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Graphite Fiber Reinforced Bone Cement

An Experimental Feasibility Investigation[1]

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This paper presents the results of a brief experimental investigation to determine the effects of graphite fiber additives on the flexural, compressive, and exothermal characteristics of surgical bone cement. The materials used in the investigation were polymethylmethacrylate (PMM) and chopped graphite (GY70) fibers. Both fiber reinforced and unreinforced beam and cylinder specimens were fabricated and tested. The unreinforced specimens were used to develop baseline data.

Comparison of static test data indicated that the graphite fiber additives yielded a twofold increase in stiffness without compromising the flexural strength of the material. The compressive strength decreased significantly, however, as a result of poor specimen compaction and the resulting presence of voids. The maximum exothermic temperature developed in the fiber reinforced specimens was approximately half that of the basic PMM.

It is concluded that graphite fiber reinforcement is beneficial in improving certain mechanical and thermal properties of surgical bone cement. However, considerable effort remains to produce a clinically usable graphite fiber reinforced bone cement.

INTRODUCTION

A brief experimental investigation was carried out in which the effects of graphite fiber additives on certain mechanical and thermal properties of surgical bone cement were determined. The investigation was aimed at studying the feasibility of improving the strength and stiffness of bone cement through graphite fiber reinforcement while at the same time reducing the thermal expansion coefficient and exotherm of the material. The motivation for this study was to evolve a cement with mechanical properties more nearly matched to those of bone and with thermal characteristics that resulted in less traumatization of the body tissues during curing. This paper summarizes the procedures employed and the results obtained from that investigation.

Early investigations in this field (e.g., Musikant, 1971) assessed several candidate composite material systems for orthopedic structural application. These

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investigations identified graphite fiber as a biologically inert reinforcement material which appeared particularly attractive for implant usage. This was recognized by Sclippa and Piekarski (1973), who were among the first to use chopped graphite fiber to reinforce a resin matrix material for ultimate orthopedic implant application. Other investigators, such as Hodosh (1974) and Kent, Homsy, and Hinds (1975), have also investigated particulate and fiber reinforced polymer materials for oral prostheses applications. In all these cases, however, the aim was to evolve improved skeletal prostheses. In this investigation attention is focused on investigating the potential of reinforcing the bone cement to aid in improving the performance of the total implant system.

MATERIAL SELECTION AND SPECIMEN PREPARATION

The materials used to fabricate the specimens were polymethylmethacrylate (PMM) surgical bone cement and chopped graphite fibers. The bone cement was Osteobond Surgical Bone Cement, manufactured by William H. Rorer, Inc. The graphite fibers were Celanese GY70 fibers hand cut into approximately 6 mm lengths. The chopped fibers were used as a practical means of preserving material isotropy during clinical application.

Both fiber reinforced and unreinforced beam and cylinder specimens were fabricated and tested. The unreinforced specimens were geometrically similar to their fiber reinforced counterparts and were tested to provide baseline data. Several batches of each type of specimen were used in the investigation.

The unreinforced beam specimens were made by casting the mixed PMM between parallel aluminum plates shimmed to a thickness of approximately 3 mm. Individual specimens were machined to the approximate dimensions 25×100 mm, then measured to the nearest 0.01 mm. The specimens were tested as simply supported beams in three-point bending in accordance with ASTM Specification D790.

The unreinforced cylinder specimens were made by mixing and casting the bone cement in 18 mm diameter glass tubing approximately 200 mm long. Specimens were machined to the approximate dimensions, 13 mm diameter by 25 mm long, then measured to the nearest 0.01 mm. The specimens were tested as compression samples in accordance with ASTM Specification D695.

The fiber reinforced specimens were made after considerable experimentation with fiber types, processing variables, and percentage (by weight) composition of fiber additive. Preliminary attempts to make graphite filled specimens using Hercules Type A graphite fiber were unsuccessful. This fiber was finer, more feathery, and more difficult to cut into 6 mm lengths than the Celanese GY70 material. Thus, the GY70 graphite fiber was selected for specimen fabrication. Successful mixes were obtained, however, by decreasing the amount of polymer powder added to the material system. A slurry was made with a portion of polymer and all of the liquid monomer and graphite fibers were then added to the mixture. After a few attempts at mixing different combinations of monomer, polymer, and fibers, it was found that a mixture of approximately 30% monomer, 60% polymer, and 10% fiber, by weight, gave the best results. The resulting combination, however, was very stiff and difficult to handle. Thus, this

TABLE 1
UNREINFORCED BONE CEMENT TEST DATA

Batch no.	No. of specimens	Data type	Av. ultimate strength ($N/m^2 \times 10^{-6}$)	Av. modulus of elasticity ($N/m^2 \times 10^{-6}$)
1	6	Compression	85	—
2	3	Compression	82	—
3	3	Compression	84	—
4	3	Flexure	52	2300
5	3	Flexure	49	2100
6	3	Flexure	48	2100

combination must not be construed as optimum, but only the best accomplished within the scope of the investigation.

Flexural specimens were prepared by pressing the material to the required thickness with considerable force. The specimens were band sawed from the cured material, which had several surface irregularities.

Compression specimens were made by compressing the material into glass tubes using tightly fitting rams. Use of more loosely fitting rams was unsuccessful because liquid was squeezed out of the mix. The resulting specimens were porous and lacked uniformity of batch control.

TEST RESULTS

Static tests were run to determine flexural and compressive mechanical material properties on the beam and cylinder specimens, respectively. All specimens were tested in an Instron machine at a loading rate of 1.3 mm/min.

Average test data for the unreinforced baseline specimens are given in Table 1. The compressive data are very similar to those reported by Lee, Ling, and

TABLE 2
GRAPHITE REINFORCED BONE CEMENT TEST DATA

Batch no.	No. of specimens	Data type	Graphite filler ratio (% by weight)	Av. ultimate strength ($N/m^2 \times 10^{-6}$)	Av. modulus of elasticity ($N/m^2 \times 10^{-6}$)
8	3	Compression	10	12	—
9	3	Compression	10	23	—
1	3	Flexure	1	48	2300
2	3	Flexure	2	51	2500
3	2	Flexure	3	48	4100
4	2	Flexure	10	49	4800
5	2	Flexure	10	43	4700
6	3	Flexure	10	51	4400
7	3	Flexure	10	40	4900

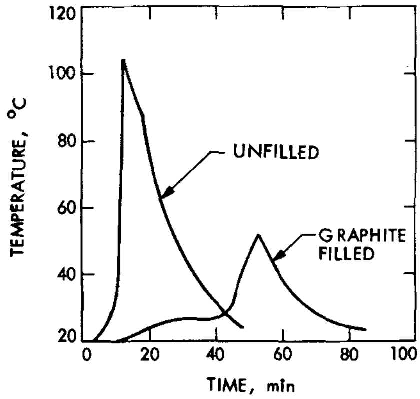

FIG. 1. Exothermic cure data.

Wrighton (1973). As can be seen from these data, the specimens were well behaved and gave repeatable results.

Such was not the case of the graphite fiber reinforced specimens, as indicated by the data of Table 2. Considerable variation and low values of compressive strength were obtained. The flexural modulus and strength values were fairly repeatable, however, as can be seen from the data of batches 4–7. Batches 1–3 were developmental to test the effect of variations in fiber content on specimen response.

The exothermic temperature–time profiles of the baseline and fiber reinforced materials are shown in Fig. 1. The data were collected by means of a thermocouple embedded in a sample of each material approximately 13 mm thick by 38 mm in diameter contained in a plastic dish.

A summary of the overall average experimental results obtained from Tables 1 and 2 and Fig. 1 is given in Table 3.

DISCUSSION AND CONCLUSIONS

As can be seen from the data summarized in Table 3, graphite fiber additives resulted in a significant increase in stiffness (modulus of elasticity) without compromising the flexural strength of the material. The compressive strength decreased significantly, however, as a result of poor specimen quality and the presence of voids. The exotherm also decreased significantly, which is due primarily to the removal of reactants from the filled material and the inhibiting effect of the graphite fibers on the rate of reaction.

TABLE 3
AVERAGE EXPERIMENTAL RESULTS

Parameter	Unreinforced	Reinforced
Flexural strength ($N/m^2 \times 10^{-6}$)	50	47
Compressive strength ($N/m^2 \times 10^{-6}$)	84	17
Modulus of elasticity ($N/m^2 \times 10^{-6}$)	2200	4600
Max. temperature exotherm (°C)	104	52

On the basis of this brief investigation, it appears feasible to use graphite fiber additives to improve certain of the mechanical and thermal properties of surgical bone cement. It is apparent, however, that a more extensive effort is required to produce a usable graphite filled bone cement. The results obtained thus far suggest that perhaps the use of graphite fiber coatings or other types of biocompatible PMM polymers and monomers will result in improved material performance.

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