Thermal Diffusivity in Bone and Hydroxyapatite

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Abstract. We report thermal diffusivity measurements in bull bone and commercial hydroxyapatite (HA), both in powder form, in order to determinate the thermal compatibility between these materials. Besides this, we report a comparison between these measured values and those of metallic samples frequently used in implants, as high purity titanium and stainless steel. Our results show a good thermal compatibility (74%) between HA and bone, both in powder form. Finally, it was obtained a one order of magnitude difference between the thermal diffusivity values of metallic samples and those corresponding values to bone and HA being this difference greater in titanium than in stainless steel, which is important to consider in some biomedical and dental applications.

INTRODUCTION

The hydroxyapatite (HA) is a ceramic mineral of exogen origin [1], it have special interest from the medical point of view since, amongst other things, HA is used in technology of osseous implants [2, 3] and dental applications [4], as well as in the reconstruction and restoration of osseous damage [3], like a coating [2] and still like cementing of porous type [5]. Besides these, it has been used as coating of metallic substrates in bone implants [6] and its applications favours the adherence and the osteoblast differentiation [7]. The HA is in the nature like mineral, as well as in the living beings, it is the most important mineral component of bone tissue, 60 to 70 % (by volume) in bone and until 98% (by volume) in dental enamel, and it can be obtained in synthetic form[8].

The study and determination of physical, chemical and biological properties of biomaterials used in implants for medical and dental applications is fundamental from the point of view of the compatibility that these materials must present with the tissue which they will replace mainly by the long time contact which they maintain with alive tissues of the body [9]. The thermal diffusivity (α) gives a measurement of the heat flow that propagates through a medium and its importance lie in, like the optical absorption coefficient, it is an unique value for each material, which it allows its thermal characterization [10]. The thermal diffusivity is a quantity extremely sensible to the composition and microstructure of the materials. This is the case in porous materials and powders, in which α depend in addition to, the present type of porous structure and its porosity degree [11]. Nowadays thermal compatibility in bone and HA has not been studied, therefore we report it now.

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RESULTS AND DISCUSSION

The bone used in this work comes from the upper part of one of the back legs of a 18 to 20 month old mature male bull. The bone was cleaned of flesh with a scalpel and boiled for 2 hours in order to remove bone issue and fat. The bone was dried in air for one weak at room temperature, after this the bone was baked in a microwave oven for 5 minutes in order to eliminate residual humidity.

The samples have a disk shape of 1 cm of diameter and thickness between 320 and 452 μm. Table 1 show samples characteristics. Samples 1 to 9 were obtained from commercial hydroxyapatite powder compressed and samples 10 to 14 consist of a pill of bull bone powder compressed. These bone powders was obtained from the dust when the dense bone was cutted with a fine handsaw. All the samples were free humidity storaged.

TABLE I. Experimental Thermal Diffusivity and Samples Characteristics

Sample type	Pressure *Tons*	Thickness (l_s) μm	Thermal diffusivity (α) 10^{-3} cm^2/s
1. Compressed hydroxyapatite	1	378 ± 08	1.4 ± 0.04
2. Compressed hydroxyapatite	2	360 ± 04	2.2 ± 0.05
3. Compressed hydroxyapatite	3	320 ± 06	2.8 ± 0.10
4. Compressed hydroxyapatite	4	326 ± 10	3.0 ± 0.08
5. Compressed hydroxyapatite	5	418 ± 12	3.2 ± 0.10
6. Compressed hydroxyapatite	6	425 ± 07	3.7 ± 0.06
7. Compressed hydroxyapatite	7	399 ± 07	3.9 ± 0.07
8. Compressed hydroxyapatite	8	392 ± 08	4.1 ± 0.07
9. Compressed hydroxyapatite	9	405 ± 08	4.1 ± 0.07
10. Compressed bone powder	5	324 ± 04	1.8 ± 0.05
11. Compressed bone powder	6	452 ± 16	2.5 ± 0.06
12. Compressed bone powder	7	400 ± 10	2.7 ± 0.06
13. Compressed bone powder	8	396 ± 14	3.0 ± 0.10
14. Compressed bone powder	9	388 ± 05	3.1 ± 0.10

We obtained thermal diffusivity values by means of the photoacoustic (PA) technique in a heat transmission configuration at room temperature [11]. Table 1 shown α values determined for the 14 studied samples. In Fig. 1(a) we show the α results data of our nine hydroxyapatite samples and Fig. 2(b) shown α values of our five samples of bone powders as a function of the compression. The data was best fitted to a curve represented by a logistic function, namely

$$\alpha = \alpha_s \frac{\exp(p - p_o/\Delta p)}{1+\exp(p - p_o/\Delta p)} \qquad (1)$$

Here α_s represents the saturation value, taking place during an interval Δp, and p_o is the interval at which the fractional change $(p-p_o)/\ \Delta p$ reaches halfway to the saturation value. The result obtained from the data fitting of α to Eq. (1), leaving α_s, p_o, and Δp adjustable parameters, is shown in Fig. 1 by the solid curve. The values obtained for the fitting parameters are given in Table 2. From these parameters we obtained the α saturation value, which represent the most representative value for the thermal diffusivity in each case, namely, 4.19 10^{-3} *cm²/s* for HA and 3.11 ± 0.09 10^{-3} *cm²/s* for Bone. These results show and excellent thermal compatibility (74%) between these materials.

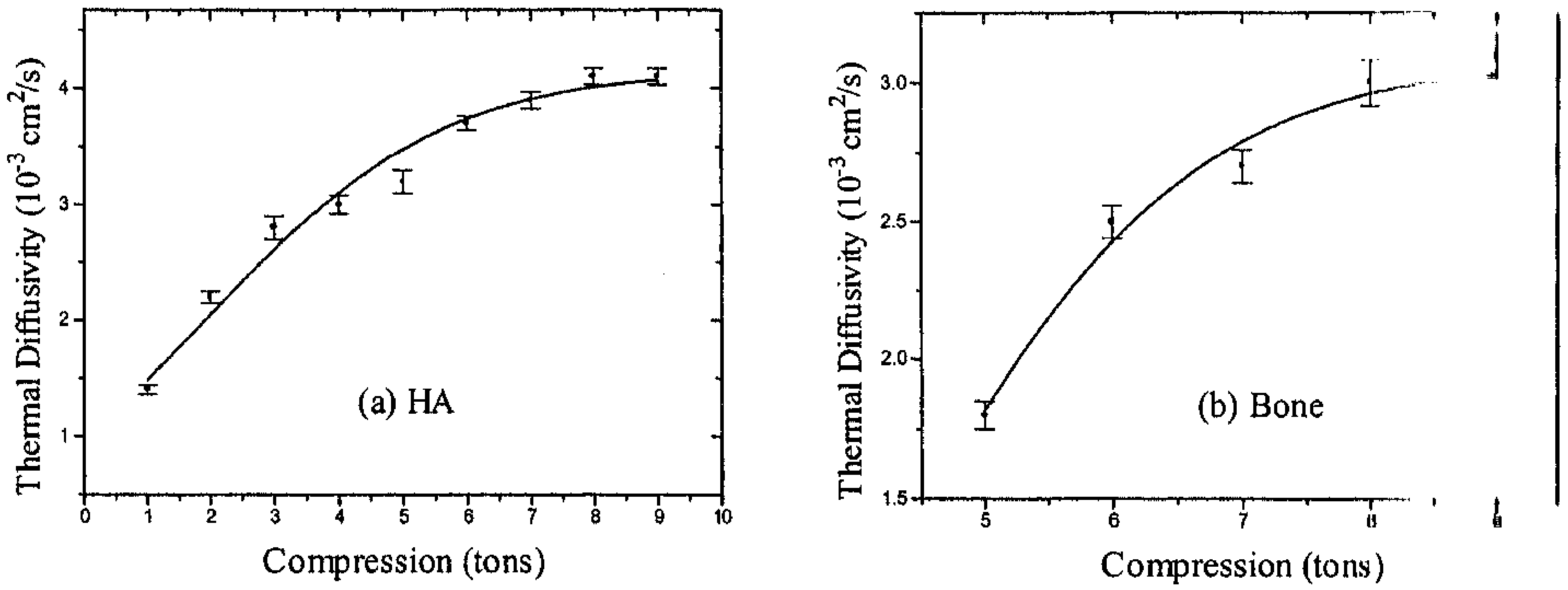

Figure 1. Thermal diffusivity versus compression for (a) hydroxyapatite powders and (b) bone powders. The curve indicate the best fit of logistic Eq. (1) to experimental data.

TABLE 2. Result parameters from the data fitting of α to Eq. (1).

Sample	α_s 10^{-3} *cm²/s*	P_o *tons*	Δp *tons*
Hydroxyapatite	4.19 ± 0.06	2.05 ± 0.09	1.80 ± 0.11
Bone Powder	3.11 ± 0.09	4.63 ± 0.09	1.10 ± 0.18

On the other hand, metals as the titanium and the stainless steel have been used extensively in dental and orthopedic surgery as screws, plates, prothesis, etc. However, from values reported in literature [12], high purity titanium and stainless steel have α values of 92 x 10 $^{-3}$*cm²/s* and 36 x 10^{-3} *cm²/s*, respectively. After we compare these values with those of HA and bone result a one order of magnitude difference, being this difference greater in titanium than in stainless steel, which would be important to take into account for biomedical and dental applications, mainly in the titanium case.

In this form, we report thermal diffusivity determination in HA and bone, in powder form, as well as a good thermal compatibility (74%) between this materials. Finally, a not good thermal compatibility among titanium, stainless steel and bone.

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