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Research Article

New Measurement Method and Uncertainty Estimation for Plate Dimensions and Surface Quality

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Dimensional and surface quality for plate production control is facing difficult engineering challenges. One of these challenges is that plates in large-scale mass production contain geometric uneven surfaces. There is a traditional measurement method used to assess the tile plate dimensions and surface quality based on standard specifications: ISO-10545-2: 1995, EOS-3168-2: 2007, and TIS 2398-2: 2008. A proposed measurement method of the dimensions and surface quality for ceramic oblong large-scale tile plate has been developed compared to the traditional method. The strategy of new method is based on CMM straightness measurement strategy instead of the centre point in the traditional method. Expanded uncertainties budgets in the measurements of each method have been estimated in detail. The capability of accurate estimations of real actual results for centre of curvature (CC), centre of edge (CE), warpage (W), and edge crack defects parameters has been achieved according to standards. Moreover, the obtained results not only showed better accurate new method but also improved the quality of plate products significantly.

1. Introduction

Advanced metrology techniques are became used in various fields of science and production engineering applications. There are two new basic approaches, the contact techniques and noncontact measuring techniques. These techniques include scanning electron microscopy (SEM), transmission electron microscopy (TEM), X-ray transmittance photoelectron spectroscopy (XPS), atomic force microscopes (AFM), computed tomography (CT), laser interferometric method, and coordinate measuring machines (CMM) use in dimensional metrology [1]. Three different methods such as AFM, stylus Talysurf system, and noncontact laser system were applied for measuring the surface roughness parameters of ceramic tiles and metallic surfaces in 1996 [2]. That work concludes: the noncontact laser method produced relatively high values of the surface roughness parameters other than stylus method regardless of the measurement accuracy, because the stylus tip size and its wear play a part in the measurement. While, with the wonderful progress in material science and CNC-CMM software, it has become very easy there small tip size, high scratch resistant and reduce tip touching force which reduces the risk of damage during measurement.

Recently, the coordinate dimensional metrology became the key to global quality assurance systems of industrial engineering products. CNC-CMM machine is a computer-numerical-controlled device equipped with ruby touch probe for measuring the physical geometrical characteristics of objects in three axes. Quality control measurements performed to ensure quality of hard industrial products like ceramic tile plates help in the detection of some defected products due to various technical and human reasons [3]. Ceramic tile plates are subject to international and national standards assessed tests such as colour analysis, surface abrasion resistance, thermal expansion, moisture expansion, friction coefficient and wear, breaking strength, and dimensions and surface quality to reveal the durability defect. Furthermore, dimensional and surface quality verification is the main standard test and also the purpose of this investigation. However, the amazing progress in the production technology has allowed a significant decrease in the deviation in the dimensional and surface quality. Accordingly, the measurement methods of dimension and geometrical surface of products should be reviewed using advanced measurement techniques such as CMM. It is a custom measurement tool using a point laser for almost plane surfaces of objects [4]. Therefore, there is limited number of studies in this area, while some new publications are carried out using image processing, vision inspection system, morphological techniques, and texture analysis [5–10]. Quality inspection of ceramic tile using statistical techniques and neural networks approach is also studied [11]. Most of the previous research work have been done to assess surface functionalization of industrial ceramic tile plates as surface micromechanical and microstructural using SEM and TEM micrographs to improve the properties of scratch and wear resistance [12–14]. Assessing the environmental impact on production of ceramic tile is also studied [14, 15], while the American National Institute of Standards and Technology (NIST) developed a sustainability resource guide that compiled the information on the environmental impact of various products, including ceramic tiles [16]. On the other hand, the ability to measure precisely and consistently is of fundamental importance in modern technology. The reliability and safety of new devices and systems are the basis of equal global manufacturing requirements. It must be noted that the detection of defect in dimensions and surface quality is an important area of tiles inspection including measurements, calculation, and characterization that are often not available in factories. The dimensions and surface quality test of the ceramic tiles represented in the curvatures of the diagonals, edges, warpages, and cracks are essential components of the inspection and evaluation in order to achieve the main purposes such as safe surface use [17–20]. One of the most important functions of the NMIs is the dissemination of the reliable reference dataset which can be used as a guide for evaluating the measurement skill and reliability of test results in industry as well as in commercial production and design process. Thus, geometrical form measurements such as straightness form of products surfaces are basic requirements in dimensional metrology for precise manufacturing engineering.

The main topic of this work is to introduce a proposed developed measurement method and assist in and compare the validity of two different methods (traditional and developed)based on fast tactile 2D metrology. The new measurement method is developed to support the quality assurance in the manufacturing of tile plates. Moreover, the possibilities of accurate inspection system to reveal four major problems namely, centre of curvature (CC), centre of edge (CE), warpage (W) parameters, and edge crack defects, have become assuredly achieved. The budgets of expanded uncertainty with the measurement results of each method have been estimated accurately. The capability of dimensions and surface quality measurement of tiles has been discussed in detail as well. Thus, the new measurement method could be able to assist the tiles of different scales not only to produce better accurate method compared to other methods [7–10] but also to permit improved manufacturing quality of ceramic tile products.

Table 1: CMM set-up and measurement strategy.

CMM strategy parameters	Specifications
Master probe radius	3.9996 mm
Reference sphere radius	14.9942 mm with $S = 0.0001$ mm
Used long probe radius	4.0000 mm with $S = 0.0002$ mm
Machine travelling speed	20 mm/s
Probe scanning speed	2 mm/s
STR scanning points	Step width = 3 mm
Fitting technique	LSQ

2. CMM Accuracy Verification

Stationary CMM in the engineering dimensional metrology laboratory is fixed and verified by the manufacture (ZEISS Co., Germany). CMM machine consists essentially of a probe supported on X, Y, and Z coordinates and capable determining spatial coordinates on a workpiece surface [21]. The procedures for measurement using CMM including verification of the probing system, defining datum(s) on the tiles surfaces, performing measurement(s), computing the required relative dimensions from measurements made previously, and assessing the tiles performance with the specifications. Intermediate verification is guaranteed by measuring standards reference sphere and comparing the measured value with the specified measurement uncertainty. The environmental conditions of testing room have been adjusted in the rage of standard specifications [21]. Laboratory room temperature was set at $20 \pm 1^{\circ}$C and relative humidity at $50 \pm 2\%$, which are suitable for the CMM operation. Table 1 comprises the specifications of the CMM machine set-up and strategy of measurements.

The maximum permissible error (MPE_E) of CMM machine can be moderated according to the ISO 10360-4 using the following equation, where L is the measured length in mm [22]:

$$\mathrm{MPE}_E = \pm\left[0.9\,\mu\mathrm{m} + \left(\frac{L}{350}\right)\right]\mu\mathrm{m}. \quad (1)$$

3. Traditional Measurement Method

The traditional method has standard procedure steps using dial gauges in the tile measurement, while in this research we will apply the standard procedures using CMM as alternative technique to avoid the manual errors and increase the speed in measurements. The curvatures of the diagonal, edge, and warpage for the ceramic tiles are measured using suitable measurement strategy of CMM based on the ISO: 10545-2: 1995 [17], EOS: 3168-2: 2007 [18], and TIS 2398-2: 2008 [20]. This traditional method is designed as explained in Figure 1.

D is the length of diagonal for oblong tile. L is the length of the edge for oblong tile. ΔC is the measured vertical difference distance between the centre point of diagonal "D" to the plane of tile. ΔS is the measured vertical difference distance between

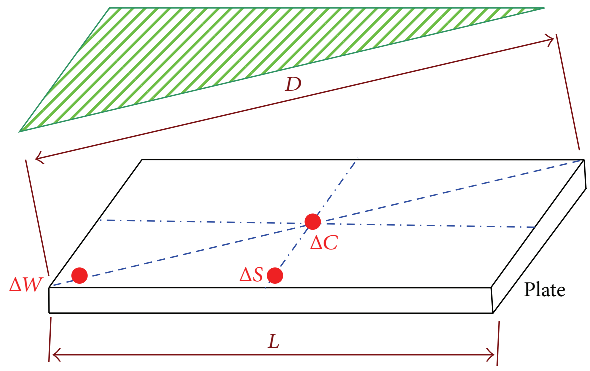

Figure 1: The position schematic of the centre points ΔS and ΔC, ΔW, and 3-point plane.

Table 2: The classification results of tile first specimen.

(a)

Test no.	Measured values		
	ΔC, mm	ΔS, mm	ΔW, mm
1	0.6244	0.6447	0.0012
2	0.6254	0.6462	0.0030
3	0.6262	0.6473	0.0024
4	0.6257	0.6467	0.0022
5	0.6262	0.6473	0.0027
Average	0.6252	0.6464	0.0023
Maximum	0.6262	0.6473	0.0030

(b)

Specific calculated parameters, %		
$CC = \Delta C/D$	$EC = \Delta S/L$	$W = \Delta W/D$
0.11	0.13	0.05

the centre point of edge "L" and the plane of tile. ΔW is the measured vertical difference distance between the centre point of warpage and the plane of tile. CC is the departure of the centre of one edge of a tile from the plane in which three of the four corners lie. EC is the departure of the centre of a tile from the plane in which three of the four corners lie. W is the departure of the fourth corner of the tile from the plane in which the other corner lies. As shown in Figure 1, the plane presented in green colour is defined by measuring three points from the four points of the tile surface.

3.1. Experimental Results of Traditional Method. The CMM machine can identify and measure the appropriate plane for three corners and the centre point for each of the diagonal, edge, and warpage is identified as obtainable in the ISO-10545-2, 1995 [17], and EOS-3168-2, 2007 [18]. It is then potential to deduce the values of each of ΔC, ΔS, and ΔW. Then, we can specify the maximum and average values of measurements for all specimens as illustrated in Tables 2–4.

3.1.1. The First Specimen. The measurement results of the traditional method are scheduled in Table 2 in addition to measuring the values of both diagonal length "D" and edge length "L" of tiles subject of the study in order to calculate the values of CC, EC, and W. The results of length measurements for both D and L are 615.2523 mm and 525.9162 mm respectively. The collection of chosen data can be used for the construction of database at NIS and NMIT considering the budget to the industry and available data sources can be chosen for building local dataset.

Table 3: The classification results of second specimen.

(a)

Test no.	Measured values		
	ΔC, mm	ΔS, mm	ΔW, mm
1	0.8716	0.6038	0.0390
2	0.8787	0.6116	0.0381
3	0.8684	0.6010	0.0257
4	0.8694	0.6017	0.0261
5	0.8696	0.6017	0.0259
Average	0.8715	0.6040	0.0310
Maximum	0.8787	0.6116	0.0390

(b)

Specific calculated parameters, %		
$CC = \Delta C/D$	$EC = \Delta S/L$	$W = \Delta W/D$
0.15	0.12	0.007

Table 4: The classification results of tile third specimen.

(a)

Test no.	Measured values		
	ΔC, mm	ΔS, mm	ΔW, mm
1	0.6608	0.5723	0.0031
2	0.6511	0.5608	0.0220
3	0.6522	0.5600	0.0225
4	0.6529	0.5606	0.0213
5	0.6529	0.5605	0.0218
Average	0.6540	0.5628	0.0181
Maximum	0.6608	0.5723	0.0225

(b)

Specific calculated parameters, %		
$CC = \Delta C/D$	$EC = \Delta S/L$	$W = \Delta W/D$
0.11	0.11	0.04

Table 5: The statistical results of tiles specimens.

Specimen	Values	ΔC, mm	ΔS, mm	ΔW, mm
First	S_D	0.0007	0.0011	0.0007
	$U_{(Xi)}$	0.0003	0.0005	0.0003
Second	S_D	0.0042	0.0044	0.0069
	$U_{(Xi)}$	0.0019	0.0020	0.0031
Third	S_D	0.0030	0.0053	0.0084
	$U_{(Xi)}$	0.0017	0.0024	0.0038

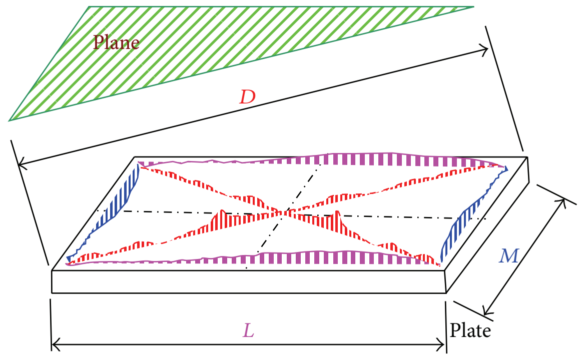

FIGURE 2: The positions of STR measurement for D, D_1, L, L_1, and M; M_1, and 3-point plane.

3.1.2. The Second Specimen. The results of measurements of the second specimen using traditionalmethod are scheduled in Table 3. The measured values for both D and L lengths are of 614.1352 mm, and 525.2716 mm, respectively.

3.1.3. The Third Specimen. The measurement results of this specimen using traditionalmethod are tabulated in Table 4. The results for both D and L lengths measurements are 613.4891 mm and 524.4620 mm, respectively, for the third sample. This assessment depends on the estimation of the percentage resulting from dividing ΔC, ΔS, and ΔW on the length for each of the D or L to give relative specific values for each CC, EC, and W parameters as recorded above in the results. The results predicted that there is relatively little variation between their values for all measured specimens. Thus, in these cases the specimens have technical acceptance in term of dimensions and surface quality using the traditional method.

3.2. Estimation of Uncertainty Budget. The uncertainties associated with the measurements results are estimated according to GUM [23]. The statistical analyses of *type A* uncertainty of centre point's measurements for the diagonal, edges, and width warpages of the tiles specimens are calculated according to the standard traditional method, the results are presented in Table 5, where S_D is the experimental standard deviation of five repeated measurements and $U_{(Xi)}$ is the standard uncertainty due to measurement repeatability ($U_{(Xi)} = S_D/\sqrt{n}$), where n is the number of repeated tests for each target measurement [24].

The *type B* uncertainty consists of the accuracy of CMM results, MPE, MPE_P of machine, and speed of scanning probe respectively. The expanded uncertainty is $U_{\exp} = k \cdot u_c$ [24], where k is the coverage factor, which equals 2 corresponding to 95% confidence level in accordance with the ISO guide to the expression of uncertainty in measurements [24, 25]. Table 6 illustrates the budget of estimated values of the expanded uncertainties for measurements in detail. The measurement uncertainties of the first, second, and third specimens are 0.98, 3.20, and 3.80 μm, respectively.

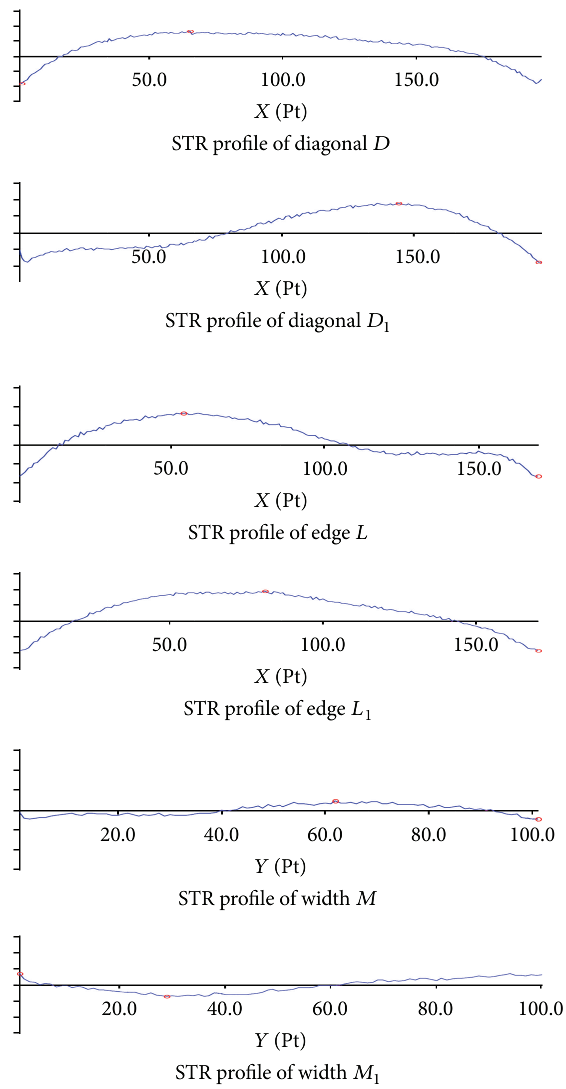

FIGURE 3: Typical result sample of STR for D and D_1, L and L_1, and M and M_1 lines for tile first specimen using new method.

4. New Measurement Method

The new method adopted to select the actual highest values of ΔC, ΔS, and ΔW using straightness (STR) form measurements of all diagonals, edges, widths, and lengths, so that we can verify the credibility and accuracy of the result performance. The proposed measurement method has been designed in more detail as shown in Figure 2.

D and D_1 are the diagonals of oblong tile. L and L_1 are the two length edges of oblong tile. M and M_1 are the two widths of oblong tile. ΔC is the achieved value of maximum centre curvature of oblong tile. ΔS is the achieved value of maximum edge curvature of oblong tile. ΔW is the achieved value of maximum warpage of oblong tile. Calculated value of CC parameter represents the maximum curvature expressed as a percentage of the length of diagonal "D" of tile. EC parameter indicates the maximum edge curvature expressed as a percentage of the edge length "L" of oblong tile, while the

TABLE 6: Estimation of uncertainty budget in point deviation for tiles measurements.

Test specimen	Sources of uncertainty	St. uncertainty, $U_{(Xi)}$			Assumed distribution	Combined uncertainty, $u_{(Xi)}$			C
		ΔC, μm	ΔS, μm	ΔW, μm		ΔC, μm	ΔS, μm	ΔW, μm	
First	Repeatability	0.3	0.5	0.3	Normal	0.15	0.25	0.15	1
	Resolution		0.05		Rectangular		0.029		1
	MPE		$0.9 + (L/350)$		Normal (based on $k = 3$)		0.30		1
	MPE_P		0.5		Rectangular		0.29		1
	Combined standards uncertainty, $u_c = \pm 0.49\ \mu$m								
	Expanded uncertainty $U_{\exp} = \pm 0.98\ \mu$m								
Second	Repeatability	1.9	2.0	3.1	Normal	0.95	1.0	1.55	1
	Resolution		0.05		Rectangular		0.029		1
	MPE		$0.9 + (L/350)$		Normal (based on $k = 3$)		0.30		1
	MPE_P		0.5		Rectangular		0.29		1
	Combined standards uncertainty, $u_c = \pm 1.6\ \mu$m								
	Expanded uncertainty $U_{\exp} = \pm 3.20\ \mu$m								
Third	Repeatability	1.7	2.4	3.8	Normal	0.85	1.20	1.90	1
	Resolution		0.05		Rectangular		0.029		1
	MPE		$0.9 + (L/350)$		Normal (based on $k = 3$)		0.30		1
	MPE_P		0.5		Rectangular		0.29		1
	Combined standards uncertainty, $u_c = \pm 1.9\ \mu$m								
	Expanded uncertainty $U_{\exp} = \pm 3.80\ \mu$m								

C is the sensitivity of measurements.

TABLE 7: The classification results of tile first specimen using new measurement method in mm.

(a)

Test no.	Measured values of ΔC		Measured values of ΔS		Measured values of ΔW	
	at D	at D_1	at L	at L_1	at M	at M_1
1	0.7321	0.8357	0.7713	0.8275	0.2141	0.3453
2	0.7318	0.8359	0.7715	0.8272	0.2140	0.3456
3	0.7322	0.8361	0.7715	0.8270	0.2139	0.3458
4	0.7319	0.8359	0.7714	0.8267	0.2138	0.3462
5	0.7320	0.8356	0.7706	0.8261	0.2137	0.3461
Average	0.7320	0.8358	0.7713	0.8269	0.2139	0.3458
Maximum	0.8361		0.8275		0.3462	

(b)

Specific calculated parameters, %		
$CC = \Delta C/D$	$EC = \Delta S/L$	$W = \Delta W/D$
0.14	0.16	0.06

W parameter represents the maximum warpage expressed as a percentage of the length of diagonal "D" for oblong tile.

4.1. Experimental Results of New Measurement Method. It is possible to identify and measure the appropriate plane of three points using CMM machine made as indicated in ISO 10545-2. However, what is new here is that there was potential to the replacement of the selected point for each of the diagonal, edge, and warpage by measuring the straightness forms of each of the diagonal, edge, and width for warpage extension lines as presented in Figures 3–5, where the vertical axes are represent the deviations of STR waviness shape of D, D_1, L, L_1, M, and M_1 dimension measurements for measured specimens. It is then possible to obtain the actual values of ΔC, ΔS, and ΔW. The maximum and the averagee value of straightness measurement for each specimen are presented in Tables 7–9.

4.1.1. The First Specimen. Figure 3 shows the sample behaviour of straightness profiles of one from five measured results along the length of the diagonals D and D_1, length of the edges L and L_1, and length of the width M and M_1 of the first ceramic tiles specimen. The results of proposed measurement method showed that the maximum values for

TABLE 8: The classification results of tile second sample using new measurement method in mm.

(a)

Test no.	Measured values of ΔC		Measured values of ΔS		Measured values of ΔW	
	at D	at D_1	at L	at L_1	at M	at M_1
1	0.7814	0.8375	0.6773	0.9625	0.1453	0.2481
2	0.7812	0.8377	0.6767	0.9625	0.1451	0.2478
3	0.7812	0.8377	0.6771	0.9626	0.1454	0.2480
4	0.7808	0.8377	0.6772	0.9623	0.1453	0.2478
5	0.7805	0.8374	0.6768	0.9625	0.1453	0.2477
Average	0.7810	0.8376	0.6770	0.9625	0.1453	0.2479
Maximum	0.8377		0.9626		0.2481	

(b)

Specific calculated parameters, %		
$CC = \Delta C/D$	$EC = \Delta S/L$	$W = \Delta W/D$
0.14	0.18	0.04

TABLE 9: The classification results of tile third sample using new measurement method in mm.

(a)

Test no.	Measured values of ΔC, mm		Measured values of ΔS, mm		Measured values of ΔW, mm	
	at D	at D_1	at L	at L_1	at M	at M_1
1	0.7413	0.6448	0.6227	0.6896	0.1307	0.1626
2	0.7403	0.6450	0.6224	0.6895	0.1307	0.1629
3	0.7399	0.6445	0.6212	0.6894	0.1306	0.1627
4	0.7400	0.6448	0.6212	0.6892	0.1309	0.1630
5	0.7392	0.6449	0.6208	0.6883	0.1309	0.1629
Average	0.7401	0.6448	0.6217	0.6892	0.1308	0.1628
Maximum	0.7413		0.6896		0.1630	

(b)

Specific calculated parameters, %		
$CC = \Delta C/D$	$EC = \Delta S/L$	$W = \Delta W/D$
0.12	0.13	0.03

TABLE 10: The statistical results of tiles specimens using proposed method.

Specimen	Values	ΔC, mm	ΔS, mm	ΔW, mm
First	S_D	0.0002	0.0005	0.0004
	$U_{(Xi)}$	0.0001	0.0002	0.0002
Second	S_D	0.0004	0.0001	0.0001
	$U_{(Xi)}$	0.0002	0.0001	0.00005
Third	S_D	0.0008	0.0008	0.0001
	$U_{(Xi)}$	0.0003	0.0004	0.0001

the STR are not at the centre as shown in Figure 3, while the total results of the first specimen using new measurement method are presented in Table 7 in order to calculate the relative specific values of CC, EC, and W parameters.

4.1.2. The Second Specimen. Figure 4 shows the behaviour of straightness form samples of the measured result along the length of the diagonals D and D_1, length of the edges L and L_1, and length of the width M and M_1 of this specimen from ceramic tiles. The sample profiles show that the maximum values of the STR form are normally not in the middle of lines, while the total result of the second specimen using the proposed measurement method presented in Table 8 includes the calculated percentage specific values of parameters CC, EC, and W.

4.1.3. The Third Specimen. Figure 5 represents straightness profiles of the measured results along the length of the diagonals D and D_1, length of the edges L and L_1, and length of the width M and M_1 of this specimen from ceramic tiles. The results of the new measurement method show that the maximum values for the STR form are not in the centre of the line. The results of the third specimen using the new measurement method are presented in Table 9 to be used for calculation of the relative specific values of CC, EC, and W parameters.

Table 11: Estimation of uncertainty budget in straightness deviation for tiles measurement.

Test specimen	Sources of uncertainty	St. uncertainty, $U_{(Xi)}$			Assumed distribution	Combined uncertainty, $u_{(Xi)}$			C
		ΔC, μm	ΔS, μm	ΔW, μm		ΔC, μm	ΔS, μm	ΔW, μm	
First	Repeatability	0.10	0.20	0.20	Normal	0.05	0.10	0.10	1
	Resolution		0.05		Rectangular		0.029		1
	MPE		0.9 + (L/350)		Normal (based on k = 3)		0.30		1
	MPE_P		0.5		Rectangular		0.29		1
	Combined standards uncertainty, $u_c = \pm 0.43\,\mu$m								
	Expanded uncertainty $U_{\exp} = \pm 0.86\,\mu$m								
Second	Repeatability	0.20	0.10	0.05	Normal	0.10	0.05	0.03	1
	Resolution		0.05		Rectangular		0.029		1
	MPE		0.9 + (L/350)		Normal (based on k = 3)		0.30		1
	MPE_P		0.5		Rectangular		0.29		1
	Combined standards uncertainty, $u_c = \pm 0.43\,\mu$m								
	Expanded uncertainty $U_{\exp} = \pm 0.86\,\mu$m								
Third	Repeatability	0.30	0.40	0.10	Normal	0.15	0.20	0.05	1
	Resolution		0.05		Rectangular		0.029		1
	MPE		0.9 + (L/350)		Normal (based on k = 3)		0.30		1
	MPE_P		0.5		Rectangular		0.29		1
	Combined standards uncertainty, $u_c = \pm 0.46\,\mu$m								
	Expanded uncertainty $U_{\exp} = \pm 0.92\,\mu$m								

It has become clear that the rate of ΔC, ΔS, and ΔW to the length of D or L that gives a final relative percentage for CC, EC, and W parameters is more accurate than those obtained from the traditional method, while the performance of characterization of results indicates that there is also relatively little variation between these values, but in all cases, the tile specimens are technically acceptable in terms of dimensions and surface quality using the proposed method. Moreover, the straightness measurement apiaries continuous clear lines without cut; this ensures that there is no edge crack defects in measured tiles, Figures 3–5. These confirmation can not be achieved when using conventional measurement method without using the new method.

4.2. Uncertainty Budget of the New Method. The statistical analyses being part of uncertainty (*type A*) of centre point's measurements for the diagonal, edges, and width warpages of the tiles specimens are evaluated and presented in Table 10. Table 11 gives the estimated values of the expanded uncertainties of the proposed method. The estimated values of expanded uncertainty ($U_{\exp}$) of first, second, and third measured samples using the proposed method are 0.86, 0.86, and 0.92 μm, respectively.

5. Comparison between Traditional and New Methods

Despite the success of the acceptance for tile specimens after the implementation of traditional and new methods, it still shows that there is clear difference in the values of the results of the specific parameters CC, EC, and W. This is because the amount of difference of the measured ΔW parameter was very large; it reaches a value of more than ten times, while the achieved different in the measured values of the ΔC and ΔS parameters was up to 10% in the new method compared to the old method. Therefore, the values of the ratios CC and EC and W parameters in the new measurement method have achieved a significant increase than the traditional method in measurement. Figure 6 clearly shows that the deviation of the maximum value of ΔS is equal to 0.6116 mm using the traditional method rather than the value of 0.9626 mm using the new method. Thus, the new measurement method showed the largest real value to the highest point and this was not achievable when using the old method. This means, applying the new method using straightness measurements, the actual characteristics of surface can be known.

Figure 7 indicates the deviation range in the percentage values of specific parameters between traditional and proposed measurement methods. It was found that the average percentage values of CC, EC, and W parameters are the biggest when we using the new measurement method. This positive difference resulted due to the used proposed method in measuring values of ΔC, ΔS, and ΔW and is able to reflect the accurate status of ceramic tile surfaces. In additions the ability of the new method is more accurate than that of the traditional one due to the reach of the highest point on the lengths of diagonal, edge, and warpage after the use of more precise measurements. Moreover, it can clear that the CMM machine has highly proved in the measurement of oblong large-scale ceramic tiles than the vision inspection methods [7–10].

On the other hand, using analytical comparison between the new and traditional measurement methods in terms of average values of the parameters and the uncertainty associated with measuring the repeated five times of three samples

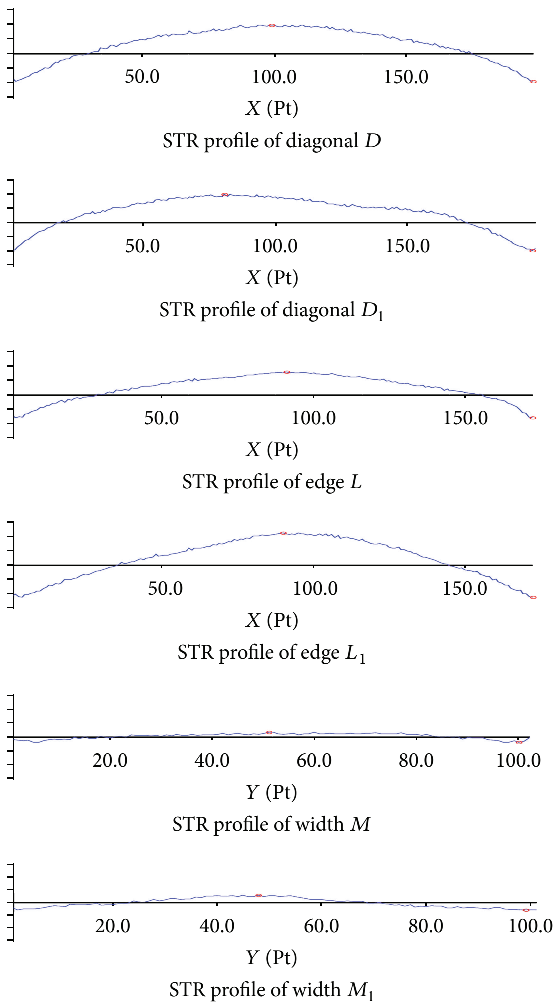

FIGURE 4: Result of STR form for D and D_1, L and L_1, M and M_1 lines of second specimen in the new method.

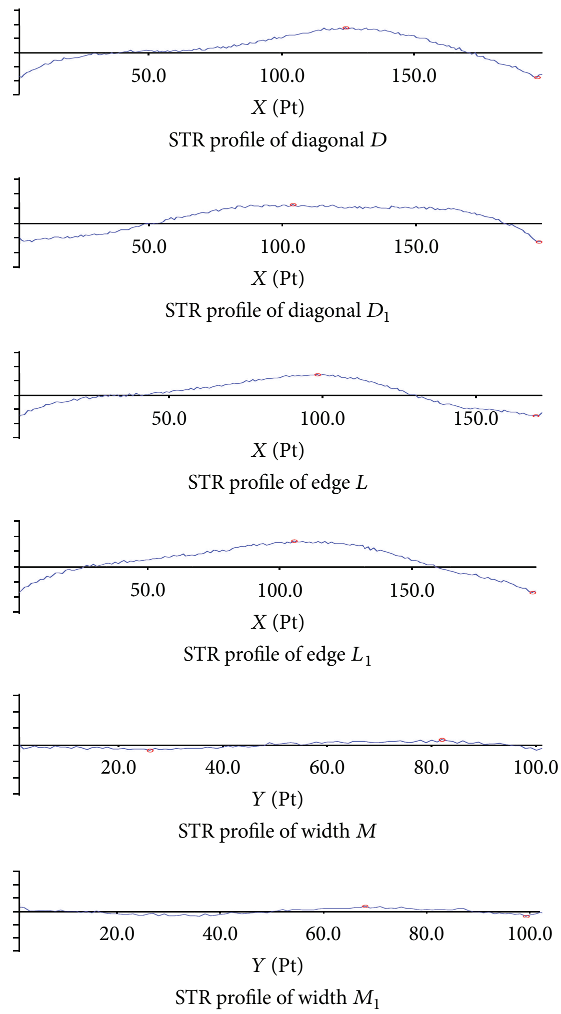

FIGURE 5: Result of STR form for D and D_1, L and L_1, M and M_1 lines for third specimen using new method.

of tiles, some observations can be seen. It was found that the accuracy of the new measurement method compared to old method is up to more than 12% in the measurements of first tile sample, up to more than 73% in the second tile, and up to about 76% in the measurements of the third tile, respectively. The observed maximum value of expanded uncertainty of the traditional method was larger 4 times than the value derived using the new measurement method, Figure 8. This means that the value of the associated uncertainty in the results of the proposed measurement method outweighs the traditional way in all circumstances.

Eventually, the estimation of specific parameters in this work reflects confidence in the high credibility of the proposed measurement method as shown obviously in Figures 7 and 8. Thus, it can say that the method of new measurement is closer to reality and very much more accurate than the traditional measurement method. In addition, a comparison to illustrate the extent of this improvement in the accuracy of measurement using the proposed method compared to the traditional way for each tile separately. Moreover, the new measurement method is able to prove the capability of computer-numerical-controlled devices as a high efficiency of coordinate measuring machines for evaluating the tile dimensions and surface quality with high accuracy.

6. Conclusion

This paper contains analyses and discusses comparison between the traditional method (ISO-10545-2: 1995, EOS-3168-2: 2007, and TIS 2398-2: 2008) and the proposed measurement method that is accepted for quantifying dimensions and surface quality of large-scale ceramic plates. A number of experimental measurements have been carried out using new strategical method on CMM. The discussions highlighted many differences in the measured values obtained by the two measurement methods. This is very important considering that the suggested measurement method is suitable for use to define the maximum centre curvature (CC), the maximum edge curvature (EC), the maximum warpage (W), and the edge crack defects specifications. Based on the experimental measurements, a relationship between the parameters

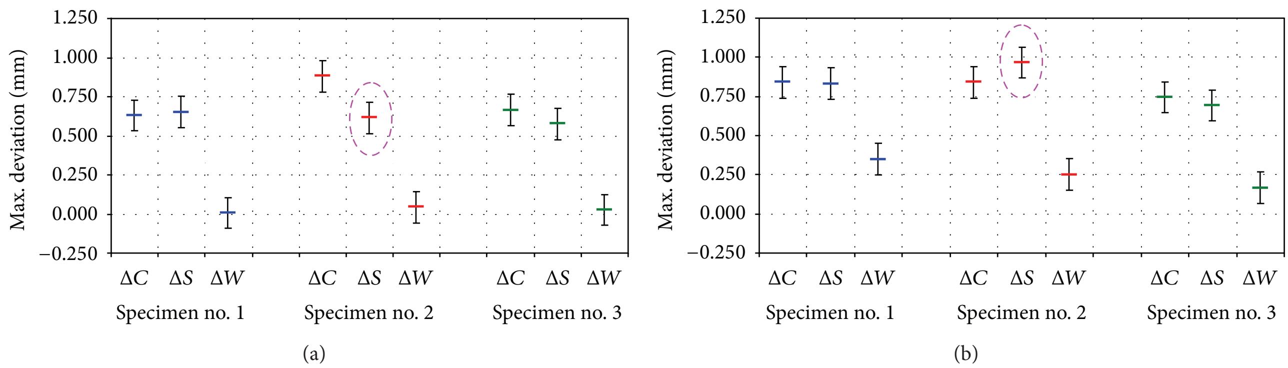

FIGURE 6: The deviation of measurement results of (a) traditional method and (b) proposed obtained method.

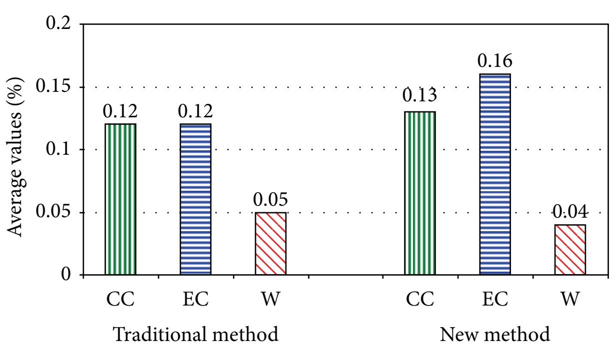

FIGURE 7: Results of important specific parameters using traditional method and proposed method.

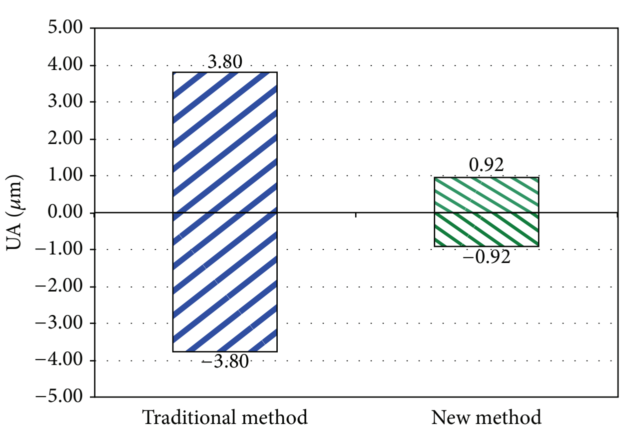

FIGURE 8: Expanded uncertainty for traditional and proposed obtained methods.

obtained by the CC, EC, and W has been achieved. The presented results can be useful to define the changes in the dimensions and surface of large-scale ceramic tiles specifications. This is due to the credibility of a proposed measurement test method as follows:

(1) The capability of the new method in the straightness form quality of large-scale ceramic tiles, CC, CE, W, and crack defect can be characterized in high accuracy. The actual values of tile dimensions and surface can be measured.

(2) Not always the maximum curvature point is at the centre of diagonal, edge, or at the width length as defined in the traditional method.

(3) The CNC-CMM machine has excellent capability to measure the dimensions and surface quality of tiles with more creditability and better accuracy than the vision inspection methods.

(4) The new method procedure is suitable for ceramic, porcelain, or any type of tiles and plates measurement.

(5) The measurement uncertainty estimated proved the accuracy and preciseness of the proposed measurement method compared to traditional method.

Consequently, the new method has excellent capability to assist in any scale of tiles and plates, not only having better accuracy and precision, but also permitting improvement of the plate quality productions.

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