NEW INSTRUMENTS FOR DETERMINING DIMENSIONAL CHARACTERISTICS OF LARGE SIZE TILES

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1. ABSTRACT

The standards for the ceramic tiles certification were developed for traditional-sized products, when large size ceramic tiles had not reached current market volumes. Consequently, the applicability of these test methods, tuned up to characterise a product according to a standard, in some cases is arduous. It occurs, for example, when measuring the dimensional characteristics (as stated in the standard ENISO 10545-2) of ceramic tiles having dimensions larger than 60x60 cm. In order to fill the gap between the test methods usually used in the laboratories and the need to certificate these novel products, some techniques, new to the ceramic field, but widely used in other industrial fields, were analysed. To this aim two new instruments were used to perform the measurements, a coordinate measuring machine CMM and a portable three-dimensional measuring arm, comparing the results with those obtained with a data-plucometer, traditionally used to perform the test. The analysis was conducted on tiles having dimensions lower than those usually

named as “large size tiles”, with the aim to demonstrate the possibility to use these new techniques also for the ceramic purposes. The work done to set up the software used to elaborate the data acquired allowed the testingto be conducted following exactly the abovementioned ISO standard. The experimental campaign conducted showed a good agreement between the data-plucometer results and the results obtained with the new techniques, confirming the possibility to use these last ones to perform the tests on large size ceramic slabs. Moreover, the work highlighted some insights to open discussion on normalisation tables.

2. INTRODUCTION

In recent years, the ceramic industry has experienced a real revolution with the production of large size ceramic tiles [1]. This type of product lead to new technological challenges linked to the production process and its energy aspects as well as to the characterization of the final product. Large size ceramic tiles require measuring systems different to those traditionally used, but with the same level of reliability. Indeed, it is essential to use appropriate testing methods to ensure quality control and product certification [2-5].

In the framework of the project “Process innovation for the sustainable ceramic tile chain, IPERCER” funded by Emilia Romagna region (Italy) with European funds (POR-FESR 2014-2020) [6], new systems to measure dimensional characteristics were tested and compared to the traditional ones normally adopted to follow the requirements of EN ISO 10545-2 “Ceramic tiles - Part 2: Determination of dimensions and surface quality”.

It is well known, thanks to the laboratory practice, that the measures performed by data-plucometers are reliable only for tiles having dimensions up to 60x60 cm. Beyond this size, the effects due to tile deformation under its own weight, and deformation of calibration plates used during testing, are no more negligible. The instruments that were chosen for this study were a coordinate measuring machine, CMM, and a portable three-dimensional measuring arm, both techniques coming from the advanced mechanics industry [7-9].

The scope of this preliminary contribution was to propose new instruments that are able to perform the measurement of large size ceramic tiles, verifying the good accordance between traditional measuring systems and novel ones.

3. EXPERIMENTAL

Three lots of tiles, having dimensions 20x20, 40x40 and 60x60 cm, and named T1, T2 and T3 respectively, were measured according to EN ISO 10545-2 standard. The measurements were firstly carried out by using a horizontal data-plucometer (Gabbrielli Technology, Italy), equipped with centesimal calibres. For all the lots, ten tiles were measured, determining dimensions (length and width, straightness of sides, rectangularity) and planarity (centre curvature, edge curvature, warpage). Before the execution of the measure for each lot, the resetting with a certified calibration plate was performed. The results obtained have been elaborated in accordance with the provisions of the EN ISO 10545-2 standard. The same tiles were measured with a coordinate measuring machine, CMM (Hexagon, UK) and with a three-dimensional portable measuring arm (Hexagon, UK). The software PC-DMIS was used to process the acquired data. During the test 21 points were measured, according to the procedure described in the ISO standard. A preliminary work was also done to tune the measurements carried out with portable arm and CMM with the procedures described by the standard. Some geometrical features were identified and an alignment by a coordinate system was done for each measurement performed; in this way, a plane on the tile surface is identified every time, substituting the role of the calibration plate. The same comparison was done on a calibration plate, in order to eliminate the effects of the possible defects of the measured object.

4. RESULTS AND DISCUSSION

The results obtained from the three lots of tiles are shown in Tables 1-6. The "a" tables refer to the results obtained with three different instruments: PL (data-plucometer), CMM (Coordinate Measuring Machine) and ARM (portable measuring arm). The requirements prescribed in the standard EN 14411:2016 are also indicated. The "b" tables are referred to the maximum differences between techniques PL-CMM, PL-ARM and CMM-ARM.

In Table 1a, length and width, in addition to the mean values obtained for each sample, the maximum differences related to manufacturing dimension (W) are reported, with the aim to evidence that these differences are the same using the three techniques. In Table 1b, the maximum differences among the mean values obtained with PL, CMM and ARM are reported, also related to the manufacturing dimensions (W). The results show that the differences among the values obtained with the analyzed techniques are very low. The Tables 2a and 2b concern the results of straightness of sides. Also in this case the differences are practically near zero. The Tables 3a and 3b are referred to the values obtained for rectangularity measures. In this case, the differences are in the order of some tenths of percentage, but in any case, under the requirement prescribed by the standard EN 14411. About the planarity measurements, in tables 4a and 4b, the values of centre curvature are reported; in tables 5a and 5b, the measures of edge curvature; in tables 6a and 6b, the values of maximum warpage. Also, in the case of planarity measurements, the deviation among the results is very low, maximum one tenth of percentage.

Table 7, that refers to the comparison among results obtained with PL, CMM and ARM for measuring a calibration plate, shows differences equal to zero.

<table>
<tr><th colspan="9">Length and width
(Tests performed on 10 specimens for each sample. Table shows the mean values)</th></tr>
<tr><td>Sample</td><td>PL (mm)</td><td>Δmax related to W (%)</td><td>CMM (mm)</td><td>Δmax related to W (%)</td><td>ARM (mm)</td><td>Δmax related to W (%)</td><td colspan="2">Requirement</td></tr>
<tr><td>T1</td><td>199.5</td><td>-0.2</td><td>199.6</td><td>-0.2</td><td>199.6</td><td>-0.2</td><td rowspan="3">± 0.6 %</td><td rowspan="3">± 2.0 mm</td></tr>
<tr><td>T2</td><td>402.5</td><td>-0.1</td><td>402.5</td><td>-0.1</td><td>402.6</td><td>-0.1</td></tr>
<tr><td>T3</td><td>606.4</td><td>0.0</td><td>606.5</td><td>0.0</td><td>606.4</td><td>0.0</td></tr>
</table>

Table 1a.*Length and wide data from the measured lots by using PL, CMM and ARM. Maximum differences related to manufacturing dimension (W) are also reported.*

<table>
<tr><th colspan="7">Length and width</th></tr>
<tr><td>Sample</td><td>Δ (PL-CMM)
Mean values
(mm)</td><td>Δ (PL-CMM)
related to W (%)</td><td>Δ (PL-ARM)
Mean values
(mm)</td><td>Δ (PL-CMM)
related to W (%)</td><td>Δ (CMM-ARM)
Mean values
(mm)</td><td>Δ (PL-CMM)
related to W (%)</td></tr>
<tr><td>T1</td><td>-0.1</td><td>0.05</td><td>-0.1</td><td>0.05</td><td>0.0</td><td>0.00</td></tr>
<tr><td>T2</td><td>0.0</td><td>0.00</td><td>-0.1</td><td>0.02</td><td>0.1</td><td>-0.05</td></tr>
<tr><td>T3</td><td>-0.1</td><td>0.02</td><td>-0.1</td><td>0.02</td><td>0.1</td><td>-0.05</td></tr>
</table>

Table 1b. *Maximum differences among the mean values obtained with the analysed techniques. Maximum differences related to manufacturing dimensions (W) are also reported.*

<table>
<tr><th colspan="6">Straightness of sides
Max. deviation (%)
(Tests performed on 10 specimens for each sample. Table shows the mean values).</th></tr>
<tr><td>Sample</td><td>PL</td><td>CMM</td><td>ARM</td><td colspan="2">Requirement</td></tr>
<tr><td>T1</td><td>0.1</td><td>0.1</td><td>0.1</td><td rowspan="3">± 0.5 %</td><td rowspan="3">± 1.5 mm</td></tr>
<tr><td>T2</td><td>0.0</td><td>-0.0</td><td>-0.1</td></tr>
<tr><td>T3</td><td>0.1</td><td>0.1</td><td>0.1</td></tr>
</table>

Table 2a.*Straightness of sides results from the measured lots by using PL, CMM and ARM.*

<table>
<tr><th colspan="4">Straightness of sides
Max. deviation (%)</th></tr>
<tr><td>Sample</td><td>Δ (PL-CMM)</td><td>Δ (PL- ARM)</td><td>Δ (CMM-ARM)</td></tr>
<tr><td>T1</td><td>0.0</td><td>0.0</td><td>0.0</td></tr>
<tr><td>T2</td><td>0.0</td><td>0.0</td><td>0.1</td></tr>
<tr><td>T3</td><td>0.0</td><td>0.0</td><td>0.0</td></tr>
</table>

Table 2b. *Maximum differences among the mean values of the analysed techniques.*

Rectangularity Max. deviation (%) (Tests performed on 10 specimens for each sample. Table shows the mean values).					
Sample	PL	CMM	ARM	Requirement	
T1	-0.5	-0.3	-0.4	± 0.5 %	± 2.0 mm
T2	-0.1	0.2	0.1		
T3	-0.2	-0.1	-0.1		

Table 3a. *Rectangularity results from the measured lots by using PL, CMM and ARM.*

Rectangularity Max. deviation (%)			
Sample	Δ (PL-CMM)	Δ (PL-ARM)	Δ (CMM-ARM)
T1	-0.2	-0.1	0.1
T2	-0.3	-0.2	0.1
T3	-0.1	-0.1	0.0

Table 3b. *Maximum differences among the mean values of the analysed techniques.*

Centre curvature (%) Related to the diagonal calculated on the basis of manufacturing dimension (W) (tests performed on 10 specimens for each sample. Table shows the mean values).					
Sample	PL	CMM	ARM	Requirement	
T1	0.1	0.1	0.1	± 0.5 %	± 2.0 mm
T2	0.1	0.1	0.1		
T3	0.1	0.1	0.1		

Table 4a.*Centre curvature results from the measured lots by using PL, CMM and ARM.*

Centre curvature (%) Related to the diagonal calculated on the basis of manufacturing dimension (W).			
Sample	Δ (PL-CMM)	Δ (PL-ARM)	Δ (CMM-ARM)
T1	0.0	0.0	0.0
T2	0.0	0.0	0.0
T3	0.0	0.0	0.0

Table 4b. *Maximum differences among the mean values of the analysed techniques.*

Edge curvature (%) Related to manufacturing dimension (W) (tests performed on 10 specimens for each sample. Table shows the mean values).					
Sample	PL	CMM	ARM	Requirement	
T1	-0.2	-0.2	-0.1	± 0.5	± 2.0 mm
T2	0.1	0.1	0.1		
T3	0.1	0.2	0.2		

Table 5a.*Edge curvature results from the measured lots by using PL, CMM and ARM.*

Edge curvature (%) Related to manufacturing dimension (W)			
Sample	Δ (PL-CMM)	Δ (PL-ARM)	Δ (CMM-ARM)
T1	0.0	0.1	-0.1
T2	0.0	0.0	0.0
T3	0.1	-0.1	0.0

Table 5b. *Maximum differences among the mean values of the analysed techniques.*

<table>
<tr><th colspan="6">**Max. warpage** (%)
Related to the diagonal calculated on the basis of manufacturing dimension (W)
(tests performed on 10 specimens for each sample. Table shows the mean values).</th></tr>
<tr><td>Sample</td><td>PL</td><td>CMM</td><td>ARM</td><td colspan="2">Requirement</td></tr>
<tr><td>T1</td><td>-0.3</td><td>-0.2</td><td>-0.2</td><td rowspan="3">± 0.5</td><td rowspan="3">± 2.0 mm</td></tr>
<tr><td>T2</td><td>0.1</td><td>0.1</td><td>0.1</td></tr>
<tr><td>T3</td><td>-0.1</td><td>0.0</td><td>0.0</td></tr>
</table>

Table 6a. *Maximum warpage results from the measured lots by using PL, CMM and ARM.*

<table>
<tr><th colspan="4">**Max. warpage** (%)
Related to the diagonal calculated on the basis of manufacturing dimension (W)</th></tr>
<tr><td>Sample</td><td>Δ (PL-CMM)</td><td>Δ (PL-ARM)</td><td>Δ (CMM-ARM)</td></tr>
<tr><td>T1</td><td>-0.1</td><td>-0.1</td><td>0.0</td></tr>
<tr><td>T2</td><td>0.0</td><td>0.0</td><td>0.0</td></tr>
<tr><td>T3</td><td>-0.1</td><td>-0.1</td><td>0.0</td></tr>
</table>

Table 6b. *Maximum differences among the mean values of the analysed techniques.*

Calibration plate
300x300 mm

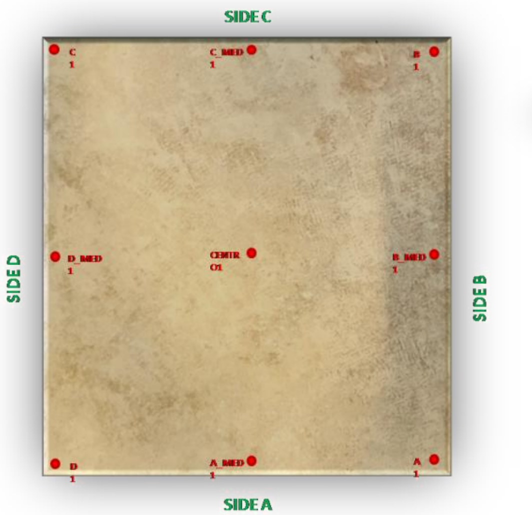
Differences obtained for calibration plate

	Δ (PL-CMM)	Δ (PL-ARM)	Δ (CMM-ARM)
All the characteristics (absolute values)(mm)	0.0	0.0	0.0

Table 7. *Differences among the values obtained with PL, CMM and ARM on the calibration plate.*

The results obtained so far showed an excellent agreement between the three techniques. The comparison of the dimensional characteristics, calculated according to the procedure described in EN ISO 10545-2, showed maximum differences in the order of a few tenths of a percentage, thus demonstrating the possibility to perform dimensional measurements of ceramic tiles in accordance with current standard with both the three-dimensional portable arm and the CMM machine.

The research highlighted as well some limitations of the current standard concerning the determination of dimensional characteristics, in particular related to the representativeness of the points selected during the test to describe the geometric characteristics of the product. In fact, EN ISO 10545-2 envisages that only 21 points on the single tile (9 on the surface and 12 on the sides, Fig.1) are taken into consideration, which, especially in the case of large size ceramic tiles, may not be sufficient to identify any defects.



- Number of points: 21
- Points on sides, at 5mm from the corners
- Points on the surface, at 10mm from the edges

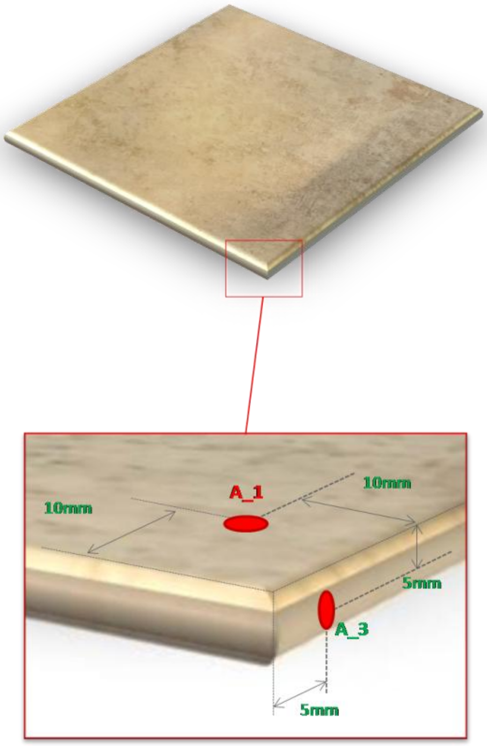


Figure 1. *Graphic representation of the points taken during the test performed according to EN ISO 10545-2.*

The activity conducted also helped highlighting the main differences between data-plucometer and the two technologies, CMM and portable measuring arm. These differences, listed below, can be read, in some cases, as strengths of a technology compared to the other:

- with the data-plucometer, the measurement is performed by comparison with a calibration plate - this is an indirect measure - while with the CMM and the portable measuring arm the measurement is performed by alignment with a theoretical plane calculated by the measurement of three points on the tile - it is therefore a direct measure;
- with the data-plucometer, the measurement is performed putting the surface of the tile turned down, on support points, which define a plane. With the CMM and the portable measuring arm the back of the tile is put on a surface, having a suitable finishing. In both cases, the measurements are made on the top surface of the tile. However, in the case of the data-plucometer, the tile must be rotated four times to perform the measurement, with the CMM and the measuring arm, once the tile is placed on the measuring flat surface, it must not be moved until the test is completed;
- with the data-plucometer it is possible to make reliable measurements (especially planarity ones) only for tiles having dimensions up to 60x60 cm, while with the CMM and portable measuring arm it is possible to measure larger tiles up to the current production sizes;
- the data-plucometer allows to measure in a fairly simple way, while the CMM technology and the measuring arm require a certain level of skill and experience of the operator. Furthermore, the software currently provided with these instruments does not lead to an immediate application for the measurements according to EN ISO 10545-2 standard. The software should be suitably modified/integrated.

5. CONCLUSIONS

In order to verify the possibility to use alternative systems to perform dimensional measurements of large size ceramic tiles, the results obtained on "small" size tiles by the data-plucometer with the ones obtained by two other instruments with probing technology were compared.

All the measurements (length and width, straightness of sides, rectangularity, surface flatness, etc.) were carried out in accordance with EN ISO 10545-2 standard.

The results obtained so far showed a good agreement among the three techniques, with maximum differences in the order of a few tenths of percentage. Consequently, the possibility to perform ceramic tiles dimensional measurements, according to ISO standard, by using a portable three-dimensional measuring arm and a coordinate measuring machine, CMM, is confirmed for 20x20, 40x40 and 60x60 cm tiles.

6. REFERENCES

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