Application of ultrasonic measurement method for investigation of green ceramic tiles

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Abstract

High quality requirements are established for ceramic tiles manufacturing, because they must be weather-resistant, durable, in general, hard, wear and corrosion resistant and also can withstand high stresses at elevated temperatures. One of the possible control methods of the manufactured tiles quality is ultrasonic method based on measurement of ultrasonic wave propagation speed. However, measurements of ultrasonic wave velocity in green ceramic tiles with an uneven surface are difficult. Therefore attention must be directed to the individual measurement problems of this method, which are the following: uneven surface of the inspected tile; necessity of a dry acoustic contact, non-uniform elastic properties of the tested tile.

Keywords: ultrasonic propagation speed, ceramic tile, zero-crossing and the cross-correlation technique.

1. Introduction

All manufacturers are constantly looking for ways to reduce the number of defective green ceramic tiles and to reduce consumption of raw materials. That leads to improvement and ensuring of quality and durability of the final product using various quality control systems, which perform the required measurements on-line.

Since ultrasonic measurement system can be installed in tiles manufacturing presses or just behind him, the bad products can be immediately removed and returned for recycling and thus reducing the spoiled tiles and raw material consumption.

The green ceramic tiles are isotropic, therefore velocities of the ultrasonic longitudinal \( c_L \) and transverse \( c_T \) waves should not depend on a propagation direction [1-3]. However, the physical properties of tiles affect the ultrasound velocity [1, 6, 7 - 11], therefore elastic properties and density of tiles may be estimated by dynamic ultrasonic and vibration resonant frequency measurements [1, 4, 5].

Since the tiles are manufactured from different raw materials blends, there mechanical properties are not uniform in space, what after firing may lead to defective deformed tiles. Application of ultrasonic measurements enabling to monitor a spatial distribution of corresponding mechanical properties in tiles would enable to detect earlier the defective green ceramic tiles and to return them for recycling. Therefore, such ultrasonic measurement method should be is very useful improvement of ceramic tiles quality.

Our previous article was devoted to spatial density measurements in green ceramic tiles in zones of the similar thickness. [1]. In practice most of tiles are manufactured with one flat surface and with pattern on the opposite surface. It means that in different sectors thickness of a green ceramic tile is different, what complicates ultrasonic measurements.

So, the aim of the research presented in this paper is investigation of spatial ultrasound velocity distributions in green ceramic tiles with varying thickness. For that it was necessary to select and experimentally verify the technique suitable for velocity measurements in tiles with uneven surface and to investigate spatial distributions of ultrasound velocity along the tested tile surface.

2. Specimen and measurements setup

For measurements of spatial ultrasound velocity distributions a 0.105 x 0.105 m size green ceramic tile, manufactured by “Dvarčioniu Keramika”, Lithuania, with a rectangular pattern on the rear side was selected. On the rear side the measurement points were marked by dots, e.g., it can by viewed as discrete matrix of measuring points \((x_i, y_j)\), with the size is \((31, 31)\) (Fig. 1). The distance between neighboring measuring points was the same and was selected \(\Delta d = 3\) mm.

Fig. 1. Green ceramic sample used for ultrasonic longitudinal wave velocity measurements

The ultrasound velocity measurements were performed across the tile at the points \((x_i, y_j)\), where \(i\) and \(j\) are 1, 2,
The ultrasonic signals used for measurements: 1 - the reference signal, 2 - the signal transmitted through the sample, but shifted back in the time domain using the delay time estimated according to the zero-crossing technique; 3 - signal transmitted through the sample, but shifted back in the time domain using the delay time estimated using the cross-correlation technique.

Measurements by both methods were performed in the rectangular tile sector marked by a dashed line, e.g., (1-30, 29), (1-30, 30) and (1-30, 31) (Fig. 1). First of all the sample thickness \( h(x_i, y_j) \) was measured at all measurement points by a micrometer with an uncertainty 0.01 mm. Then at the same points the propagation time \( t(x_i, y_j) \) of a longitudinal ultrasonic wave was measured with an uncertainty 12 ns by using the computerized measuring system.

Each measurement result of the ultrasonic wave propagation time \( t(x_i, y_j) \) was recorded in a computer memory and then using the measured tile thickness the ultrasound velocity of \( c(x_i, y_j) \) using Eq. 1 was estimated.

Each value of \( c(x_i, y_j) \) was recorded in a computer memory and was displayed as a spatial velocity distribution of \( c(x_i, y_j) \) using the coordinate system related to the tested tile (Fig. 1).

The measurement results are presented in Fig. 4 – 6. The obtained results clearly show that the spatial distribution of ultrasound velocity \( c(x_i, y_j) \) in the sample is not uniform, what indicates that distribution of mechanical properties and, particularly of the density, is not uniform as well. Let us compare the results obtained by the zero-crossing and the cross-correlation techniques.

In Fig. 4-6 measurement results obtained by both methods are presented. The differences between those two methods are shown in Fig. 7. From the results obtained follows that there is no essential differences, except some systematic shift, which may be eliminated by a calibration. For example, the average ultrasound velocity in the sector of the tile (1-30, 31) using zero-crossing technique is equal to 1250 m/s. Correspondingly, when using the cross-correlation technique the average ultrasound velocity is 1230 m/s. Similar results are obtained in neighboring sectors of the tile (1-30, 30) and (1-30, 29). The average ultrasound velocity in those sectors obtained by the zero-crossing technique is the same and equal to 1250 m/s. The
cross-correlation technique in the same sectors gives slightly different ultrasound velocity values- 1218 m/s and 1215 m/s. It is possible to conclude that in a laboratory conditions both methods demonstrate a similar performance. On the other hand, in the case of in-line measurements the cross-correlation technique should be more preferable due to a better noise robustness.

The results presented in Fig.4 - 7 show slow and fast spatial variations of ultrasound velocity $c(x_i, y_j)$ along the tile. The results obtained indicate that these variations are not measurement errors, but are due variations of mechanical properties in the tile, because there is no essential difference obtained by two different measurement techniques (Fig. 7). The slow variations are very likely to corresponding density $\rho(x_i, y_j)$ variations in the tile.

The ultrasound velocity variations in the sector (1-30, 31) are ±(16-17) m/s with respect to the average ultrasound velocity independently on the measurement method (Fig. 4).

In the neighboring sectors of the tile (1-30, 30) and (1-30, 29) spatial variations of the ultrasound velocity obtained by the zero-crossing and the cross-correlation methods are similar and equal to ±(12-13) m/s (Fig.5 and 6).

Since the ultrasound velocity $c(x_i, y_j)$ measurements are performed in sectors with different green ceramic tile thickness, therefore the differences of ultrasound velocity values between adjacent measurement points were analyzed also. In this case the $c(x_i, y_j)$ value differences along the two lines (1-31, 30) and (1-31, 29) were determined between the neighboring measurement points located at two different lines- $y=29$ and $y=30$. So determined ultrasonic wave propagation velocity differences at sectors of the tile ((1-31, 30) and (1-31, 29)) are presented in Fig. 7, with allows to determine the differences between the measured values $c(x_i, y_j)$ along the axis $y$ also.
Conclusions

1. The obtained results clearly show that a spatial distribution of the ultrasound velocity \(c(x, y)\) in the green ceramic tiles is not uniform, what indicates that distribution of mechanical properties and, particularly of the density, is not uniform as well.
2. The results obtained by the zero-crossing and the cross-correlation techniques give very similar results, except some systematic shift, which may be eliminated by a calibration.
3. The obtained spatial ultrasound distributions of ultrasound velocity \(c(x, y)\) allow to determine the minimal distance between the measurement points, necessary for accurate reconstruction of ultrasound velocity spatial distributions.
4. The ultrasound velocity variations in the sector (1-30, 29) - (1-30, 31) reach \(\pm(16-17)\) m/s with respect to the average ultrasound velocity independently on a measurement method.

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References


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Ultragarso bangų sklidimo greičio, įmatuoto keraminės plytelės ruožinėje, analizė

Reziumė


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