Laser profilometry and flash thermography for surface roughness assessment of Pentelic marble

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Abstract

Two non-contact NDT & E (non-destructive testing and evaluation) techniques were employed in the inspection of quarry Pentelic marble samples; surface profilometry and infrared thermography. The samples were processed with different roughness treatments (i.e. 60, 80, 100, 220, 400 and 600 mesh) and were evaluated in the laboratory. Furthermore, different surface cleaning treatments were applied to a Pentelic marble surface in situ and then representative samples were collected and evaluated in the laboratory by the means of these two non-destructive techniques. Quantitative analysis of all samples was performed. In particular, the surface roughness parameter Rq at a specific length scale and 3-D micro-topography plots were attained by the use of the laser profilometry scanning approach, whilst temperature – time plots displaying the intensity of pixels as a function of time on the obtained thermal images were also obtained with the intention of distinguishing the influence of the applied roughness treatments. Results indicate that these two non-destructive techniques can be used for the assessment of surface roughness.

Keywords: infrared thermography, laser profilometry, marble, pixels intensity, surface roughness.

1. Introduction

Surface texture can be in various modes, such as tiny scratches, grooved structure produced by machining, etc. In the area of surface science and engineering, this issue becomes gradually of great magnitude [1]. It is a feature that includes roughness, waviness and lay, all being significant for surface science characterisation. Roughness includes the finest (shortest wavelength) irregularities of a surface and it is generally a result from a particular production process or material condition, whilst waviness includes the more widely spaced (longer wavelength) deviations of a surface from its nominal shape. As far as the lay is concerned, it refers to the predominant direction of the surface texture; ordinarily lay is determined by the particular production method and geometry used. Typically, when the surface texture is quantitatively measured it is only the roughness that it is analysed and the waviness and lay elements are either mechanically or electrically or even digitally filtered out of the recorded data [2]. Nowadays, there are standard procedures [3-5] that illustrate such procedures.

2. Experimental procedures & techniques

Laser profilometry and pulsed thermography were used in the inspection and evaluation of surface roughness on white Pentelic marble, a metamorphic limestone consisting almost exclusively of calcite grains and quarried from mountain Penteli in Athens [6]. LP is one of the most recently developed approaches for surface roughness measurements, whilst PT was used with the intention of associating the influence of surface roughness with thermal radiometry [7].

Quantitative analysis of the marble was performed. Surface roughness parameters and topography from the LP approach, as well as temperature – time plots displaying the intensity of pixels as a function of time on the thermal images (PT) were obtained. As a result, information about the influence of surface roughness for each examined sample was attained. The investigated samples are shown in the following table (Table 1).

Sample	**Description of sample**
I-60	Pentelic marble that was processed using a 60 grit number (diameter of 250 microns)
I-80	Pentelic marble that was processed using a 80 grit number (diameter of 180 microns)
I-100	Pentelic marble that was processed using a 100 grit number (diameter of 150 microns)
I-220	Pentelic marble that was processed using a 220 grit number (diameter of 63 microns)
I-400	Pentelic marble that was processed using a 400 grit number (diameter of 35 microns)
I-600	Pentelic marble that was processed using a 600 grit number (diameter of 25.75 microns)
Pentelic - Front	Pentelic sample used as a reference
Kn1a	Ion exchange resin with 10% w/v $(NH_4)_2CO_3$ applied on the Pentelic marble surface
Kn3c	AB57 poultice applied on the Pentelic marble surface

Table 1: Description of investigated samples

The last two investigated samples (Kn1a and Kn3c) were collected from surface Kn (figure 1) after cleaning on the National Archaeological Museum in Athens, Greece. This surface was characterised with specific decay patterns such as black-grey crusts and washed-out surfaces.

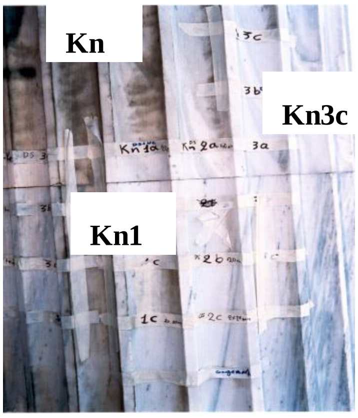

Figure 1: Photograph of investigated surface in the National Archaeological Museum in Athens, Greece.

As far as the laser profilometry measurements are concerned, Rq, which is a roughness parameter that can be used to describe surface topography, was obtained for all samples. However, Rq is a length scale dependant property. In other words, in order to be able to compare Rq values, they have to have been evaluated over the same measurement length [7]. In this case, the length scale for all investigated samples was 1.25mm. A Proscan 2000 instrument was used for the measurements; using a laser triangulation sensor with a resolution of 1μm. The marble surfaces were scanned over a distance of 1.25mm (X-axis) x 1.25mm (Y-axis) using a step size of 1μm on both axes. Since the software within the instrument calculates, amongst others, the Rq parameter on a specific length scale via a two-dimensional line profile, 5 line profiles across the X-axis and 5 line profiles across the Y-axis at values of 0.125mm, 0.375mm, 0.625mm. 0.875mm and 1.125mm were acquired with the intention of determining the Rq value for each tested sample. The Rq values presented in this paper are the average values from these two batches of 5 line profiles. It is also worth mentioning, that before the acquisition of the line profiles and in accordance to the BS EN ISO 4288:1998 [4] a cut-off filter of 0.25mm was used in each line profile, in order to dispatch the unnecessary frequencies (waviness information) and keep only the roughness data.

An integrated pulsed thermographic system (Thermoscope) employing a medium wave infrared camera (Merlin 3-5 μm by Indigo) that uses a cooled indium antimonide detector with a frame rate of 60 Hz, a focal plane array pixel format of 320 (H) x 256 (V) and an optical lens of 13 mm focal length was utilised for the pulsed thermographic analysis. The system has an integrated power flash heating system with a power output of 2KJ in 2-5 ms. Temperature – time plots, displaying the intensity of pixels against time were plotted from the acquired pulsed thermographic images. Such quantitative data could provide information concerning the surface roughness; i.e. the rougher the material the higher the intensity, since the thermal diffusion length is altered at the material's surface and the thermal effusivity is also changed (becomes lower) there is a rapid increase in temperature, thus higher intensity values [8].

3. Results and discussion

A representative 3-D micro-topography result showing one of the investigated Pentelic marble surfaces is presented in the following figure (figure 2). Furthermore, surface roughness parameters (i.e. Rq, Ra, Rz, etc) can be evaluated through the formation of specific line profiles, like the example presented in figure 3. The average Rq values, obtained from the attained line profiles, for all tested samples are presented in table 2.

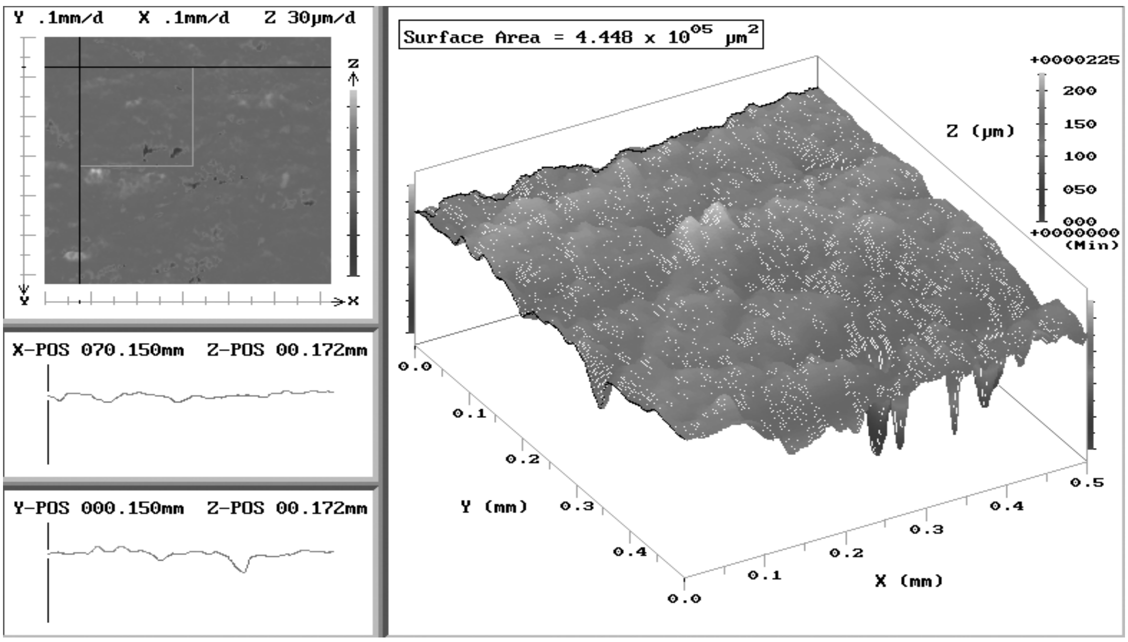

Figure 2: Representative 3-D micro-topography of investigated sample.

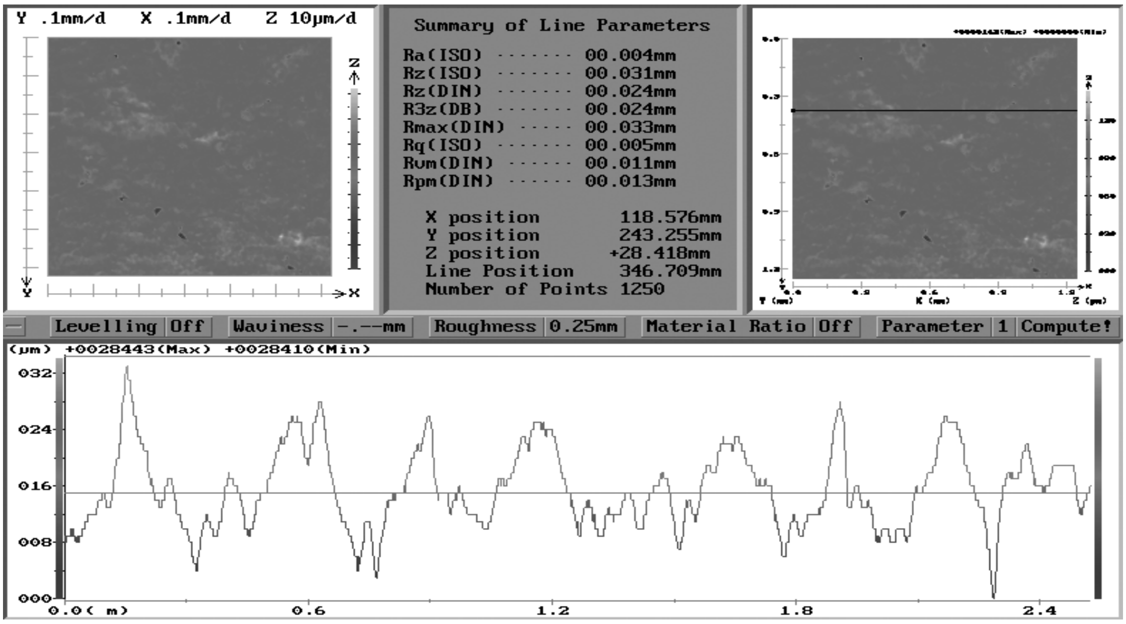

Figure 3: Representative X-line profile of investigated sample.

Sample	Rq Value (average of 5 X-line profiles)	Rq Value (average of 5 Y-line profiles)
I-60	0.006 mm	0.008 mm
I-80	0.005 mm	0.008 mm
I-100	0.004 mm	0.005 mm
I-220	0.010 mm	0.014 mm
I-400	0.013 mm	0.017 mm
I-600	0.020 mm	0.019 mm
Pentelic - Front	0.004 mm	0.004 mm
Kn1a	0.009 mm	0.008 mm
Kn3c	0.013 mm	0.014 mm

Table 2: Average Rq values of all investigated samples.

The following remarks can be made from the LP results:

- The Rq values of samples I-60, I-80 and I-100 are relatively comparable, meaning that the process between 150 and 250 microns has a similar effect on the Pentelic marble surface, whilst for the other three samples (I-220, I-400 and I-600) the Rq values are fairly considerable.

- The Rq values are not in an increasing order according to the process of the grit number used (referring to the processed samples using different grit numbers), since the selected process has also to do with the waviness parameters that were not taken into consideration in this analysis.

- As far as the cleaned samples are concerned, their Rq values are quite higher when compared to the reference Pentelic sample tested, showing the relatively higher roughness values of cleaned samples due to the surface process of the marble.

Furthermore, figures 4 and 5 show the intensity of pixels against time (Temperature – Time plot) for all investigated samples [9].

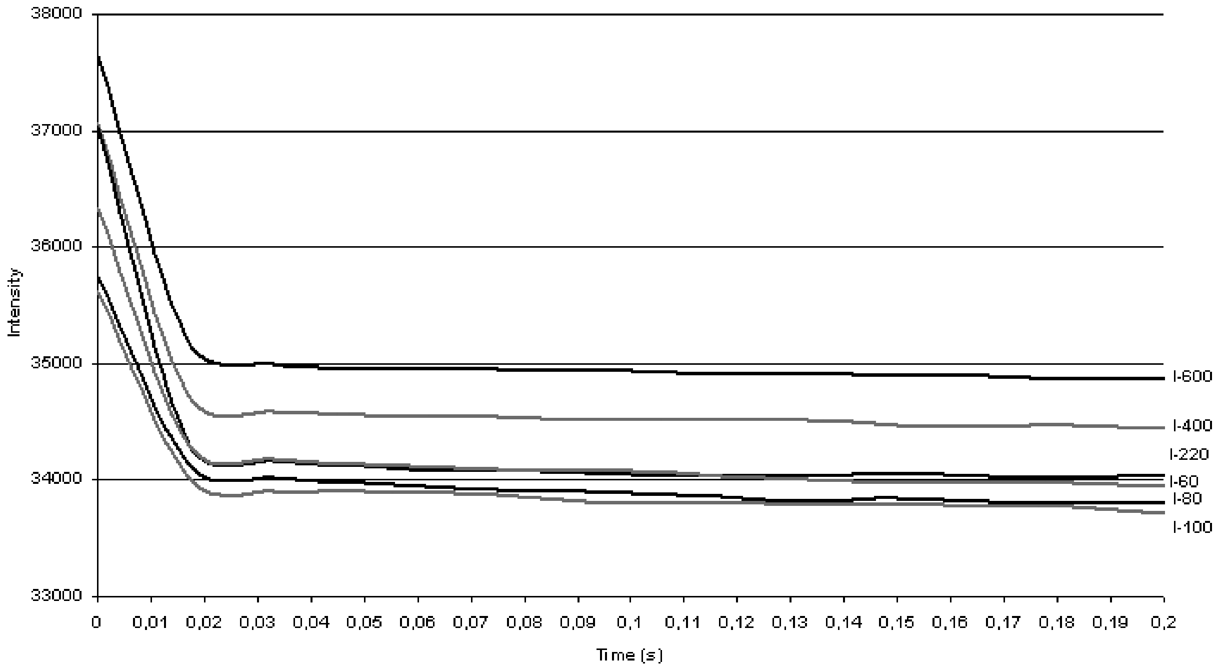

Figure 4: Temperature – Time plot for processed samples using different grit numbers.

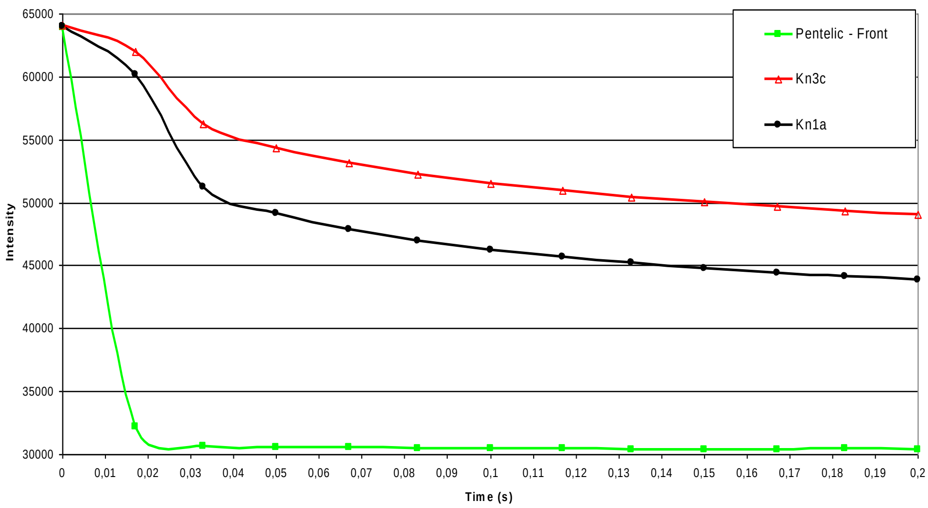

Figure 5: Temperature – Time plot for reference sample and cleaned samples.

The following remarks can be made from the pulsed thermography results:

- The intensity curves of all investigated samples are in the following increasing order: I-600>I-400>I-220>I-60>I-80>I-100, which is in good agreement with the Rq values that were determined by laser profilometry.

- Samples I-400 and I-600 present the highest intensity curves (as far as the processed samples using different grit numbers are concerned), as it would have been expected, because of the process of the used grit number.

- The cleaned samples present higher intensity values and curves when compared to the reference Pentelic marble sample. This is obviously because the cleaning treatments have affected (increase) the surface roughness of the marble.

4. Conclusions

The main objective of this work was to study the surface roughness on processed Pentelic marble surfaces using two non-destructive testing and evaluation techniques, LP and PT. LP provided surface roughness parameters, such as the Rq values, through the formation of X and Y line profiles on the obtained scans, assisting this way in the quantitative evaluation of each processed marble, in accordance with the relative standard procedures. Furthermore, PT was also used, with the intention of associating the influence of surface roughness with thermal radiometry. As a result, the quantitative analysis (temperature – time plots) that took place on the acquired thermal images proved to be a skilful means of inspecting surface roughness on marble. Future work will involve the investigation of more marble samples collected from various surfaces that were cleaned using different cleaning techniques.

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References

[1] J.M. Bennett, "Review Article: Recent developments in surface roughness characterization". *Journal of Measurement Science & Technology*, **3**, pp. 1119-1127, 1992.

[2] K.J. Stout, L.A. Blunt, "Application of 3-D topography to bio-engineering", *Journal of International Machine Tools and Manufacture*, **35**, pp. 219-229, 1995.

[3] BS EN ISO 4287:2000, "Geometrical product specification – surface texture: profile method – terms, definitions and surface texture parameters", British Standards Institution, 2000.

[4] BS EN ISO 4288:1998, "Geometrical product specification – surface texture: profile method – rules and procedures for the assessment of surface texture", British Standards Institution, 1998.

[5] BS 1134-2:1990, "Assessment of surface texture – Part 2: guidance and general information", British Standards Institution, 1990.

[6] N.P. Avdelidis, A. Moropoulou, E.T. Delegou, "Applications of thermography in the assessment of masonry, airport pavements and composite materials", *Journal of Insight*, **45**, pp. 836-841, 2003.

[7] W.J. Stemp, M. Stemp, "UBM laser profilometry and lithic use-wear analysis: a variable length scale investigation of surface topography", *Journal of Archaeological Science*, **28**, pp. 81-88, 2001.

[8] H.G. Walther, "Surface roughness influence on photothermal radiometry", *Journal of Applied Surface Science*, **193**, pp. 156-166, 2002.

[9] N.P. Avdelidis, D.P. Almond, "Through skin sensing assessment of aircraft structures using pulsed thermography", *Journal of NDT & E International*, 37, pp. 353-359, 2004.