

THE METROLOGY OF GROUND CONCRETE SURFACES MORPHOLOGY WITH 3D LASER SCANNER

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ABSTRACT

This paper is devoted to machining of concrete by grinding and the metrology of its surface morphologies. The surface morphology is still open problem from metrological as well as mathematical morphology points of views. In order to understand better abrasive process the raw morphologic state is compared with the ground concrete surfaces. The most significant results are presented in the form of profiles, 3D isometric views and isotropy analysis. Several 3D surface roughness parameters were calculated.

KEYWORDS

concrete, metrology, morphology, 3D laser scanner, grinding, roughness parameters.

Nomenclature

| | | |
|-------|---|---|
| Sq | – | root mean square height [mm], |
| Ssk | – | skewness [–], |
| Sku | – | kurtosis [–], |
| Sp | – | maximum height of summits [mm], |
| Sv | – | maximum depth of valleys [mm], |
| Sz | – | maximum height [mm], |
| Sa | – | arithmetic mean height, [mm], |
| Smr | – | areal material ratio [%], |
| Smc | – | inverse areal material ratio [mm], |
| Sxp | – | extreme peak height [mm], |
| Sal | – | auto-correlation length [mm], |
| Str | – | texture-aspect ratio [–], |
| Std | – | texture direction [°], |
| Sdq | – | root mean square gradient [–], |
| Sdr | – | developed interfacial area ratio [%], |
| Vm | – | material volume [mm ³ /mm ²], |
| Vv | – | void volume [mm ³ /mm ²], |
| Vmp | – | peak material volume [mm ³ /mm ²], |
| Vmc | – | core material volume [mm ³ /mm ²], |
| Vvc | – | core void volume [mm ³ /mm ²]. |

Introduction

It has been generally admitted, essentially for economical reasons, that final concrete surfaces are raw and only in specific cases will be machined [1, 2].

Recent technological progress in Civil Engineering and worldwide diversified requirements contributes to development of new science surfometry concerning metrology of surfaces. It is not only due to increasing interest of sensor analysis and good looking impression of concrete but also thanks to growing quality of coatings and of its adhesion quantification depending also on roughness.

The surface morphology is still open problem from metrological as well as mathematical morphology points of view [3–8]. Today there are great number of techniques for surfaces metrology of machined or not surfaces but mostly devoted to mechanical industry due to tremendously increasing demand. That proliferation of multi-scale techniques from optical non-contact to tactile devices connected to rough parameters created a great number of industrial difficulties [9]. In recent years has been observed a proliferation of parameters justified or not for description and metrological approach to specify surface texture. Some of these parameters are useful, but most are not even for mechanical industry. The result of this rash is confusion and expense.

For concrete morphology description situation is opposite to previous case. There is total lack of knowledge and specific metrological equipment's.

The tactile techniques are eliminated for time consuming reasons on the one side and wear problems of the tip on another side [10]. The authors present the today's morphological aspect of concretes in context of control of machining and functional as well as architectural aspects. For specific application reasons in present study a novel 3D laser scanner in assessment of concrete's morphology subjected to grinding is presented. Moreover in order to understand better two bodies abrasive process the raw morphologic state is compared the ground concrete surfaces. The most significant results are presented in the form of three-dimensional images of axonometric projections and several surface determinable morphology parameters.

Metrological strategy

In order to take into consideration real civil engineering problem a few square meters has to be analyzed and for statistical reasons a significant number of measurements has to be carried out on pertinent areas of analyzed concrete. For that reasons 40 of 50×50 mm concrete surfaces selected on a 125 mm thick concrete substrate layer were investigated. Also for technological reasons the concrete substrates were prepared of grade C30/37 concrete with the maximum grading of 8 mm of crushed basalt aggregate. The scanning field corresponds to the one tested by the semi-nondestructive pull-off method in order to identify the adhesion between concrete layers [16–18].

In order to discriminate the effect of grinding on large scale of machined concrete the surfaces were prepared differently:

- raw surface (half space as after concreting),
- ground (half space subjected to grinding).

A 3D laser scanner, developed and described in details in [11–14] was used. That 3D laser scanner principle (Fig. 1c) is based on triangulation modified method, exploiting a set of laser spots forming a 50 mm long line. In order to obtain a 3D image of the tested surface the scanner was equipped with a stepwise motor whereby measurements could be performed at a sampling range of 0.1 mm along a measuring length of 50 mm. As mentioned in [15] in the case of highly rough surfaces, to which concrete surfaces belong, the laser triangulation method has a certain limitation (shadow effect) due to its principle of operation. However, in the case of measured ground concrete surfaces no influence of the shadow effect on the obtained results was observed taking several metrological precautions.

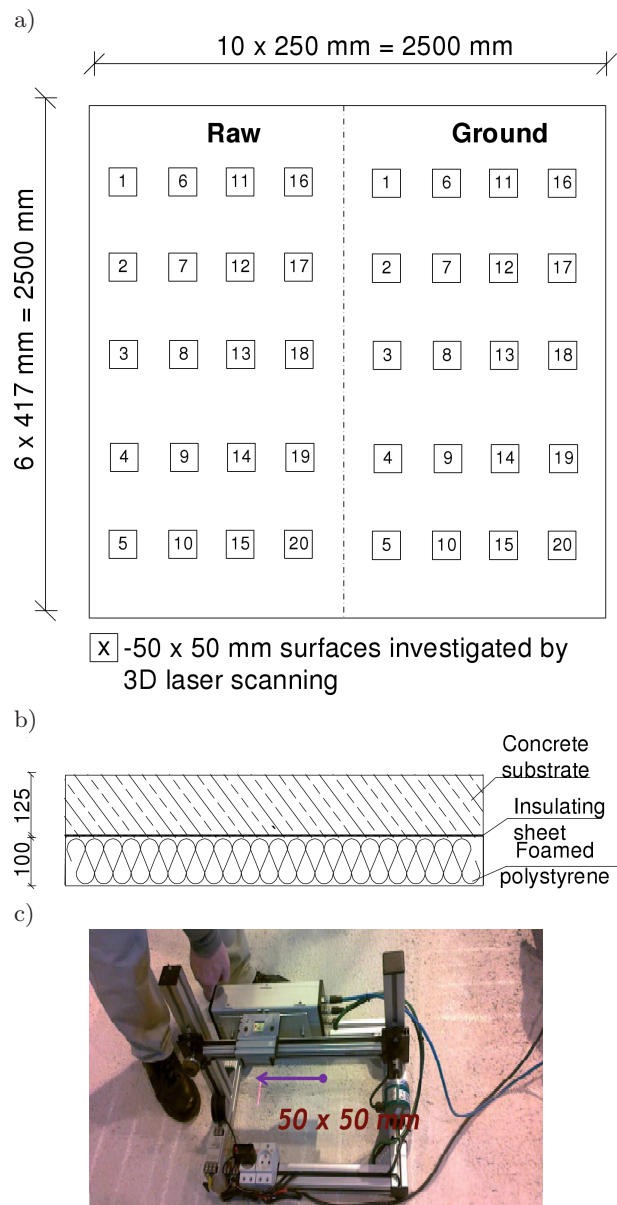


Fig. 1. View of selected surfaces locations (a) orthogonal section (b) 3D operating laser scanning device (c).

The main advantages of developed 3D laser scanner technique are its speed, achieved owing to the fitting of the scanning parameters to the measurement requirements, and its mobility.

Selected results and discussion

In order to illustrate the morphology evolution due to grinding process pertinent 3D isometric views, extracted significant profiles, and isotropy of the raw and ground concrete substrate surfaces are shown in Figs. 2 and 3.

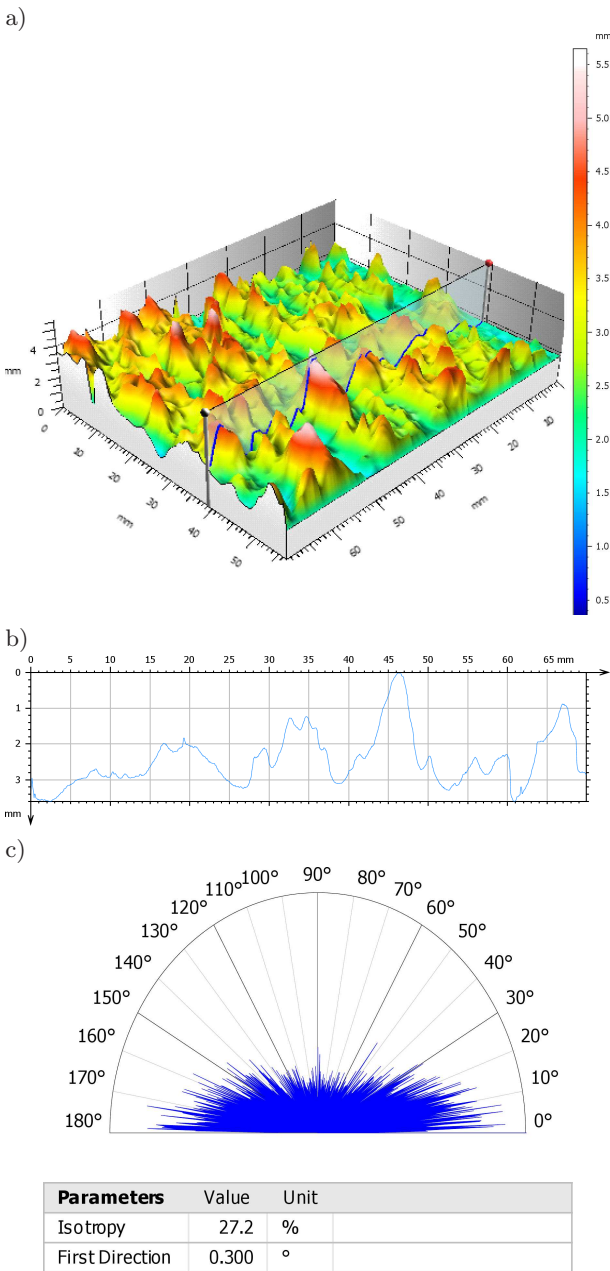


Fig. 2. 3D isometric view (a) profile (b) and isotropy analysis (c) of raw concrete surface.

From the analysis of Figs. 2 and 3 it is easy to state that profile of ground concrete surface is characterized by lower amplitude than for raw surface. It is the effect of cutting “peaks”. From profile of Fig. 3 the crushing effect of emerging gravels can be easily observed. Interest to morphological anisotropy concrete is justified by directional flattening before solidification and it is attention-grabbing to measure if it is possible to quantify the effect of machining in case of present study grinding. Effectively the isotropy of ground concrete surface is twice higher than for

the raw one. One can state that grinding process in present situation contributes to homogenization of ground surfaces.

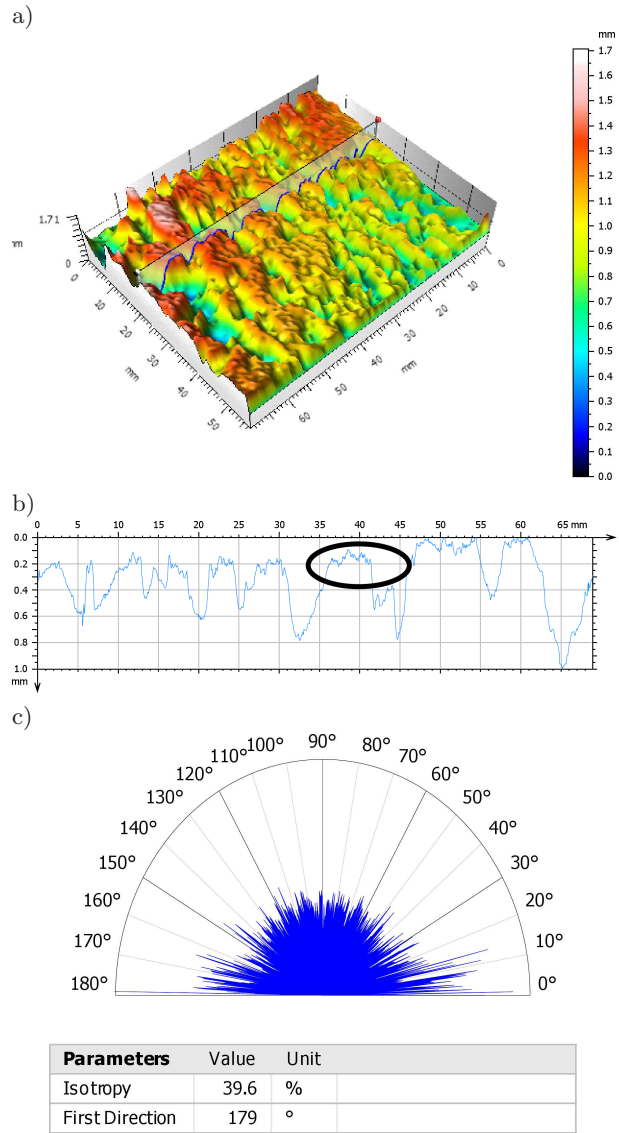


Fig. 3. 3D isometric view (a) profile (b) and isotropy analysis (c) of ground concrete surface.

The morphological characterization and the surface roughness parameters were calculated thanks to MountainsMap [19] in accordance to ISO 25178 standards [20]. Statistical treatments of 3D morphological parameters (3D optical scanning) are presented in Tables 1–5.

An analysis of the test results presented in Table 1 shows that the grinding of the concrete surface resulted in a reduction in the average values of all amplitude roughness parameters except *Sku* in comparison with the average values of the same parameters describing the raw surface.

Table 1
Statistical treatment of 3D morphological height parameters (3D optical scanning of concrete surfaces)

| Parameter symbol | Name and value of characteristic | | | |
|-------------------------|----------------------------------|--------|-------|-------|
| | Raw concrete surface | | | |
| | Average | Min. | Max. | STD |
| <i>Sq</i> [mm] | 0.718 | 0.398 | 1.140 | 0.200 |
| <i>Ssk</i> [-] | 0.651 | -0.501 | 4.020 | 0.925 |
| <i>Sku</i> [-] | 4.923 | 2.560 | 5.200 | 1.884 |
| <i>Sp</i> [mm] | 3.654 | 1.950 | 5.840 | 1.209 |
| <i>Sv</i> [mm] | 2.150 | 0.779 | 3.450 | 0.748 |
| <i>Sz</i> [mm] | 5.805 | 3.570 | 8.960 | 1.483 |
| <i>Sa</i> [mm] | 0.559 | 0.306 | 0.928 | 0.173 |
| Ground concrete surface | | | | |
| <i>Sq</i> [mm] | 0.253 | 0.137 | 0.484 | 0.085 |
| <i>Ssk</i> [-] | -0.786 | -1.610 | 0.148 | 0.544 |
| <i>Sku</i> [-] | 4.240 | 1.990 | 6.650 | 1.495 |
| <i>Sp</i> [mm] | 0.665 | 0.384 | 1.060 | 0.180 |
| <i>Sv</i> [mm] | 1.269 | 0.658 | 2.320 | 0.456 |
| <i>Sz</i> [mm] | 1.935 | 1.070 | 3.000 | 0.544 |
| <i>Sa</i> [mm] | 0.198 | 0.105 | 0.416 | 0.071 |

It appears from the Table 2 that grinding caused the largest reduction in the average values of parameters *Smc* and *Sxp*, but it had no effect on the value of parameter *Smr*, which did not change in comparison with that obtained for the surface not subjected to grinding process.

Table 2
Statistical treatment of 3D morphological selected functional parameters (3D optical scanning of concrete surfaces).

| Parameter symbol | Name and value of characteristic | | | |
|-------------------------|----------------------------------|-------|-------|-------|
| | Raw concrete surface | | | |
| | Average | Min. | Max. | STD |
| <i>Smr</i> [%] | 0.003 | 0.002 | 0.006 | 0.001 |
| <i>Smc</i> [mm] | 0.927 | 0.527 | 1.490 | 0.274 |
| <i>Sxp</i> [mm] | 1.154 | 0.311 | 2.180 | 0.497 |
| Ground concrete surface | | | | |
| <i>Smr</i> [%] | 0.002 | 0.001 | 0.006 | 0.002 |
| <i>Smc</i> [mm] | 0.277 | 0.000 | 0.636 | 0.123 |
| <i>Sxp</i> [mm] | 0.608 | 0.338 | 1.110 | 0.221 |

An analysis of the statistical treatment of 3D morphological spatial parameters presented in Table 3 shows that the grinding of the concrete surface resulted in a reduction in the average values of two spatial roughness parameters *Str* in comparison with the average values of the same parameters describing the raw surface. Average value of *Sal* increases in comparison with the ones described raw surface. However it is proper to note that the following changes are not more than 20% and changes of the average value of *Std* is not significant.

Table 3
Statistical treatment of 3D morphological spatial parameters (3D optical scanning of concrete surfaces).

| Parameter symbol | Name and value of characteristic | | | |
|-------------------------|----------------------------------|-------|---------|--------|
| | Raw concrete surface | | | |
| | Average | Min. | Max. | STD |
| <i>Sal</i> [mm] | 3.694 | 2.230 | 9.670 | 1.549 |
| <i>Str</i> [-] | 0.555 | 0.225 | 0.835 | 0.191 |
| <i>Std</i> [°] | 66.119 | 3.000 | 177.000 | 82.200 |
| Ground concrete surface | | | | |
| <i>Sal</i> [mm] | 3.971 | 1.700 | 9.790 | 2.483 |
| <i>Str</i> [-] | 0.472 | 0.132 | 0.687 | 0.164 |
| <i>Std</i> [°] | 64.845 | 0.335 | 176.000 | 71.370 |

It can be stated from the Table 4 that grinding caused the largest reduction in the average values of both hybrid parameters *Sdq* and *Sdr* in comparison with that obtained for the surface not subjected to grinding.

Table 4
Statistical treatment of 3D morphological hybrid parameters (3D optical scanning of concrete surfaces).

| Parameter symbol | Name and value of characteristic | | | |
|-------------------------|----------------------------------|--------|---------|--------|
| | Raw concrete surface | | | |
| | Average | Min. | Max. | STD |
| <i>Sdq</i> [-] | 2.653 | 0.918 | 4.670 | 1.035 |
| <i>Sdr</i> [%] | 156.165 | 22.600 | 391.000 | 99.865 |
| Ground concrete surface | | | | |
| <i>Sdq</i> [-] | 0.488 | 0.330 | 0.713 | 0.097 |
| <i>Sdr</i> [%] | 10.362 | 5.030 | 17.600 | 3.336 |

By analysis the results from Table 5 it also can be stated that grinding caused the largest reduction in the average values of all volume parameters in comparison with that obtained for the surface not subjected to grinding process.

Table 5
Statistical treatment of 3D morphological volume parameters (3D optical scanning of concrete surfaces).

| Parameter symbol | Name and value of characteristic | | | |
|--|----------------------------------|-------|-------|-------|
| | Raw concrete surface | | | |
| | Average | Min. | Max. | STD |
| <i>Vm</i> [mm ³ /mm ²] | 0.045 | 0.026 | 0.088 | 0.015 |
| <i>Vv</i> [mm ³ /mm ²] | 0.973 | 0.554 | 1.560 | 0.279 |
| <i>Vmp</i> [mm ³ /mm ²] | 0.045 | 0.026 | 0.088 | 0.015 |
| <i>Vmc</i> [mm ³ /mm ²] | 0.598 | 0.277 | 1.070 | 0.216 |
| <i>Vvc</i> [mm ³ /mm ²] | 0.910 | 0.516 | 1.490 | 0.266 |
| <i>Vvv</i> [mm ³ /mm ²] | 0.063 | 0.014 | 0.141 | 0.030 |
| Ground concrete surface | | | | |
| <i>Vm</i> [mm ³ /mm ²] | 0.008 | 0.003 | 0.024 | 0.005 |
| <i>Vv</i> [mm ³ /mm ²] | 0.294 | 0.137 | 0.650 | 0.111 |
| <i>Vmp</i> [mm ³ /mm ²] | 0.008 | 0.003 | 0.024 | 0.005 |
| <i>Vmc</i> [mm ³ /mm ²] | 0.225 | 0.116 | 0.503 | 0.086 |
| <i>Vvc</i> [mm ³ /mm ²] | 0.256 | 0.108 | 0.611 | 0.106 |
| <i>Vvv</i> [mm ³ /mm ²] | 0.037 | 0.022 | 0.070 | 0.014 |

Conclusion and perspectives

It has been demonstrated that metrology of ground concrete's morphology is possible and necessary in manufacturing of this surfaces of high value added processes. The non-destructive metrology of the morphology of ground concrete in relation to raw surface can be determinist and is discriminative by means of 3D laser scanner measurements.

It appears from the selected results that grinding process contributes to reduction in the average values of most 3D topographical parameters. Only average values of spatial parameters have been stated as similar.

It is still the open problem to select the most relevant 3D morphological descriptors as pertinent parameters for specific function of raw as well as finished surfaces by grounding of concrete.

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