Two-Solution Bone Cement with Cross-Linked PMMA Beads

Imad K. Merkhan, Jeremy L. Gilbert, Julie M. Hasenwinkel.
Department of Biomedical and Chemical Engineering, Syracuse University, Syracuse, NY 13244.

Statement of Purpose: Two-solution (TS) bone cement requires increased monomer levels compared to powder-liquid cements. This increase in monomer is necessary to achieve the proper viscosity, however increased concern arises as a result of this increased monomer in terms of exotherm, volumetric shrinkage, shrinkage induced porosity, and residual monomer.[1-4] The reduction of monomer is limited by solution viscosity, which is a function of PMMA molecular weight (MW) and polymer-to-monomer ratio (P:M). Decreasing the MW in order to increase P:M ratio leads to a significant decrease in the mechanical properties. Therefore, cross-linked PMMA beads (Pb), in varying concentration, have been introduced into two-solution bone cement in order to significantly increase the P:M ratio. The goal of this work was to seek minimal monomer levels in these cements and to determine the effect of these new compositions on solution viscosity, cement setting and mechanical properties.

Materials and Methods: The materials used in this research were PMMA powder (Mw 84,000), methyl methacrylate (MMA), benzoyl peroxide (BPO), N,N-dimethyl-p-toluidine (DMPT), polyvinyl alcohol (PVA), and 2,2-azobis-isobutyronitrile (AIBN). Cross-linked PMMA beads were synthesized via suspension polymerization of MMA using AIBN as the initiator, ethylene glycol dimethacrylate (EGDMA, 12 % w/v) as the cross-linker, and PVA as the stabilizer. Compositions were determined by their total P:M ratio and the ratio of PMMA beads (Pb) to linear polymer (Pl). A constant initiation chemistry was used (1.25 g BPO and 0.7 ml DMPT per 100 ml MMA). Initiator chemicals were dissolved in MMA in separate polypropylene cartridges. PMMA powder and beads were added in various concentrations and ratios. Cartridges were sealed, shaken, placed on a mixing drum for 18 hours, and then stored upright at 4 ºC. Viscosity was measured using a Brookfield rotational viscometer. Exotherm tests were performed according to ASTM F451-95. Three point bend testing was conducted on molded samples, polished to 600 grit, according to ASTM D790-86. All experiments were performed at least in triplicate. Results were analyzed using ANOVA techniques and post-hoc Newman Keuls tests for statistical significance (P<0.05).

Results and Discussion: Figure 1 shows the effect of P:M ratio and Pb:Pl ratio on viscosity of two-solution bone cement with cross-linked PMMA beads. As shown increasing P:M ratio leads to significantly higher viscosity at each Pb:Pl ratio. Viscosity vs. Pb:Pl ratio shows second order behavior with a minimum at the Pb:Pl ratio of 2:1 at each P:M ratio. CMW3 bone cement tested by the same viscometery technique has dough stage viscosities ranging from 188±20 to 978±146 Pa*s when measured after 1 and 3.5 minutes from mixing, respectively.

Viscosities measured in these new compositions compare favorably with dough stage commercial cements.

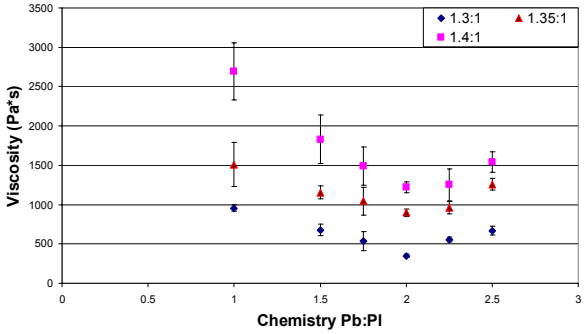

Figure 1. Viscosity of two-solution bone cement with cross-linked PMMA beads as a function of Pb:Pl ratio, at P :M ratios ranging from 1.3 to 1.4 :1.

Table 1 shows the effect of P:M ratio in two-solution bone cement with cross-linked beads on exothermic and flexural mechanical properties. These compositions had a constant Pb:Pl of 2 :1. Increasing the P:M ratio, by adding PMMA beads, significantly reduces the maximum polymerization exotherm, compared to standard TS cement. Flexural strength of TS bone cement was significantly higher than TS cements with PMMA beads. There is no significant effect of P:M ratio on flexural strength. TS cements with PMMA beads showed comparable flexural strength to Palacos. TS cement with beads has significantly higher bending modulus than standard TS and Palacos cements. Bending modulus increased with decreasing P:M ratio in TS bone cements with beads. Strain-to-failure in the TS cements with PMMA beads is significantly lower than Palacos and standard TS cement.

P:M	T max	t set	σ	ε %	E_b
1.3:1	80.1 ±	9.24 ±	91.22 ±	3.38 ±	2.95 ±
1.35:1	72.49 ±	8.46 ±	87.96 ±	2.66 ±	3.34 ±
1.4:1	67.72 ±	8.64 ±	89.61 ±	2.73 ±	3.42 ±
TS	95.02±	8.73 ±	102.12	7.03 ±	2.56 ±
Palacos	81.18 ±	8.48 ±	90.91 ±	4.69 ±	2.66 ±

Table 1. Exotherm and flexural mechanical properties of different cement compositions with varying P:M ratio compared to standard TS bone cement, and Palacos.

Conclusions: The P:M ratio of two-solution bone cement can be increased significantly by adding cross-linked PMMA beads. A variety of cement compositions can be made with viscosities in the range of dough stage commercial cements by changing the P:M ratio and the Pb:Pl ratio. Increasing the P:M ratio led to lower exothermic temperature while maintaining flexural strength and setting time.

References:

1. Hasenwinkel et al., JBMR 1999 Oct;47(1):36-45.
2. Gilbert et al., JBMR 2000 Oct;52(1):210-8.
3. Hasenwinkel et al., JBMR 2002 Mar 5;59(3):411-21.
4. Merkhan et al., JBMR B 2005 July 74B(1): 643-8.