Microstructure and Thermal Characterization of Dense Bone and Metals for Biomedical Use

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Abstract. We present a microstructural study and thermal diffusivity measurements at room temperature in two different sections of bull dense bone, bull bone and commercial hydroxyapatite, the last two in powder form. A comparison was realised between these measured values and those obtained from metallic samples frequently used in implants, as high purity titanium and 316L stainless steel. Our results show that the porosity and its orientation in the bone are two important factors for the heat flux through the bone. On the other hand, we obtained that the hydroxyapatite, in compact powder form, presents a thermal diffusivity value close to those obtained for the samples of bone which gives a good thermal agreement between these materials. Finally, it was obtained at one order of magnitude difference between the thermal diffusivity values of metallic samples and those corresponding values to bone and hydroxyapatite being this difference greater in titanium than in stainless steel.

INTRODUCTION

The study and determination of physical, chemical and biological properties of biomaterials used in implants for medical or dental applications is fundamental from the point of view of the biocompatibility 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 [1]. The biomaterials derived from calcium phosphates, have proven to be biocompatible with human bone tissues, which present a composition structure that consists, among others, of a bioceramic crystals of this type, the hydroxyapatite (HA), which is in the bone in an organic matrix medium. The HA is the most important mineral component of bone tissue, 60 to 70% (by volume) in bone and until 98% (by volume) in dental enamel [2]. The HA is a mineral of special importance from the medical point of view since it has been used as coating of metallic substrates in bone implants [1,3]. On the other hand, metals as the titanium

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and the stainless steel have been used extensively in dental and orthopedic surgery as screws, plates, prothesis, etc.[4].

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 characterization [5]. The thermal diffusivity is a quantity extremely sensible to the composition and microstructure of the materials. Thermal properties in porous materials, depend in addition to, the present type of porous structure and its porosity degree [6, 7]. Nowadays this kind of materials has not been studied enough however its scientific and technological research become to be very important in many application.

RESULTS AND DISCUSION

The samples have a disk shape of 1 cm of diameter and thickness between 200 and 239 μm. The bone used in this study come 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 tissue and fat. The bone was dried in air for one week at room temperature, after this the bone was baked in a microwave oven for 5 minutes in order to eliminate residual humidity. Using a low speed cutter several cuts were realized. Sample 3 was obtained from a longitudinal cut, in the same direction of the bone porosity and sample 4 obtained from a transversal cut in relation to the porosity direction. The samples were cleaned in alcohol and then in ultrasonic treatment to remove residual dust. Sample 5 consists of a pill of bull bone powder compressed at 10 tons, this bone powder was obtained from the dust when the dense bone was cutted with a fine handsaw. Sample 6 is a pill obtained from commercial HA powder compressed at 10 tons. All the samples were humidity free storaged.

We obtained thermal diffusivity values by means of the photoacoustic technique (PA) in a heat transmission configuration at room temperature [8, 9]. The table 1 shows the thermal diffusivity values for the studied samples. In Fig. 1 we show the amplitude of the photoacoustic signal obtained as a function of the light modulation frequency in the measurements for samples 3 to 6. The fitting curves shown in this figure were obtained from the same procedure described by Calderon A. et. al.[7].

TABLE 1. Experimental Thermal Diffusivities and Thickness.

Sample Type	Thickness (l_s) μm	Thermal Diffusivity (α) 10^{-3} cm^2/s
1. Stainless Steel 316L	239 ± 5	36 ± 2
2. High Purity Titanium	200 ± 4	92 ± 4
3. Bull Dense Bone (Longitudinal Cutting)	232 ± 4	4.4 ± 0.1
4. Bull Dense Bone (Transversal Cutting)	239 ± 4	5.4 ± 0.1
5. Compressed Bull bone Powders	203 ± 6	3.1 ± 0.1
6. Compressed Hydroxyapatite Powders	227 ± 7	4.0 ± 0.2

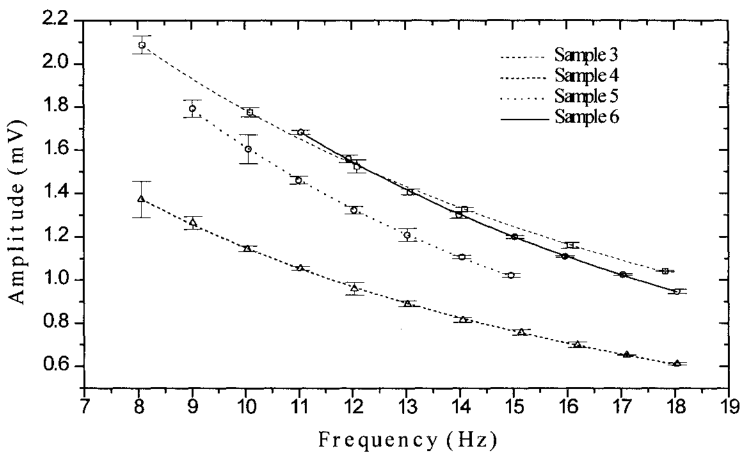
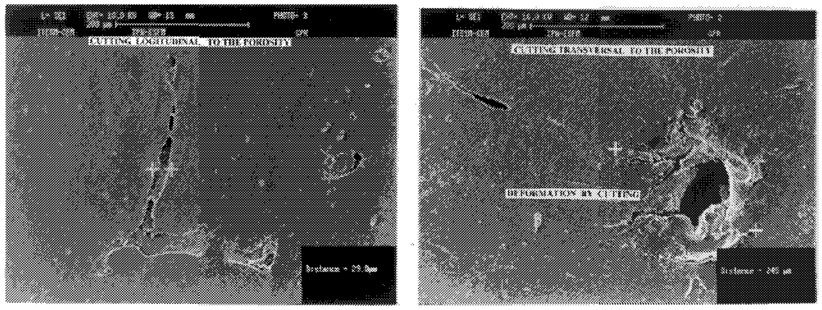


Figure 1. PA signal amplitude versus frequency. The curves indicate the best fitting to the experimental data from the same procedure described in reference [7].

The porous structure of the bone samples was studied by scanning electronic microscopy (SEM, Cambridge 360). In Fig. 2(a) it is shown a microphotograph corresponding to sample 3, in which we can see the bone microstructure in the normal direction to the porosity structure. Fig. 2(b) corresponds to microphotograph of the sample 4, in which can be observed the bone microstructure in the same direction of the porosity structure.

In Table 1 we observed the α values of dense bone (samples 3 and 4) which are greater than the α value for compressed bull bone powders (sample 5), in 42 % and 74%, respectively. This difference in the thermal diffusivity corresponds mainly to the porous structure which is present in the samples 3 and 4 and absent in sample 5. The α value of sample 4 is greater in 23% than the sample 3. We can see from these α values the importance of the porosity in the direction to the heat flow. The heat diffusion is better in the direction of the porosity (transversal cutting) than those that corresponding to perpendicular direction (longitudinal cutting). We observe close α values between the compressed hydroxyapatite powders (sample 6) and the bone samples (samples 3 to 5). Which reveal a similar thermal behavior between these materials. Finally, we observed a difference of one order of magnitude between the thermal diffusivity of metals (samples 1 and 2) with the other samples.

In this form, we show that the porosity and its direction are important factors in the heat flow through the bone. The similar α values obtained between the commercial HA and the bone samples indicate an excellent thermal compatibility between these materials, by the other hand, the α values of titanium and stainless steel 316L show a very big difference with those measured in bone which would be important to take into account for biomedical applications, mainly in the titanium case.



(a) (b)

Figure 2. Microphotograph of Bull Dense Bone by SEM, a) Longitudinal Cutting and b) Transversal Cutting.

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