

# Development and Characterization of Porous Alumina for Controlled Drug Release

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Received: 26 Sept 2020; Received in revised form: 10 Nov 2020; Accepted: 15 Nov 2020; Available online: 19 Nov 2020

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**Abstract**— Alumina is a bioceramic material used in the biomedical area as implants and as drug delivery material; it is considered an inert material, presenting good mechanical properties. Drug delivery is the process of transporting and releasing drugs into the human body in a controlled manner. Due to its characteristics, alumina was chosen as a carrier, since it must have adequate porosity to store and release the drug when implanted or grafted. Starch was used as a sacrificial material to improve porosity in the sample. Alumina samples with 5% and 10% starch addition were compared to pure alumina in relation to its porosity and mechanical properties. X-ray diffraction test confirmed the presence of the corundum structure in the alumina. The tensile strength limit by diametral compression and Young's modulus of samples presented the same value, and approximately half of the value when compared to pure alumina. Regarding porosity, the scanning electron microscope was relevant to highlight the porosity and grain differences in the samples. The mercury porosimetry assay was performed to quantify the porosity percentage, which increased with starch content and decreased with increasing final sintering temperature. In general, increasing sintering temperature reduced drug release, and increased starch content increased drug release. Therefore, it can be concluded that the samples with 5% starch presented the highest drug release in the proposed analysis.

**Keywords**— Alumina, Drug Delivery, Implants, Porosity.

## I. INTRODUCTION

The area of biomaterials is an area in constant growth. New biomaterials are being developed, while existing ones are being improved on a daily basis, as well as their syntheses and production processes [1]. Some of these materials are used in implant components in the human body, with the aim of replacing diseased body parts. These materials must not produce toxic substances when in contact with the body and must be compatible with body tissues [2]. There are reports of alumina being used as biomaterial in several unsuccessful applications, until its use by Sami Sandhaus as a dental implant in the first half of the 1960's [3]. Consisting of aluminum-oxygen

bonding, commercial alumina is usually presented as  $\alpha$ - $\text{Al}_2\text{O}_3$ , where the oxygen ions are organized in a compact hexagonal arrangement with the aluminum ions in two thirds of the octahedral places [4, 5]. Its mechanical properties and its minimum porosity directly depend on the purity of the alumina [4, 6]. For correct femoral implant function, the alumina sphere must present high mechanical resistance to replace the head of the femur. Failure in this type of implant requires a relatively complex surgery. In this way, the implant laboratories focused on processes to obtain high purity alumina, materials presenting low porosity, in addition to the introduction of zirconia as a reinforcement material along with alumina in some applications [7, 8].

However, for alumina to be used as an implant and drug carrier, it must have adequate resistance and present pores in its structure, respectively. For a femur implant, for example, the porosity process required for controlled release would be impracticable. However, a dedicated implant for an area that is not subjected to constant mechanical stress, such as cranial implants, may be feasible. Cranial implants do not undergo frequent mechanical stresses, impacts, or wear [9]. Therefore, the possibility of porosity is acceptable, and may even bring benefits to this type of application. Porous ceramics could allow the growth of connective or bone tissues in the implant [10].

The implanted materials must have mechanical properties and density as similar as possible to the replaced bone. Table 1 lists some materials that present such characteristics. In addition to the materials presented in Table 1, hydroxyapatite [9], titanium and several titanium alloys (Ti-6Al-4V, Ti<sub>cp</sub>, Ti-15Zr, Ti-19.1Nb-8.8Zr, Ti-41.2Nb-6.1Zr e Ti-25Hf-25Ta) [11] can also be used in bone growth treatments. Two relevant mechanical properties must be considered: the tensile strength limit (TSL), which considered the greatest stress that the material can achieve in a stress vs strain diagram, and the Young's Modulus (YM), which represents the elasticity of the material. YM is obtained by the coefficient between stress and strain at given points in the elastic region of the stress x strain diagram [10, 12, 13].

Pure alumina has low porosity when sintered. This results in excellent mechanical characteristics when compared to other materials (maximum resistance to abrasion/flexion/compression, Young's modulus, hardness, impact resistance). However, it restricts the absorption of actives, essential for controlled release. The inclusion of pores in alumina will provide the possibility of the absorption of a higher amount of actives and consequently, improve the controlled drug release process.

The production of meso/macro porosity can be achieved with the addition of organic compounds in the ceramic. An example is the production of ceramic suspensions with starch particles, where starch acts as a gelling agent [14]. During heating in hot water, the starch passes its gelation point, where the rheological characteristics, such as viscosity, are drastically changed, precisely by passing from solid to gel [15]. After the inclusion of starch to the alumina, the mixture is sintered. The organic material is burned and released, forming pores in the alumina.

For the purpose of carrying and controlled release of drugs, alumina can be used in the form of macroscopic implants, acting as a "sponge" [16]. Thus, the main

purpose of this article is the development of porous alumina for drug carrying and be used as cranium implant. For this, the porosity and the mechanical properties of alumina must be taken into consideration, which are two types of antagonistic properties.

## II. MATERIAL AND METHODS

Alumina was donated from Treibacher Schleifmittel Brasil Ltda. Starch was purchased from Alphatec. Bupivacaine Hydrochloride (BUP) was provided by Dr. Eneida de Paula from the Department of Biochemistry at University of Campinas (Unicamp).

### 2.1 Preparation of samples

Starch samples were mixed in hot water (90 °C) under magnetic stirring until reaching the gelation process. The starch samples (5% and 10% by weight for alumina) were then slowly poured over alumina. The mixtures were placed in the jar mill (SOLAB SL 34) and mixed for 48 hours at 150 rpm. After that, the material was left to dry at room temperature (without ventilation or kiln) for approximately one week. After drying, the material was ground in a mortar and pestle and sieved through a 53- $\mu$ m sieve (Bronzinox - 270 Mesh).

### 2.2 X-ray diffraction analysis

Samples of pure alumina and alumina containing 5% and 10% starch were analyzed using X-ray diffraction. The analyses were performed on a D2 Phaser Bruker diffractometer. The X-ray diffractograms were obtained between 20° to 80° in 2 $\theta$  with 0.03°/s steps and 0.2-mm slit.

### 2.3 Thermal analysis

Samples of pure alumina and alumina containing 5% and 10% starch were submitted to thermogravimetric analysis (Shimadzu TGA-51H Thermogravimetric Analyzer). The samples were heated to 800 °C, with a heating rate of 10 °C/min and a flow of synthetic air carrier gas of 20 mL/min.

### 2.4 Sintering of samples

Before sintering, the samples were pressed (SKAY 30-Ton uniaxial hydraulic press) with 2-ton pressure to produce the specimens in two different shapes (rectangular and cylindrical formats). The samples were then sintering in a Nabertherm LHT 02/17 LB Speed furnace according to the curve shown in Figure 1.

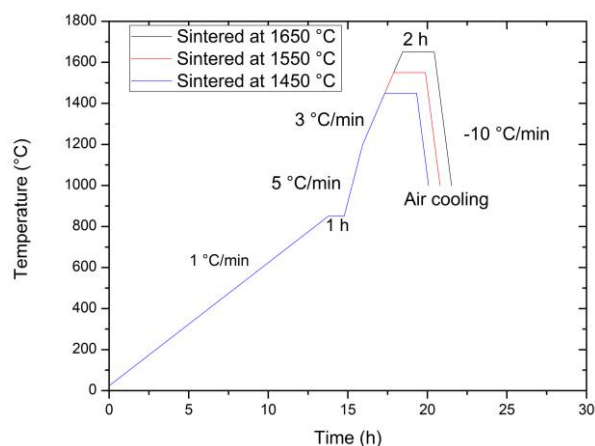


Fig. 1 – Sintering curve of the alumina sample.

## 2.5 Dilatometry

The samples were pressed and placed in a dilatometer (Netzsch DIL 402 dilatometer). The measurement was performed with the same sintering curve as shown in Figure 1 (1450 °C and 1550 °C) for samples of pure alumina, alumina with 5% starch and 10% starch. The sintering curve with temperature at 1650 °C could not be performed due to the equipment operating at temperatures up to 1600 °C.

## 2.6 Scanning electron microscope

Rectangular samples were broken and the fractured surface was analyzed at SEM FEI quanta 200. To allow responses from the microscope surface, the surfaces were sputtered with gold particles (sputtering/coating Bal-Tec SCD-050 device). Only the rectangular samples were analyzed under magnifications of 42x, 600x, 2400x, 10000x, and 30000x.

Table 1 – Bone properties and their possible implant substitutes (\*Ti-6Al-4V alloy recovered - post-heat treatment).

	Density (kg/m <sup>3</sup> )	Tensile strength limit (MPa)	Young's Module (GPa)
Cranium (bone)	1728	92.72	8
PEEK (implant)	1300	-	3.2
HAP (pure)	2500	-	0.75
HAP with bone (implant)	2224	20.5	1.25
Titanium (pure)	4510	240	103
Titanium (alloys)	-	900-1172	53-113
Alumina (90-98% purity)	3600- 3900	104-551	275-380

Adapted de [11, 9]

## 2.7 Diametral compression

The cylindrical samples were subjected to the diametral compression test on a universal testing machine (Shijin WDW100E Testing Machine). The cylindrical samples were subjected to compression until fracturing. The stress ( $\sigma$ ) is calculated considering the diameter (D) and thickness of the cylinder (h), in addition to the force (P) applied to the specimen (Equation 1) (Marion & Johnstone, 1975).

$$\sigma = \frac{2P}{\pi Dh} \quad \text{Equation 1}$$

## 2.8 Mercury porosimetry

Mercury porosimetry was performed only on rectangular samples using a Micromeritics Autopore<sup>TM</sup> IV porosimeter. Mercury intrusion was performed from low (50  $\mu$ mHg) to high pressure (4.45 psi). Each pressure point had a 300-second equilibrium time.

## 2.9 Bupivacaine absorption and release

The drug absorption test was performed with the rectangular shape alumina specimens (previously weighed) from three different samples: pure alumina, alumina 5% starch, and alumina 10 % starch (all of them sintered). The specimens were immersed in 5-mL Bupivacaine hydrochloride (BUP) (3.00 mg/mL) for 24 h under agitation. After this period, the alumina samples were removed from the drug solution and weighed.

For the absorbed BUP release study, the BUP/alumina specimens were immersed in 30-mL phosphate buffer solution, 7.4 pH (0.2 M). Buffer solution aliquots (2 mL) were removed at regular intervals: 0.5h; 1h; 2h, 3.5h; 5h; 7.5h; 26.5h; 28h; 51h; 172h; 197h; 268h; 315h; 338h; and 482h. The release tests for the different samples (pure alumina, alumina 5% starch, and alumina 10% starch) were performed in triplicates. The aliquots were analyzed in UV<sub>vis</sub> (Biochrom Libra) spectrophotometer to determine the BUP content released from the alumina. After analysis, samples were returned to the flask containing the phosphate buffer solution.

A BUP calibration curve was performed in advance using standard solutions with concentrations ranging from 0.5 to 3 mM (BUP absorption at 263 nm).

## III. RESULTS AND DISCUSSIONS

Alumina samples containing starch were prepared under the same conditions. The amount of starch used was 5% and 10%. Two specimen shapes were prepared: rectangular and cylindrical. Three sintering temperatures were used: 1450, 1550, and 1650 °C.

X-ray diffraction analysis was performed to verify the phase of the acquired alumina, as well as any possible contamination. According to the RRUFF website, the alumina is used in the corundum phase (website catalog: R040096.2) (Figure 2) indicating that there is only the presence of the alumina phase.

A pure starch sample was submitted to thermogravimetric analysis in order to define the starch degradation, as well as adjusting the sintering heating curve (Figure 3). Starch degradation occurs in 3 stages: up to 120 °C water and other small molecules are lost; between 280 and 390 °C series reactions occur, such as depolymerization (breaking of polysaccharide chains) and decomposition of amylopectin/amylase; and between 390 and 625 °C carbonization reactions take place, which leads to the formation of amorphous carbon structures [17].

The sintering test was carried out with initial heating at a slow rate until reaching the temperature of 800 °C for one hour (Figure 1) [18]. This slow heating (1 °C/min) is intended to completely degrade the starch. The heating process from that point until reaching the temperature of 1200 °C was fast (5 °C/min).

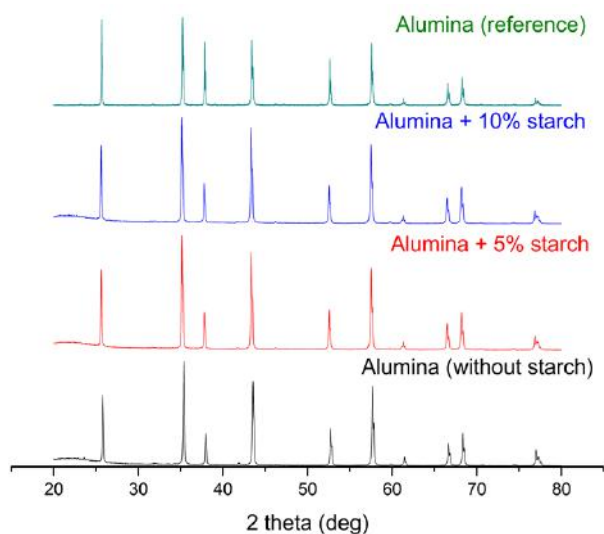


Fig. 2 – X-ray diffractometry for pure alumina (without starch); 5% starch alumina; 10% starch alumina; and alumina reference.

From 1200 °C, the heating was moderate (3 °C/min) until reaching the sample sintering temperature, where the temperature was maintained for two hours. The sintering process was carried out by varying the temperature from 1450, 1550, and 1650 °C. In this case, it is assumed that these temperatures result in partial samples sintering and therefore, differences in alumina properties must also be presented. The samples were cooled in a controlled

manner (10 °C/min) up to 1000 °C to avoid cracks in the alumina.

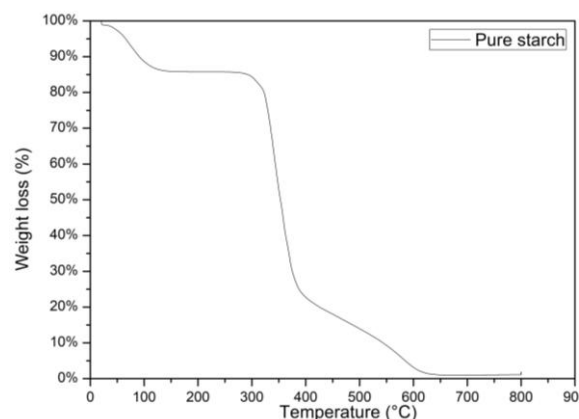


Fig. 3 – Thermogravimetric analysis of pure starch in an oxidizing atmosphere

The samples were then submitted to a dilatometry test, with the objective of verifying the contraction process of the samples during sintering. The analysis compares the contraction of samples in relation to their starch content and sintering temperature. The dilatometry analysis was performed reproducing the thermal ramps of 1450 °C and 1550 °C (Figure 4).

Figure 4 shows an almost-constant expansion in the samples with the increase in temperature (obeying the increase in heating rate). The sintering temperature starts at approximately 900 °C, with the process of contraction of samples. The samples burned at 1450 °C presented less contraction than those burned at 1550 °C, precisely because the sintering process is more effective at higher temperatures.

Another important analysis is the influence of porosity in the shrinking process. The greater porosity interferes in the proximity between the particles, making the sintering process and consequent shrinkage difficult. Thus, it was expected that samples presenting 5% starch presented greater retraction than those with 10% starch content. However, at a temperature of 1450 °C, an inversion in the results can be observed, that is, a greater retraction was observed in the 10% starch samples. This can be explained by the fact that at this temperature the sintering process is in the intermediate phase in which the amount of pores is still moving, and depending on the size, it influences the contraction, thus being an obstacle during the sintering process. At 1550 °C, the temperature at the final sintering phase, the contraction was practically the same for all samples, regardless of the amount of pores in them.



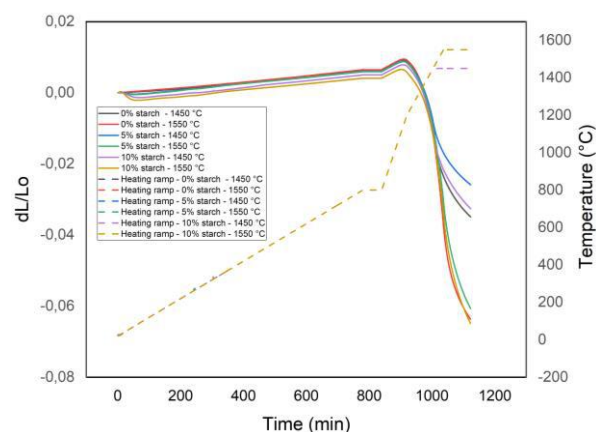


Fig. 4 - Dilatometry performed on alumina samples.

After the heat treatment, the samples were submitted to scanning electron microscopy (SEM) analysis to check the alumina porosity. It is possible to observe in the SEM images (Figure 5) that with the increase in the sintering temperature, the pure samples became more spherical and with rounded corners [19]. Besides that, the increase in sintering temperature induces a decrease in space between particles, an increase in particle size, and an apparent reduction in porosity and pore size. At 1650 °C sintering temperature, there is little porosity, and thus, it would not be considered a temperature of interest to obtain pores. The difference in terms of porosity is not noticeable when comparing the starch percentages (5 and 10%) since they are relatively low content levels. Li et al. (2013) found noticeable results due to the use of samples showing a large variation (10 to 40%) of starch.

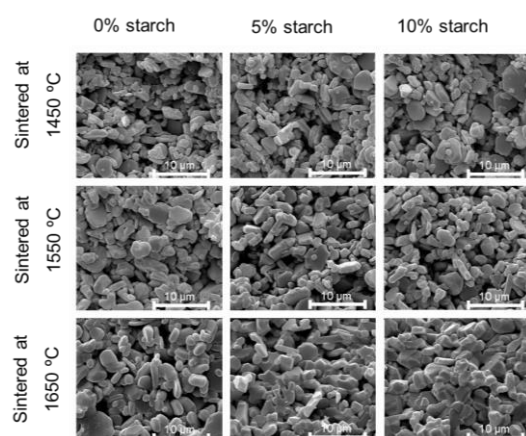


Fig. 5 - SEM microphotograph of fracture surface of pure alumina; alumina starch (5 and 10%) at temperature 1450 °C, 1550 °C, and 1650 °C.

The porosity index related to the starch percentage and sintering temperature was checked using mercury porosimetry test (Table 2). Regarding the sintering temperature, it can be observed that porosity decreased

with the increase in sintering temperature. At the temperature of 1450 °C, an increase in porosity could be observed in samples with an increase in the starch percentage. At the sintering temperature of 1550 °C, a small decrease in porosity could be observed when compared to samples at the temperature of 1450 °C. The highest value was observed for 10% starch samples at 1550 °C. At the sintering temperature of 1650 °C, the sample without starch and with 10% starch presented similar porosity values. However, for the sample with 5% starch, a higher porosity index could be observed (Table 2). All porosity values at 1650 °C are lower than at other sintered temperatures, which corroborates with the concept that an increase in the sintering temperature decreases the porosity.

The result of the three analysis (dilatometry, SEM, and porosimetry) related to the pore formation indicates low efficiency in the mixture between starch and alumina, and at 1650 °C sintering temperatures the amount of starch used (5 and 10%) is not sufficient to form porosity.

The development of sintered alumina with pores for drug delivery systems has been successfully carried out. The presence of pores may reduce the mechanical resistance of the material, and therefore, it is important to check its properties. Diametrical compression tests were performed (Table 3) with samples of pure alumina and alumina samples containing 5 and 10% starch at different sintering temperatures.

Table 2 – Mercury porosimetry analysis for samples with rectangular shape.

Samples	Porosity (%)
1450 °C / 0 % starch	29.7752
1450 °C / 5 % starch	31.1073
1450 °C / 10 % starch	34.9708
1550 °C / 0 % starch	25.8941
1550 °C / 5 % starch	24.7535
1550 °C / 10 % starch	31.8249
1650 °C / 0 % starch	15.6107
1650 °C / 5 % starch	21.4169
1650 °C / 10 % starch	14.9683

The tests were performed with 5 replicates for each sample to reduce the standard deviation and allow greater statistical validation of the values. It is important to emphasize that the elevated standard deviation can be explained due to the greater amount of pores, distribution defects, and small quantity of samples.

By analyzing the samples submitted to the 1650 °C sintering temperature, it can be observed that the values regarding tensile strength limit and Young's Modulus are much higher when compared with the samples with starch percentage (Table 3). However, the results at other

sintering temperatures did not present significant variation when comparing the pure sample and starch samples. This indicates that at 1650 °C the alumina is possibly near the final sintering phase.

Table 3 – Diametrical compression test results.

	Tensile strength limit (diametrical compression) (MPa)	Total deformation (%)	Young's modulus (approximate)(GPa)
1450 °C / 0 % starch	7.13 ± 2.65	0.66 ± 0.30	49.19 ± 4.19
1450 °C / 5 % starch	7.48 ± 1.98	0.65 ± 0.51	71.67 ± 40.74
1450 °C / 10 % starch	6.37 ± 1.54	0.67 ± 0.86	54.75 ± 2.75
1550 °C / 0 % starch	20.18 ± 5.73	1.02 ± 0.43	134.01 ± 64.33
1550 °C / 5 % starch	18.24 ± 6.78	0.87 ± 0.13	133.86 ± 32.14
1550 °C / 10 % starch	17.73 ± 2.69	1.02 ± 0.20	119.05 ± 15.98
1650 °C / 0 % starch	69.30 ± 17.05	1.55 ± 0.27	278.20 ± 48.27
1650 °C / 5 % starch	32.82 ± 10.30	1.21 ± 0.56	151.74 ± 44.07
1650 °C / 10 % starch	33.95 ± 11.63	1.54 ± 0.20	1.14 ± 55.42

When comparing the values obtained from literature regarding alumina (Table 1), it can be noted that the tensile strength limit for alumina samples sintered at 1650 °C was below that found in literature. In addition to the use of an indirect method for obtaining the tensile strength, which can influence the values, the study used one of the simplest pressing/burning methods. Young's modulus was close to that found in the literature for alumina with 90% purity at temperature 1650 °C.

When compared to the value of Young's modulus for the cranial bone present in Table 1, the Young's modulus value for the analyzed samples was much higher, which indicates greater rigidity. In relation to the titanium alloys, the values for Young's modulus at 1450 °C are close, while those burning at 1550 °C and 1650 °C exceeded the limits.

Regarding the tensile strength limit, for samples burning at 1450 °C, the values were close to those of HAP with bone sample. Samples burning at 1550 °C and 1650 °C exceeded the value obtained for HAP with bone, but did not reach the bone tensile strength limit, and are much lower than the limit value for pure titanium (and in the case of titanium alloys, this value can be 5-fold greater than the tensile strength limit for pure titanium).

The tensile strength limit is a property that must be improved in these samples. The polymers and metals currently used have a high tensile strength limit, and the bone itself has a higher tensile strength limit than the analyzed samples. However, HAP with bone, which is

currently used in implants, presents a lower tensile strength limit than most tested samples, and thus, porous alumina can be considered a possible alternative for use in cranial implants, considering the strength limit traction.

### 3.1 Bupivacaine absorption and release test

The absorption and release of BUP in the alumina was measured through the determination of the maximum absorbance wavelengths of BUP in the UV<sub>vis</sub> ( $\lambda = 263$  nm), and a calibration curve for the BUP concentration ranging from 0.5 to 3.5 mM produced a regression equation ( $r^2 = 0.9844$ ):

$$y = 2.305x - 0.0654 \quad \text{Equation 2}$$

In the drug absorption assay, the alumina was immersed in a BUP solution for a period of 24 h. The alumina sample was weighed before and after immersion in the BUP solution (Table 4). Table 4 indicates that the increase in the sintering temperature resulted in a lower absorption of the BUP. This can be explained by the decrease in porosity with the increase in the sintering temperature. Regarding the starch content at temperatures of 1450 °C and 1550 °C, it could be observed that samples of pure alumina (0% starch) showed less absorption due to their lower porosity. Regarding the temperature of 1550 °C, the absorption values were relatively similar, but higher than that of pure alumina and below those for 1450 °C. This drug absorption equality indicates that the porosity reached for alumina with 5% starch and 10% starch did not differ, despite doubling the amount of starch.

For the BUP release test, the alumina samples containing BUP were immersed in 30-mL phosphate buffer solution under constant agitation. Aliquots were removed at specific times and analyzed under UV<sub>vis</sub>. The aliquots were returned to the release test reaction medium. It was assumed that the maximum concentration of BUP absorbed by alumina was estimated as the final BUP concentration of the absorbed solution minus the initial BUP concentration of the solution in the absorption test. The results were compared in percentage terms in relation to its maximum BUP concentration value.

Figure 6 presents the results of the release tests as a percentage of BUP released in relation to time. A similar release profile could be observed for all samples, with the highest release intensity in the first 100 h. Low release rates were also observed at a temperature of 1650 °C.

These results can be explained by the low BUP concentration absorption at high sintering temperatures (1650 °C) due to the low level of porosity.

The BUP release from alumina samples with 10% starch showed the highest release values for the sample sintered at 1450 °C, followed by the ones sintering at 1550 °C and 1650 °C, respectively. These results are expected due to the greater amount of starch used to form the pores and the greater number of pores at 1450 °C (approximately 80% release). At 1550 °C, the release value was approximately 60%.

Table 4 - Sample absorption (water and BUP) in alumina in relation to sample weight.

1450 °C / 0 % starch	11.00%
1450 °C / 5 % starch	15.84%
1450 °C / 10 % starch	15.84%
1550 °C / 0 % starch	11.22%
1550 °C / 5 % starch	12.40%
1550 °C / 10 % starch	12.25%
1650 °C / 0 % starch	3.05%
1650 °C / 5 % starch	5.53%
1650 °C / 10 % starch	7.47%

In general, when comparing the samples in the three different sintering temperatures, it can be concluded that at 1450 °C more drugs were released, followed by 1550, and finally 1650 °C. Regarding the starch contents, the release increased for samples with 10% starch due to the greater formation of pores and greater absorption of BUP.

An exception was a sample of pure alumina sintered at 1450 °C, which showed greater release when compared to the sample with 5% starch. This may be due to the high surface porosity on the pure alumina due to processing.

#### IV. CONCLUSIONS

It was possible to prepare the samples with 5 and 10% starch, as expected. However, the amount of starch released during sintering was lower than the initially added, as shown in the thermogravimetry tests, indicating that it is likely that the starch was not fully distributed during incorporation into the alumina, or that the distribution of starch in the alumina was not homogeneous due to the use of uncontrolled drying.

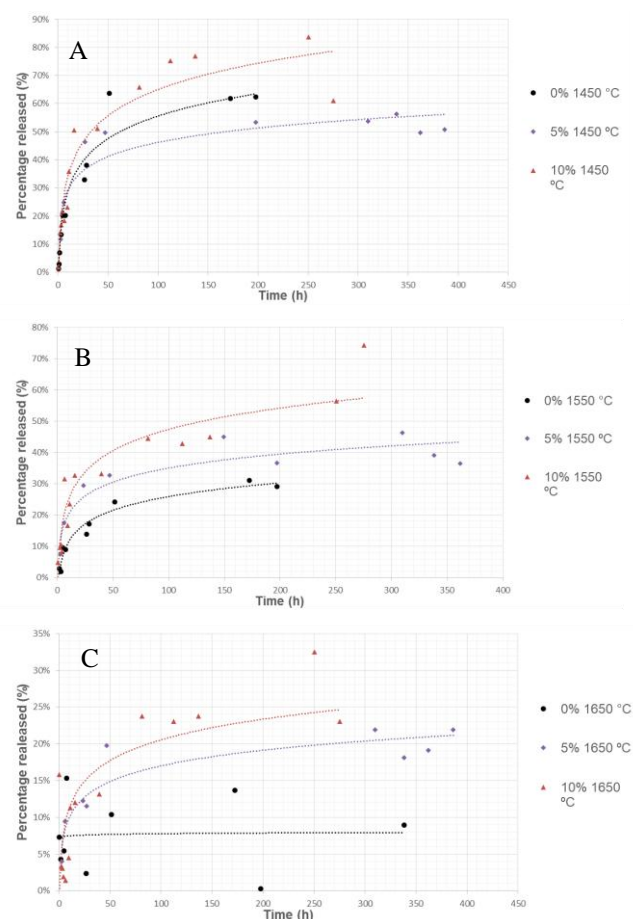


Fig. 6 - Percentage of BUP release as a function of time (hours). A) sintering temperature of 1450 °C; B) sintering temperature of 1550 °C; and C) sintering temperature of 1650 °C.

Scanning electron microscopy determined the particle morphology of the samples in addition to observing the differences in porosity in the samples.

As for dilatometry, it was possible to observe that the samples sintered at 1550 °C presented greater contraction than those sintered at 1450 °C, thus resulting in greater porosity at lower temperatures. It was also possible to observe that the starch content did not influence the temperature at the beginning of sintering.

It was possible to verify that the loss of mechanical properties occurs at temperatures of 1450 and 1550 °C for all samples, possibly due to the complete sintering of the samples rather than the incorporation of starch. At a temperature of 1650 °C, it is possible to notice that the porosity generated by the starch reduces the mechanical properties in almost 50%. However, both samples with starch contents presented similar properties. This means that possibly the influence of the addition of a greater amount of starch did not impair the mechanical properties. Nevertheless, further studies must be developed in order to confirm this behavior at higher starch levels.

Regarding the porosity analyzed by the mercury porosimetry, it can be inferred that a decrease in porosity could be observed with the increase in sintering temperature. Considering the temperature of 1450 °C, the increase in the starch content resulted in an increase in porosity. However, at the sintering temperatures of 1550 °C and 1650 °C, the same could not be observed, that is, the variation in the percentage of starch may have been different from the expected and with the increase in the sintering temperature, a reduction in porosity was observed.

The weighing of the samples before and after immersion allowed to infer which samples presented greater absorption of the diluted drug in relation to their initial mass. It was noted that the increase in the sintering temperature in samples with the same starch content resulted in a decrease in the absorbed percentage. The absorption percentages were lower for samples of pure alumina and equivalent for samples containing 5 and 10% starch.

Regarding controlled release, considering the released concentrations between the two samples with starch, samples with 10% starch were the ones presenting the greatest release of drugs. Considering the three sintering temperatures, the samples with the lowest sintering temperature (1450 °C) were the ones that released most drugs due to their higher porosity.

The addition of pores in the alumina resulted in a greater controlled release, but a decrease in the mechanical properties. The samples sintered at 1550 °C were the ones that released most drugs in relation to the initially absorbed amount. At this temperature, some of its

mechanical properties are compared to that of PAH, which is frequently used for this type of implant. However, since it was the first formulation of the samples, future changes in the process for obtaining the samples can be made, which could result in samples with greater mechanical strength than the current ones. For the results obtained in this study, the samples with 5 and 10% of starch sintered at 1550 °C could be chosen for use in this type of application.

## ACKNOWLEDGEMENTS

The authors would like to thank the Labmult laboratory at the Technological Federal University of Paraná, in Londrina, PR, for using their facilities. The authors would also like to thank the Laboratory of Spectroscopy at the State University of Londrina.

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