Acta Biomaterialia 6 (2010) 3187–3192

Contents lists available at ScienceDirect

Acta Biomaterialia

journal homepage: www.elsevier.com/locate/actabiomat

PMMA-based bone cements containing magnetite particles for the hyperthermia of cancer

M. Kawashita *, K. Kawamura, Z. Li

Graduate School of Biomedical Engineering, Tohoku University, Sendai 980-8579, Japan

ARTICLE INFO

Article history:
Received 24 August 2009
Received in revised form 15 February 2010
Accepted 24 February 2010
Available online 1 March 2010

Keywords:
PMMA cement
Magnetite
Hyperthermia
Alternating magnetic field

ABSTRACT

Polymethylmethacrylate-based cements containing magnetite (Fe_3O_4) particles were prepared and their structure and properties were investigated. The Fe_3O_4 particles were uniformly dispersed in the cement matrix and constituted a maximum of 60 wt.% of the total weight of cement. The setting time of the cement increased and the maximum temperature during the setting reaction decreased with increasing Fe_3O_4 content. The compressive strength of cement increased with increasing Fe_3O_4 content. Cement with 50 wt.% Fe_3O_4 particles generated heat in alternating magnetic fields of 300 and 120 Oe at a frequency of 100 kHz.

© 2010 Acta Materialia Inc. Published by Elsevier Ltd. All rights reserved.

1. Introduction

Metastatic bone tumors often cause a decrease in bone quantity, resulting in either a compression fracture of bone or severe pain. Conservative therapy has been applied for the treatment of compression fractures of bone. In this therapy, patients are placed under bed rest with fixation of the diseased part of the body, with any pain being controlled through medication. However, patients sometimes require bed rest for a few months with this treatment, and such a long period of bed rest may increase the risk of dementia in elderly patients.

Recently, percutaneous vertebroplasty, in which a polymethylmethacrylate (PMMA) bone cement is injected into vertebrae, has been used as a new treatment of compression fractures of vertebrae. This treatment decreases the period of bed rest and, in most cases, patients can walk within a few days after treatment. Percutaneous vertebroplasty was first reported as a treatment for angioma of the spine by Galibert et al. [1], and has since been applied for the treatment of osteoporotic vertebral compression fractures [2–7] or malignant tumors, such as osteolytic metastases or multiple myeloma [8,9].

On the other hand, hyperthermia utilizing various magnetic materials has been widely investigated as a minimally invasive treatment of cancer, since magnetic materials can generate heat in an alternating magnetic field [10]. The most common magnetic thermoseed material for hyperthermia is magnetite (Fe_3O_4), which has an inverse spinel structure. Matsumine et al. [11] proposed an Fe_3O_4-containing calcium phosphate-based cement for the hyperthermia of metastatic bone tumors in the femur, fibula, humerus or tibia, and reported good clinical results with these cement samples. However, the mechanical strength of calcium phosphate cement is generally lower than that of PMMA-based cement and, hence, Fe_3O_4-containing calcium phosphate cement is not ideal for use in percutaneous vertebroplasty. We expect that novel PMMA-based cements with high mechanical strength, which would be useful for the hyperthermia of bone tumors, especially those that have developed in vertebrae, will be obtained when magnetic materials, such as Fe_3O_4, are successfully dispersed in a PMMA cement matrix.

So far, PMMA–Fe_3O_4 composite microspheres [12] or PMMA-based cement containing bioactive glass ceramics [13–15] have been developed but, to the best of our knowledge, there has been no fundamental research on the possibility of obtaining Fe_3O_4-containing PMMA-based cements. In this study, we attempted to prepare PMMA-based cement containing Fe_3O_4 nanoparticles and investigated the structure and properties of the resulting cement samples.

2. Materials and methods

2.1. Preparation of the cement samples

Commercially available Fe_3O_4 powder (Wako Pure Chemical Industries, Ltd., Osaka, Japan) and spherical PMMA powder with an average molecular weight of 270 kDa and an average particle

* Corresponding author. Tel./fax: +81 227953937.
E-mail address: m-kawa@ecei.tohoku.ac.jp (M. Kawashita).

1742-7061/$ - see front matter © 2010 Acta Materialia Inc. Published by Elsevier Ltd. All rights reserved.
doi:10.1016/j.actbio.2010.02.047

size of 5 μm [16] were used in our experiments. In addition, liquid methylmethacrylate (MMA) monomer (Wako Pure Chemical Industries, Ltd., Osaka, Japan) was used.

Four types of cement, designated M-40c, M-50c, M-60c and PMMAc, were prepared. PMMAc was an Fe_3O_4-free cement used as a control material. The sample name and composition of each Fe_3O_4-containing cement is shown in Table 1. PMMA powder/MMA liquid weight ratio was 2/3 according to a previous study [17]. As an initiator, benzoyl peroxide (Tokyo Chemical Industry, Co., Ltd., Tokyo, Japan) was added to the powders at a concentration of 4.0 wt.% of the monomer, and an accelerator, *N*,*N*-dimethyl-*p*-toluidine (Wako Pure Chemical Industries, Ltd., Osaka, Japan), was dissolved in the liquid at a concentration of 2.0 wt.% of the monomer. Each cement was prepared by mixing the powder with the liquid for 3 min.

2.2. Setting of the cement samples

The setting time of the cement samples was measured using a vicat needle (SS-S-403, Shinohara Manufacturing Co., Ltd., Tochigi, Japan). The cement pastes were mixed for 3 min and cast into a cylindrical mold made of polytetrafluoroethylene (inner diameter = 6 mm, inner depth = 6 mm). The 300 g vicat needle with a cross-sectional area of 1 mm^2 was gently placed on the surface of the molded cement for time intervals of 30 s. The time required for the needle trace to disappear after placing the vicat needle on the surface was measured under ambient conditions of temperature = 21–22 °C and humidity = 26–28%. The setting time was defined as the time from the start of mixing at which the vicat needle no longer gave a trace in the cement surface. The measurements were repeated three times.

The cement pastes were also mixed for 3 min and cast in a cylindrical mold made of polytetrafluoroethylene (inner diameter = 50 mm, inner depth = 9 mm), and the change in temperature during the setting reaction was measured using an infrared thermometer (SK-8700II, Sato Keiryoki Mfg. Co., Ltd., Tokyo, Japan).

2.3. Mechanical testing of the cement samples

The compressive strength of the cement samples was measured according to the standard ISO 5833 procedure. The cement paste was poured into a stainless steel mold containing five holes (diameter = 6 mm, height = 12 mm) and clamped with stainless steel sheets. The cylindrical samples were removed from the mold after they had fully set. The surfaces of the samples were abraded using #400 sandpaper to reduce the stress concentration at the sample's surface. A compressive test was conducted using an Instron-type mechanical testing machine (AG-I 50 kN, Shimadzu Co., Kyoto, Japan). At least 14 samples were tested for each cement using a crosshead speed of 20 mm min^{-1}.

2.4. Structural analysis of the Fe_3O_4 powder and cement samples

The microstructure of the Fe_3O_4 powder and cement samples was observed using scanning electron microscopy (SEM; VE-8800, Keyence Corp., Tokyo, Japan). The crystal structure of the Fe_3O_4 particles used in this study and sample M-50c was verified by X-ray diffractometry (XRD; RINT-2200VL, Rigaku Corp., Tokyo, Japan) using the following experimental settings: X-ray source = Ni-filtered Cu K_α radiation, X-ray power = 40 kV, 40 mA, 2θ scanning rate = 2° min^{-1} and sampling angle = 0.02°.

Table 1
Compositions of the cement samples.

Sample	Powder/wt.%		Liquid/wt.%
	Fe_3O_4	PMMA	MMA
M-40c	40	24	36
M-50c	50	20	30
M-60c	60	16	24
PMMAc	0	40	60

2.5. Measurement of the magnetic properties of the Fe_3O_4 powder and cement samples

The magnetization properties of the Fe_3O_4 powder and the cement containing 40 and 50 wt.% of Fe_3O_4 powder (samples M-40c and M-50c) were measured using a vibrating sample magnetometer (VSM-5, Toei Industry Co., Ltd., Tokyo, Japan) in magnetic fields of 120, 300 and 10,000 Oe at room temperature.

2.6. Measurement of the in vitro heat generation of the cement samples in an alternating magnetic field

The in vitro heat-generating ability of samples M-40c and M-50c was measured in an alternating magnetic field of 120 and 300 Oe at a frequency of 100 kHz using an apparatus developed by the present authors [18]. The change in surface temperature of sample M-50c was measured using a fluoroptic thermometer (Model-3000, Luxtron Co., California, USA) as a function of time in the alternating magnetic field.

3. Results

Fig. 1(a) shows an SEM photograph and Fig. 1(b) shows the XRD powder diffraction pattern of the Fe_3O_4 powder used in this study. It was confirmed that this powder consisted of cubic crystals

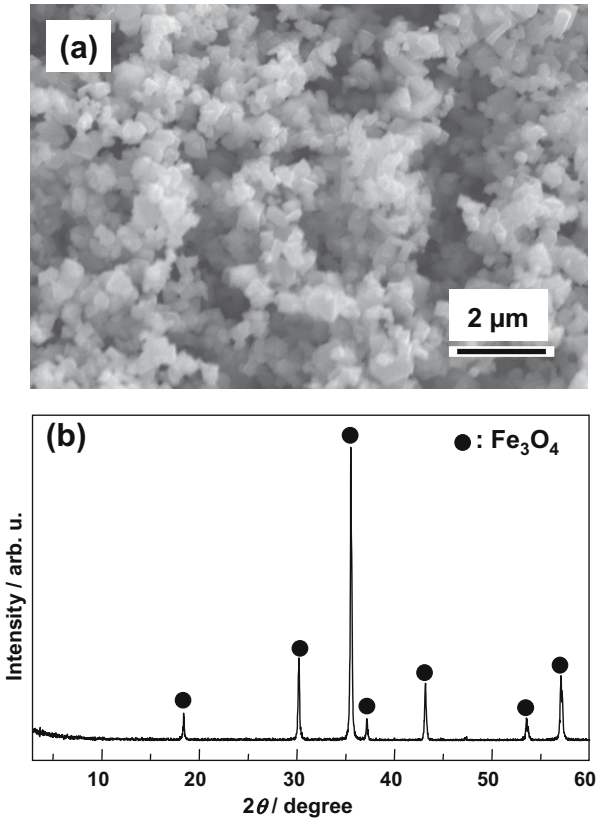
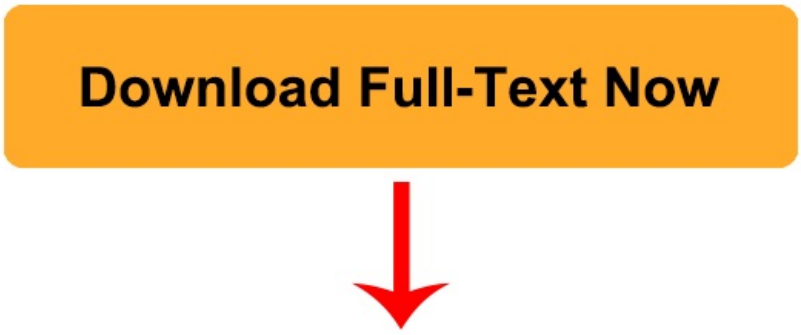


Fig. 1. (a) SEM photograph and (b) XRD pattern of the Fe_3O_4 powder used in this study.

ID	Title	Pages
2283	PMMA-based bone cements containing magnetite particles for the hyperthermia of cancer	6



http://fulltext.study/article/2283

FullText.study

Categorized Journals
Thousands of scientific journals broken down into different categories to simplify your search

Full-Text Access
The full-text version of all the articles are available for you to purchase at the lowest price

Free Downloadable Articles
In each journal some of the articles are available to download for free

Free PDF Preview
A preview of the first 2 pages of each article is available for you to download for free

http://FullText.Study