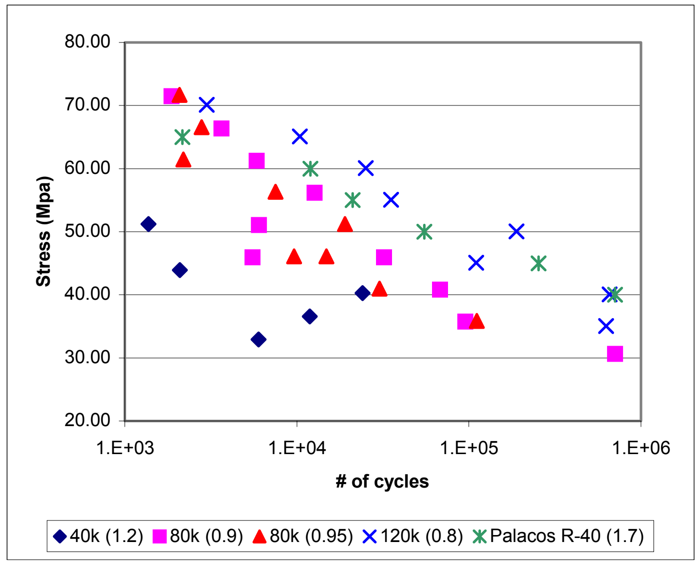

Figure 1. S-N curves showing fatigue testing results for all cement compositions tested. Parentheses in the legend indicate P:M ratio.

CONCLUSIONS

The results of this study indicate that the mechanical properties of the two-solution cements can be affected by the molecular weight of the starting polymer and the polymer to monomer ratio. These data show that using a low molecular weight polymer such as the 40k tends to have deleterious effects on the mechanical properties as compared to higher molecular weight compositions. Furthermore, it has been shown that the 120k molecular weight composition has similar fatigue behavior to that of Palacos® R-40 cement.

REFERENCES

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