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Acoustic waves testing to evaluate the compressive strength of ceramics bricks

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***Abstract*—** *The present study seeks to develop a simple methodology capable of relating the propagation of acoustic waves with the compressive strength of ceramic sealing bricks. For this purpose, were captured acoustic signals generated by the impact of a steel sphere on the surface of ceramic bricks from three different origins. With the acoustic signal as a function of frequency, was possible to identify the main amplitude peak, which increases with the increase in compressive strength. Other characteristics of the acoustic signal, such as for instance a greater number of amplitude peaks presented below 5 mHz, could be also related to the compressive strength of the bricks indicating a possibility of fast and non-destructive testing.*

I. INTRODUCTION

The Brazilian civil building industry is among those that most consume ceramic products. This fact is associated to the large number of buildings that use various types of ceramic materials for coverings, in addition to the sealing and structural bricks that have a prominent position. According to the National Association of Ceramic Tile Manufacturers, Brazil occupies the 3rd position of the production and in the 2nd position of consumption of ceramic materials in the world [1]. That is because there is an ease of obtaining ceramic materials due to the abundance of raw materials available in the country [2].

The ceramic bricks are produced using clay (with or without additives) and generally has a reddish color. In the manufacturing process, the bricks must be fired at controlled temperatures between 800 °C and 1000 °C. This temperature range increases the mechanical strength of the bricks by decreasing the internal porosity [3]. However, it is known that many bricks are produced by some potteries that use empirical procedures for dosing and firing. In this case, there is a possibility to compromise the mechanical properties of the final product, also influencing the quality of the building with the use of materials that do not comply with the technical standards.

Among the main requirements for a ceramic sealing brick, the followings stand out: regular geometry, water absorption capacity and compression strength [4]. The absence of these requirements can directly influence the mechanical strength of masonry, which affects the installations, frames and building coatings. Thus, it is important to carry out testing to determine the geometric characteristics, water absorption and compressive strength of ceramic bricks.

For the compression testing, it is recommended use a press that is in accordance with the descriptions in Annex C of [5], in addition to taking care with the receipt, preparation and packaging of the bricks that will be used as bodies of proof for rupture. Generally, these procedures demand more time and cost to acquire the results.

An alternative that could reduce the time and cost of preparing samples for the compression testing is the possibility of using non-destructive tests, especially those that use ultrasonic waves (frequency above 20 kHz) to determine the mechanical properties of ceramic materials [6, 7, 8]. However, techniques that use acoustic waves with frequencies below 20 kHz have been used for investigating compressive strength and other properties that can be associated to the behavior of the acoustic signal propagated in the material [9, 10, 11].

Therefore, according to the above reports, this study sought to develop a proposal for a fast and non-destructive methodology to determine the compressive strength of ceramic sealing bricks. Recent publications about the subject and the use of a simple technique based on the theory of acoustic waves propagation were motivators to this study.

II. MATERIAL AND METHODS

2.1 Characteristics of the samples for the acoustic testing

To execute the test with acoustic waves were acquired commercially twelve samples of ceramic bricks used for sealing masonry. The bricks were chosen by visual analysis, which allowed the identification of samples free from systematic manufacturing defects, such as superficial cracks, burrs and square deviations. After this, the bricks were divided into 3 groups according to the provenance of the pottery. Table 1 shows the physical characteristics of the samples and the origin of the batch.

Table 1: Physical characteristics of the samples

Pottery	Batch	Samples	Dimensions (mm)	Average weight (kg)
A	CC	04	240 x 90 x 190	2.770 ± 0.015
B	MZ	04	240 x 90 x 190	2.830 ± 0.079
C	CM	04	240 x 90 x 190	2.905 ± 0.068

The average weight of the samples from each batch was determined using an analytical balance with a resolution of 0.1 g. For to verify the approximate dimensions of the samples (length, width and height) was used a pachymeter with a resolution equal to 0.005 mm. Then, the samples of each batch were identified such as T1, T2, T3 and T4.

2.2 Generation and capture of acoustic waves

After measuring the dimensions and weight, two small flat regions (~ 6 cm^2) were delimited at ends of one the lateral faces on the samples. The flat regions were obtained by polish that favored the surface wear. Afterwards, the samples were supported on the sides opposite to the polishing to carry out the test with acoustic waves generated using the impact of a steel sphere.

For analyze the propagation of acoustic waves on the surface of the samples, a simple methodology was used which consists of using a steel sphere and a free software [12]. This methodology has been used in the study of different materials, such as ceramic tiles, concrete and steel [10, 11, 13]. In the present study, the methodology was adapted and the brick samples were impacted using a steel sphere with 5.5 g and 23 mm diameter. The acoustic signals generated by the strike with the steel sphere were captured with the Soundcard Oscilloscope software. This software represents a digital oscilloscope with a visual interface similar to the conventional oscilloscope. The average acoustic signal for the batches was obtained from 20 measurements. For this, were performed 5 measurements on each one of the 4 bricks belonging to the respective batch.

The amplitude of the signals measured (in the arbitrary unit a.u.) was investigated as a function of the acoustic wave propagation time in the range between 0 and 20 milliseconds (ms). A stereo phone Plug P2 was used as a receiver for the acoustic signals. The phone was positioned in one of the polished regions to capture the signal produced by the deferred impact with the sphere at the other end of the sample. The setup of the experiment is illustrated in Figure 1. Figure 1(a) shows the computer with Soundcard Oscilloscope software installed. The impact locations with the sphere and the capture of acoustic signals can be seen in the top view shown in Figure 1(b). A detail of the polished region is shown in Figure 1(c).

In Figure 2 there is an example of an acoustic signal captured on the side of the bricks and presented on the computer screen. The type of headphone used as a signal receiver does not have sensitivity to capture noise or external vibrations that could be transmitted to the digital oscilloscope and interfere with the measurements. The red line represents the signal on the computer screen before the measurements, while the green line represents the acoustic signal after the sphere impact. Thus, the absence of noise or external vibrations was verified before taking the measurements.

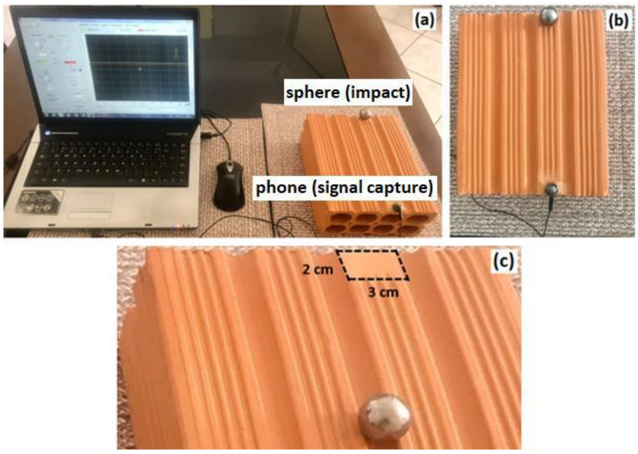

Fig. 1: Set up of the experiment to generate and capture the acoustic signals: (a) system used, (b) top view and (c) detail of the polished region

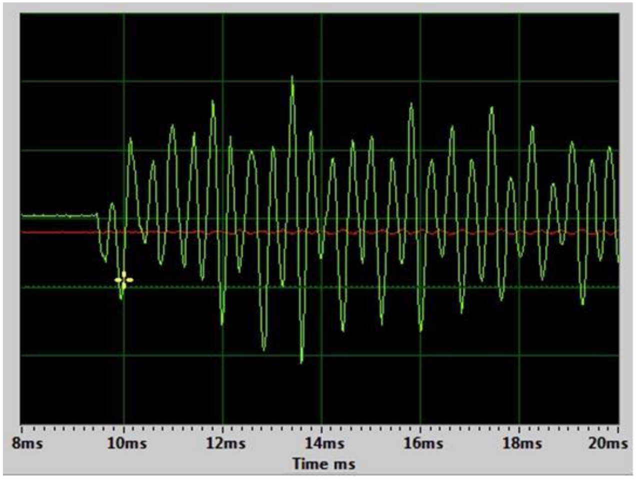

Fig. 2: Example of the acoustic signal on the sample

The data collected in the experiment were analyzed in the Origin® program. Thus, it was possible to decompose the temporal function of the acoustic signal in the frequency domain, using the Fast Fourier Transform (FFT) method. The FFT method is widely used in the study of signals processing and other applications in physics and engineering [14, 15].

The FFT method was performed to relate the frequencies excited in the acoustic signal with the average values of compressive strength of the bricks (fbm). For the compressive strength testing were used 13 ceramic bricks from A, B and C potteries. These bricks presented visual and physical similar characteristics to the samples used on the test with acoustic waves. The compressive strength testing was carried out with a hydraulic press following the procedures described in [5].

III. RESULTS

The average signals as a function of the acoustic wave propagation time on the surface of the bricks is shown in Figure 3. Each curve presented in the figure represents the average acoustic signal, in arbitrary unit (a.u.), obtained with 5 measurements on the samples. Analyzing the results, it can be seen that the average signals obtained in each of the 4 samples of the CC batch are quite reproducible, with only small variations in the amplitudes of the signals, as can be seen in Figure 3(a). Although there are small variations in the amplitude values, the 26 peaks presented in the acoustic signals of the samples are located in practically the same positions in relation to the time axis between 8 ms and 20 ms.

The behavior of the acoustic signals observed in samples from CC batch is also similar to that presented by samples from CM batch, whose results are shown in Figure 3(b). However, the mean signal obtained from the T1 sample has a much smaller amplitude compared to the mean signal amplitude from the T2, T3 and T4 samples. It is known that in the proposed methodology, the signal amplitudes are very dependent on the impact energy caused by the strike with the steel sphere on the brick surfaces. However, the hypothesis that T1 sample was strike with a much lower impact energy than the other samples was discarded in this study. With the performance of 5 measurements per sample it is evident that the average signal obtained in the T1 sample is more attenuated and this fact was considered an intrinsic characteristic of this sample.

Comparing the shape of the acoustic signals, the results obtained in samples from MZ batch were different in relation to samples from batches CC and CM. The mean signals found in the samples from MZ batch is shown in Figure 3(c). In the result, the amplitude peaks increase and decrease together for all samples. This behavior can be observed in the region of the time axis between 9 ms and 15 ms. On the other hand, the increase and decrease of amplitude peaks behave randomly in the region between 15 ms and 20 ms, but without modifying the location of the 26 amplitude peaks on the time axis. For all batches investigated it was found that the acoustic signal consists of 26 amplitude peaks, indicating that this behavior can be a characteristic of ceramic bricks, regardless of the origin of the pottery.

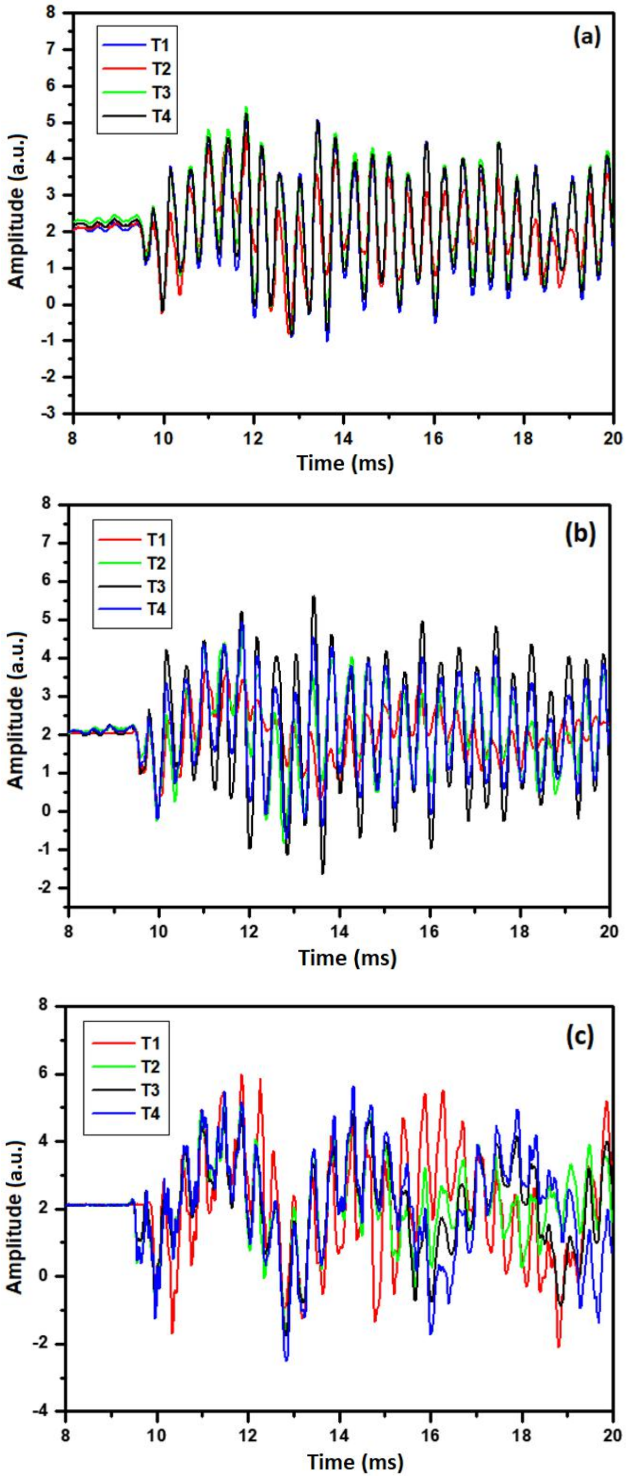

Fig. 3: Average acoustic signal of the batches: (a) CC, (b) CM and (c) MZ

The acoustic signals as a function of time did not present significant differences that could be related to the values of compressive strength of the bricks. Therefore, an attempt was to analyze the amplitudes of the acoustic signals as a function of vibration frequencies. The results are shown in Figure 4. Thus, it was found that the acoustic signals for CC, CM and MZ batches are constituted by a different number of amplitude peaks, which are present in a low frequency range between 1 mHz and 8 mHz. Figure 4(a) shows the signal with the characteristic vibration frequencies for the CC batch samples. The result shows 19 amplitude peaks, where 15 peaks are present in the region between 1 mHz and 5 mHz, and the other 4 peaks are between 5 mHz and 8 mHz. The locations of the amplitude peaks (in mHz) on the frequency axis are reported in detail in parentheses inserted in the figure.

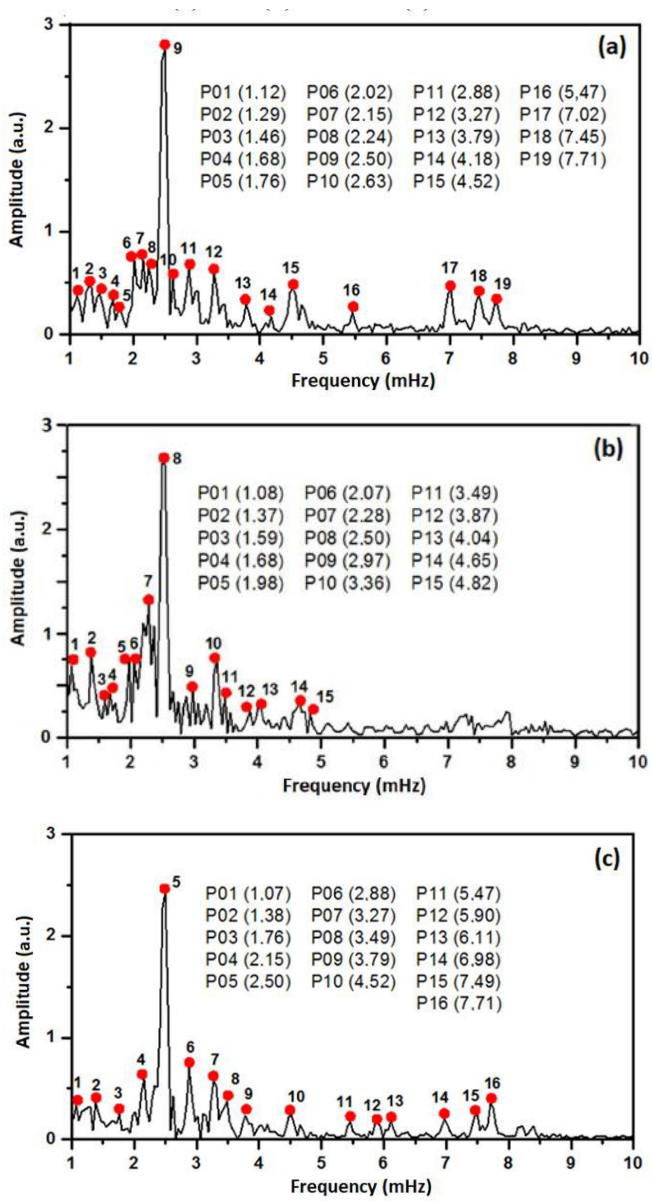

Fig. 4: Average acoustic signal as a function of frequency: (a) CC, (b) CM and (c) MZ

The characteristic vibration frequencies for the CM batch samples are shown in Figure 4(b). In this case, only 15 amplitude peaks are observed on the frequency axis and all are present in the region between 1 mHz and 5 mHz.

For the samples from the MZ batch, 16 amplitude peaks were observed, with 10 peaks in the region between 1 mHz and 5 mHz and the other 6 peaks between 5 mHz and 8 mHz, as shown in Figure 4(c).

Some differences were identified using the representation of acoustic signals as a function of vibration frequency. For example, where the number of amplitude peaks and the frequency range are presents. Furthermore, only one peak of greater amplitude, located at a frequency of 2.5 mHz, was present in the acoustic signals associated to batches CC, CM and MZ. These peaks correspond to peaks P09, P08 and P05 shown in Figures 4(a), 4(b) and (c), respectively. For better visualization, the amplitude values for characteristic peaks shown in parentheses were overlapping in Figure 5. In this way, it was possible to verify more clearly the differences between the acoustic signals obtained in the different batches.

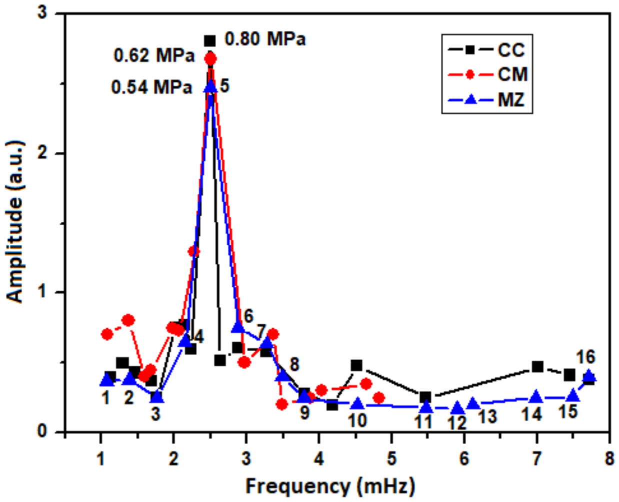

Fig. 5: Overlapping the amplitudes of the average acoustic signals

In Figure 5 it is noticed that the main peak (at a frequency of 2.5 mHz) has a greater amplitude for the CC batch. However, the amplitude value decreases consecutively for CM and MZ batches. This behavior seems to agree with the results of the compressive strength testing performed on samples of ceramic bricks from the same potteries, what are: CC batch (fbm = 0.80 MPa ± 0.05 MPa), CM batch (fbm = 0.62 MPa ± 0.02 MPa) and MZ batch (fbm = 0.54 MPa ± 0.03 MPa). It is observed that the mean strength values (fbm) are below 1.5 MPa, that is the value recommended in section 4.3 of part 1 of [4] standard. This result is probably related to the empirical dosage and burning procedures adopted in potteries.

Other peaks observed in the acoustic signals were also related to the compressive strength, but none of them appeared simultaneously in all the signals obtained in the lots and in the same position in relation to the vibration frequency. Furthermore, all other peaks had completely random amplitude values. Table 2 shows the values of average compressive strength (*fbm*), as well as some characteristics of the acoustic signals.

Table 2: Compressive strength (fbm), Amplitude (*A*) *and characteristics of acoustic signals*

Batch	*fbm* (MPa)	*A* (a.u)	N° peaks (< 5mHz)	N° peaks (> 5 mHz)	N° total peaks
CC	0.80 ± 0.05	2.88	15	4	19
CM	0.62 ± 0.02	2.71	15	0	15
MZ	0.54 ± 0.03	2.49	10	6	16

The compressive strength to the batches is supposedly not associated with the number of amplitude peaks in the acoustic signal, but with the presence of a greater number of amplitude peaks located in the frequency range below 5 mHz and with the greater amplitude of the main peak at 2.5 mHz. This assumption is reinforced by the characteristics presented in the acoustic signal of the MZ batch, which has the lowest compressive strength value and the combined effects of smaller main peak amplitude and smaller number of peaks with amplitudes located below 5 mHz. The combined effects can be more clearly observed by analyzing the indicative numbering of the amplitude peaks (from 1 to 16) presented in the acoustic signal of the batch MZ, as previously shown in Figure 5.

IV. CONCLUSION

The main amplitude peak at frequency of 2.5 mHz and observed in the batches, may be associated with an intrinsic characteristic of the ceramic bricks that does not depend on the origin of the pottery. Furthermore, a greater number of amplitude peaks at frequencies below 5 mHz and the greater amplitude of the main peak can be also combined effects that are associated to value of the compressive strength. The proposed methodology, although simple, demonstrated a possibility of non-destructive testing for ceramic bricks. However, it is still necessary to carry out more studies to reaffirm the results and prove the feasibility of the method for estimating the compressive strength of ceramic sealing bricks.

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