Evaluation of Concrete Pavement Texturing Using PhotoTexture

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ABSTRACT

Texturing concrete pavement is the conventional option for enhancing tire/pavement noise and friction. It is performed while concrete is still in a plastic state or on a hardened concrete pavement. A new paved section in Illinois included nine different “formed” textures (tining or drag finishes created in fresh concrete) and three different “cut” textures (ground or grooved finishes created in hardened concrete) has been tested to study the effect of texturing type on tire/pavement noise and friction. For all of the texturing types, the widely accepted testing methods, CT Meter and high-speed profiler, have been used to measure the pavement surface properties shortly after construction.

PhotoTexture was used for the testing performed immediately before the road was opened for traffic. PhotoTexture is a photometric stereo device for measuring the 3D surface heights of pavement surface. It has been developed by the Pavement Research Group at the University of Manitoba as a non destructive that is successfully used to measure pavement texture.

This paper presents the analyses of the data obtained from the test measurements to determine the agreement between PhotoTexture and current standardized and widely accepted testing methods for measuring texture. Data analysis demonstrates the ability of PhotoTexture to detect texturing successfully.

1. Introduction

Texture measurements allow several applications that can improve how we monitor numerous pavement surface functional characteristics. However, current approaches for measuring texture features in road pavements have several limitations. Traditionally, sand patch measurements (ASTM E965) have been used to evaluate the texture of a road pavement. This and other static measurement devices (such as the Circular Track Meter, ASTM E2157) have the disadvantage of reducing the data to a single attribute such as mean profile depth or hydraulic radius. Although mean profile depth was correlated to friction and noise, it is not the only contributing factor. Texture size, spacing, and distribution should also be

considered. Therefore, advanced tools that characterize pavement texture in three dimensions are needed. For example, imaging techniques are extensively used as advanced tools for pavement texture evaluation where surface texture can be measured efficiently.
Based on imaging techniques, PhotoTexture, a photometric stereo device for measuring the 3D surface heights of pavement surface, has been developed by the Pavement Research Group at the University of Manitoba as a non destructive that is successfully used to measure pavement texture. PhotoTexture has been successfully used in many of the surface texture applications (El Gendy 2009). Of these applications, PhotoTexture has been used in the evaluation of texturing concrete pavement.
Texturing concrete pavement is the conventional option for enhancing tire/pavement noise and friction. It is performed while concrete is still in a plastic state or on a hardened concrete pavement. A new paved section in Illinois included nine different “formed” textures (tining or drag finishes created in fresh concrete) and three different “cut” textures (ground or grooved finishes created in hardened concrete) has been tested to study the effect of texturing type on tire/pavement noise and friction. For all of the texturing types, the widely accepted testing methods, CT Meter and high-speed profiler, have been used to measure the pavement surface properties shortly after construction (National Cooperative Highway Research Program, NCHRP, 2009).

The main objective of this paper is to present the analyses of the data obtained from the test measurements to determine the agreement between PhotoTexture and current standardized and widely accepted testing methods for measuring texture. This includes a summary of the pavement texturing techniques that are used in the analyses. Furthermore, image-texture related information and applications based on the current state of practice are introduced.

2. Surface Texture Indicators and PhotoTexture Applications

2.1. PhotoTexture

Image processing techniques are widely applied in monitoring pavement conditions. In general, photometric stereo technique requires a minimum of three images under three different directions. But because of the surface material of pavement, specularity and shadow effects are some of the problems encountered when photometric techniques are used. Therefore, the fourth source provides redundancy and is used to detect and correct the specular and shadow effects. El Gendy (2009) used PhotoTexture, a four-source photometric stereo system that is built inside a smaller box to be isolated from ambient environment to reduce image noise (Figure 1a). The box measures 0.6 m x 0.6 m x 0.6 m. In this small mobile system, a fibre optic light source with adjustable illumination intensity is used. The light intensity is adjusted so that the digital still camera has an optimum scene exposure. The light source was tested so that it produces a constant incident illumination with parallel lighting direction over the scene.
PhotoTexture captures pavement surface image within a template of an area of 160 mm × 160 mm used to adjust the image scale (Figure 1b). Also, the contrast between the template colour and pavement helps in improving the Focus setting.
The digital camera captures four images of a pavement sample under four illumination angles with 90° increment. The scene is isolated from ambient lights therefore the changes in pixel intensities are caused only by surface orientation and reflectance properties. Image processing software was developed for recovering the three-dimensional pavement surface heights from the change in the four-image intensities (Figure 2b).

2.2. Texture Depth

A practical application of PhotoTexure is the determination of commonly used parameters to measure texture depth. The most common texture depth indicator, the mean profile depth (MPD), is the standard method for computing the average depth of pavement surface macrotexture from surface profile (ASTM E1845 2001 and ISO 13473-1 1997). The root mean square roughness, RMSR, is another texture depth indicator. For a typical profile of pavement, RMSR is the standard deviation of the height of the surface profile (ISO 13473-1 1997, ISO 4287 1997, Bennett and Mattsson 1999).

2.3. Power Spectrum Energy

As an advantage, the area-based measurement technique allows computing the power spectrum energy (PSE). El Gendy and Shalaby (2007a) presented the total PSE of the two-dimensional Fourier transform of the three-dimensional recovered surface as a texture classification indicator. While maximum power spectrum is affected by surface mean depth, the distribution of the power spectrum over the spatial frequencies is affected by the surface roughness distribution. Therefore the maximum power spectrum value and the distribution of the power spectrum over spatial frequencies maybe considered as surface texture indicators. They are replaced by the area under the power spectrum function. In this research the total energy of the Fourier transform will be tested as a pavement texture indicator. The total power spectrum energy, PSE, can be computed as:

$$PSE = \frac{1}{nm}\sum_{i=1}^{n-1}\sum_{k=1}^{m-1}\left|Z(i,k)\right|^2 \qquad [1]$$

Where

Z(i,k) = The Fourier transform of surface function in discrete units (e.g. pixels).
n,m = The surface dimensions in discrete units.

3. Classifying Pavement Texturing Using PhotoTexture

Texturing concrete pavement is the conventional concrete pavement surface option for controlling tire/pavement noise and friction. Texturing is performed while concrete is still in a plastic state or on hardened concrete pavement. A variety of concrete pavement texturing methods are used to enhance tire/pavement noise and friction (American Concrete Pavement Association, ACPA, 2000 and National Concrete Pavement Technology Center, NCPTC, 2006).

The Applied Research Associates Incorporated, ARA, tested a new paved section at the south extension of the north-south tollway (I-355), east of Joliet – Illinois to study the effect of texturing type on tire/pavement noise and friction (National Cooperative Highway Research Program, NCHRP, 2009). Through an agreement with ARA, University of Manitoba was invited to propose a method for measuring the pavement texture. PhotoTexture was used for the testing which was performed in October 2007 immediately before the road was opened for traffic.

Figure 3 shows the location of the test section which is divided into 160-m segments as shown in Figure 4. Each of these segments represents a different type of Portland cement concrete (PCC) pavement texturing. Table 1 lists the primary and secondary texture used for each segment. For each texturing segment, six locations are measured by using PhotoTexture. For each location, three manual measurements are taken for groove depths, widths and spacing between grooves if existed. The following sections summarize the pavement texturing techniques that are used in the test section accompanied with their corresponding PhotoTexture results.

1.1 Types of Pavement Texturing

1.1.1 Drag Textures

Drag textures, including artificial turf and burlap drag, are performed while the concrete is still in a plastic state to create a shallow texture that typically consisted of 1.5 mm to 3 mm deep grooves. Grooves are constructed either longitudinal or transverse to the centerline of the roadway. The artificial turf drag surface is created by dragging an inverted section of artificial turf from a device that allows control of the time and rate of texturing. The burlap drag surface is created by dragging moistened coarse burlap from a device that allows control of the time and rate of texturing.

Figure 5a shows the turf drag texture of area of 100×100 mm^2. The corresponding map of heights is shown in Figure 5b. A height profile at a diagonal cross-section is shown in Figure 5c.
Drag texturing techniques provide less costly and often quieter pavement (NCPTC 2006). Because these shallower texturing techniques do not produce a pavement with adequate skid resistance, usually these methods are combined with tining techniques.

1.1.2 Tined Textures

Tined textures are performed while concrete is still in a plastic state to provide grooves deeper than drag textures. A tined texture is achieved by a mechanical device equipped with a tining head (metal rake) that moves across the paving surface. The deep macrotexture of the tined textures provides high friction qualities by reducing the water film thickness. Tined texture is performed in transverse, longitudinal or skewed directions. Transverse tining, the most commonly used method, provides undesirable noise emissions depending on tine spacing, depth and width. Longitudinally tined textures are preferred for their low noise emissions. To help diminish the noise's qualities, random tining has been recommended (NCPTC 2006). A longitudinally tined texture is shown in Figure 6 and a randomly tined texture is shown in Figure 7.

1.1.3 Diamond Grinding

Diamond grinding is performed on a hardened concrete pavement by using closely spaced diamond saw blades. Diamond grinding has been used to rehabilitate existing pavements by restoring smoothness. Diamond grooving is performed with the same technique as diamond grinding with a deep groove depth and wide space between grooves. Diamond grinding is shown in Figure 8 and diamond grooving is shown in Figure 9.

1.2 Results

Table 1 summarizes the pavement texturing types used in the test section accompanied with their corresponding PhotoTexture results (map of heights) for textures of area of 100 mm ×100 mm. Tested samples with their corresponding map of heights demonstrate the ability of the system to detect texturing successfully. For example, the manual measurements for Texture label 8-Sample 1 have an average groove depth of 4.25 mm which is equivalent to an image-based depth of 1.95mm (0.41x4.25+0.21) according to linear regression model listed in (El Gendy and Shalaby 2007b). The image-based depth of 1.95mm is close to the values shown Figure 9.
Tested samples with their corresponding PhotoTexture data in addition to manual measurements are listed in El Gendy (2009) while high-speed profiler and CT Meter measurements are list in NCHRP report 634 (NCHRP 2009). Summary of Field measurements from the three devices (PhotoTexture, CT Meter and high-speed profiler) are listed in Table 2.
Figures 10 to 15 show the statistical correlation between PhotoTexture results and other equipments. Figures 10 and 11 show the linear relationship between MPD from PhotoTexture and texture results from high-speed profiler and CT Meter respectively. The correlation coefficients between MPD from PhotoTexture and texture results from high-speed profiler and CT Meter are 0.71 and 0.79 respectively. Linear relationship has been chosen when examine the relationship between PhotoTexture MPD and other devices in order to provide a consistency with all other macrotexture equipments when correlated with sand patch method. While this is not the case when examining other PhotoTexture results, the statistical relationships between PhotoTexture measurements (RMSR and PSE) and measurements from high-speed profiler and CT Meter are chosen to exponential relationships in the form $x=ay^b$ which have the best coefficients of correlations (Figures 12 to 15). The correlation coefficients between RMSR from PhotoTexture and texture results from high-speed profiler and CT Meter are between 0.81 and 0.82 while the correlation coefficients between PSE from PhotoTexture and texture results from high-speed profiler and CT Meter are between 0.79 and 0.84. In general, PhotoTexture has a good correlation with current texture measuring equipments with correlation coefficients equal to or larger than 0.79 except for the linear relationship between MPD from PhotoTexture and MPD from high-speed profiler with 0.71 coefficient of correlation.

4. Conclusion

Texturing concrete pavement is the conventional option for enhancing tire/pavement noise and friction. It is performed while concrete is still in a plastic state or on a hardened concrete pavement (ACPA, 2000; NCPTC, 2006). A new paved section in Illinois has been tested to study the effect of texturing type on tire/pavement noise and friction (El Gendy 2009). PhotoTexture was used for the testing performed in October 2007 immediately before the road was opened for traffic. The comparison of the tested samples with their corresponding map of heights demonstrates the ability of PhotoTexture to detect texturing successfully. Also the analyses of the data obtained from the test measurements to determine the agreement between PhotoTexture and current standardized and widely accepted testing methods for measuring texture demonstrate the ability of PhotoTexture to detect texturing successfully.

5. References

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Table 1 Texture types

Label	Primary Texture	spacing × depth	Secondary Texture
1A	None	MTD 0.4– 0.8 mm	Heavy turf drag
1B	None	MTD 0.6– 1.1 mm	Heavy turf drag
2	Longitudinal tining	19 mm × 3.2 mm	None
3	Longitudinal diamond grind	2.8 mm	None
4	NOT INSTALLED		
5A	Longitudinal tining	19 mm × 3.2 mm	Turf drag
5B	Longitudinal tining	19 mm × 3.2 mm	Heavy turf drag
6	Shallow-longitudinal tining	19 mm × 2.5 mm	Turf drag
7	Longitudinal groove	19 mm × 6.4 mm	Burlap drag
8	Longitudinal groove	19 mm × 6.4 mm	Turf drag
9	Transverse tining	12 mm × 3.2 mm	Burlap drag
10	Random-transverse tining	random[1] × 3.2 mm	Burlap drag
11	Transverse tining	25.4 mm × 3.2 mm	Burlap drag
12	Skewed random tining	random[2] × 3.2 mm	Turf drag
13	Grinding/ Groove		—
14	Grinding/ Groove		—

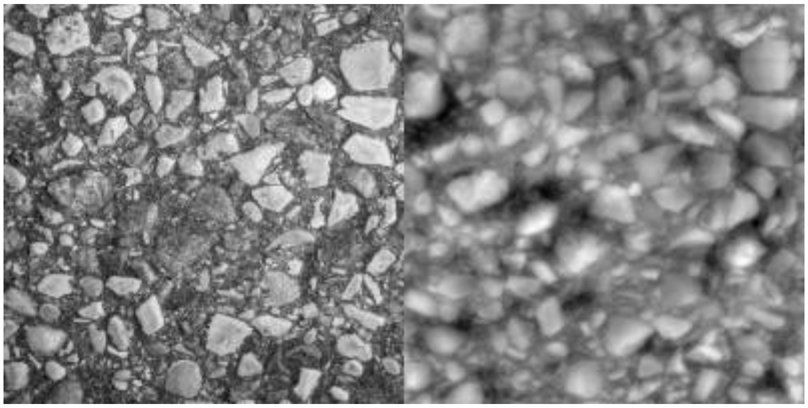
1 Spacing varies from 10 to 21 mm, with average spacing of 12.7 mm.
2 Spacing varies from 17 to 54 mm, with average spacing of 37.1 mm.

Table 2 Summary of Field measurements

	High-speed Profiler		CT Meter		PhotoTexture		
Section No.	MPD [mm]	EMTD [mm]	MPD [mm]	MTD [mm]	MPD [mm]	RMSR [mm]	PSE [mm2 per cycle per mm]
1a	0.4	0.52	N/A	N/A	0.50	0.02	1.36E+09
1b	0.32	0.46	0.28	0.36	0.41	0.01	8.97E+08
2	0.71	0.75	0.6	0.66	1.00	0.18	1.23E+10
3	0.35	0.48	0.65	0.71	0.99	0.04	2.7E+09
5a	0.55	0.65	0.51	0.58	0.93	0.14	9.79E+09
5b	1.22	1.2	1.02	1.06	1.38	0.24	1.72E+10
6	0.54	0.63	0.49	0.56	0.52	0.04	2.89E+09
7	1.04	1.05	1.02	1.06	1.86	0.81	5.25E+10
8	0.98	0.98	1.22	1.25	1.38	0.53	3.38E+10
9	0.48	0.59	0.48	0.55	0.55	0.04	3.04E+09
10	0.62	0.7	0.62	0.68	0.78	0.08	5.48E+09
11	0.5	0.6	0.44	0.51	0.52	0.04	2.85E+09
12	0.64	0.71	0.58	0.65	0.80	0.08	7.55E+09

a) PhotoTexture Equipment b) Scale template

Figure 1 Measuring surface three-dimensional heights using PhotoTexture



a) Pavement surface b) Map of heights

Figure 2 Three-dimensional surface recovery of pavement surface

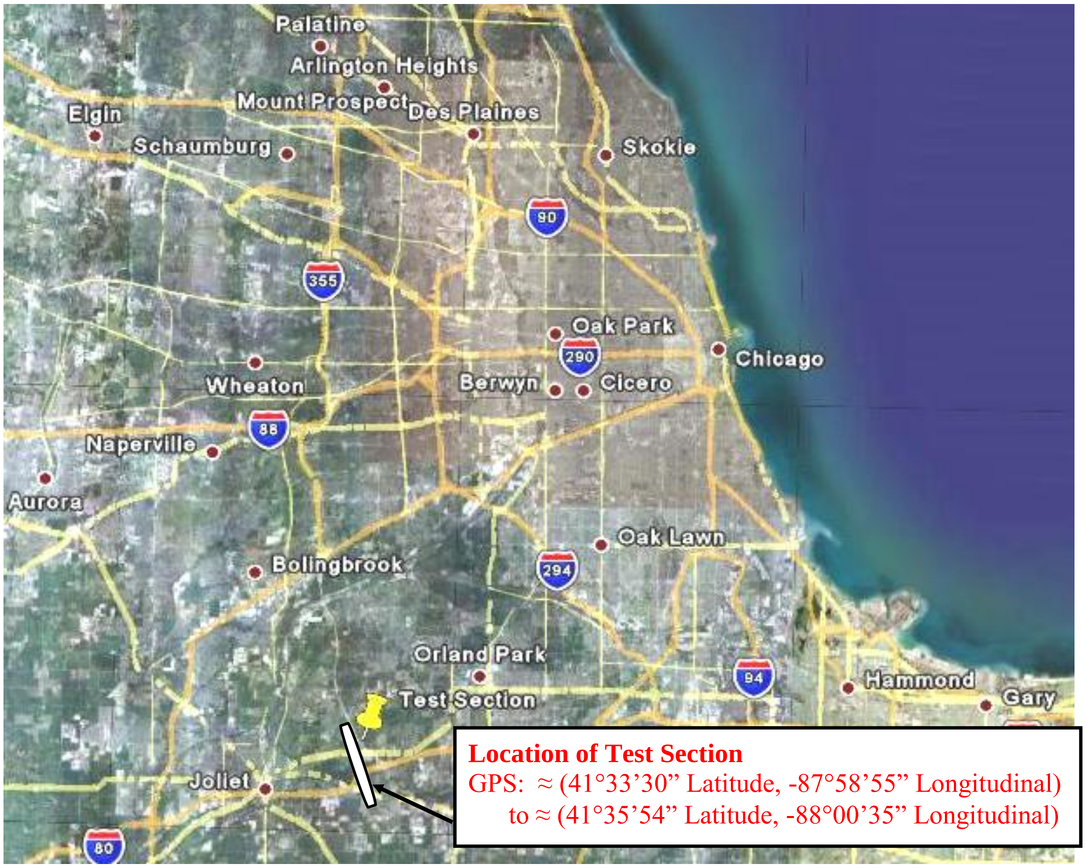


Figure 3 Location of texture test sections

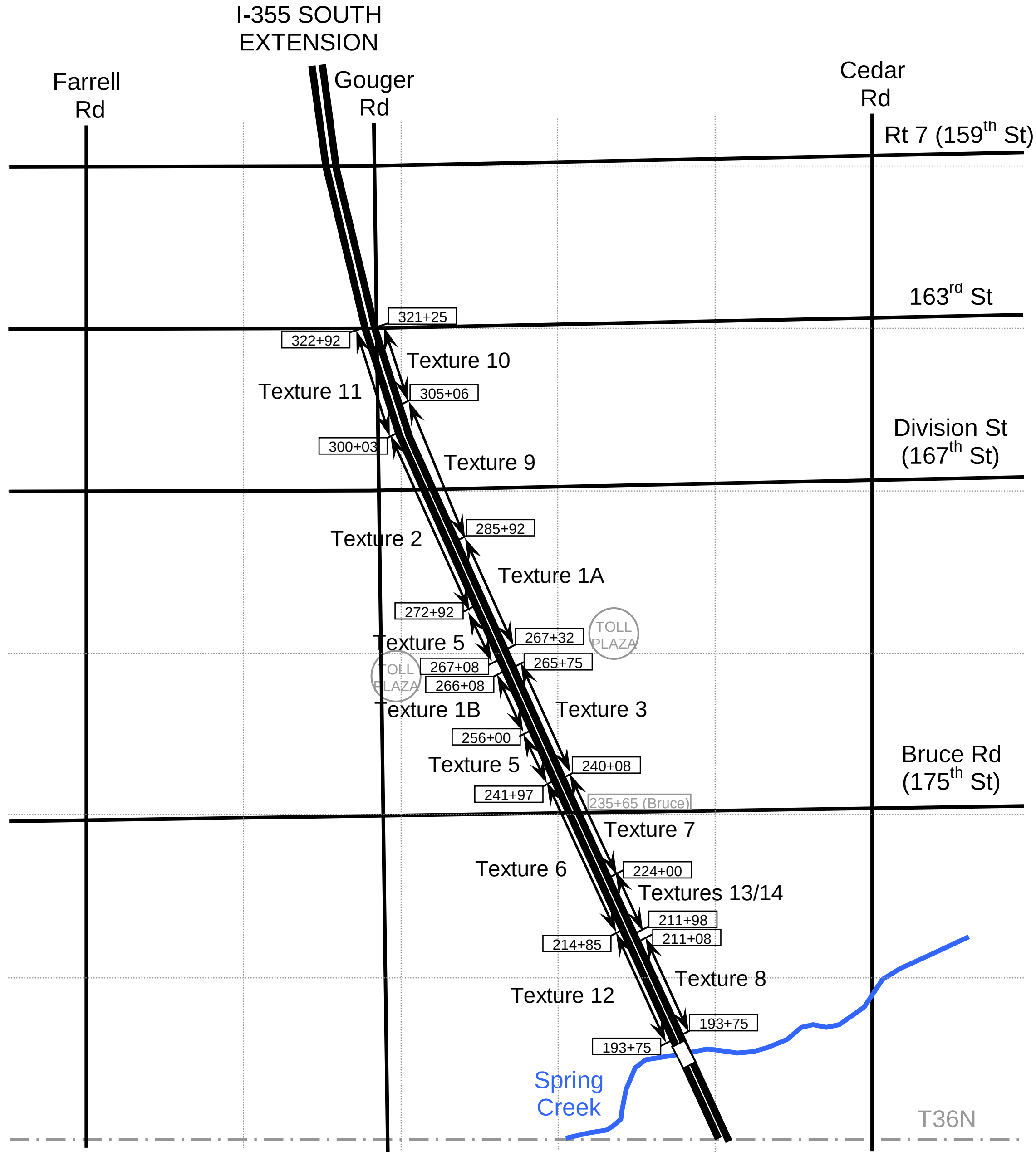
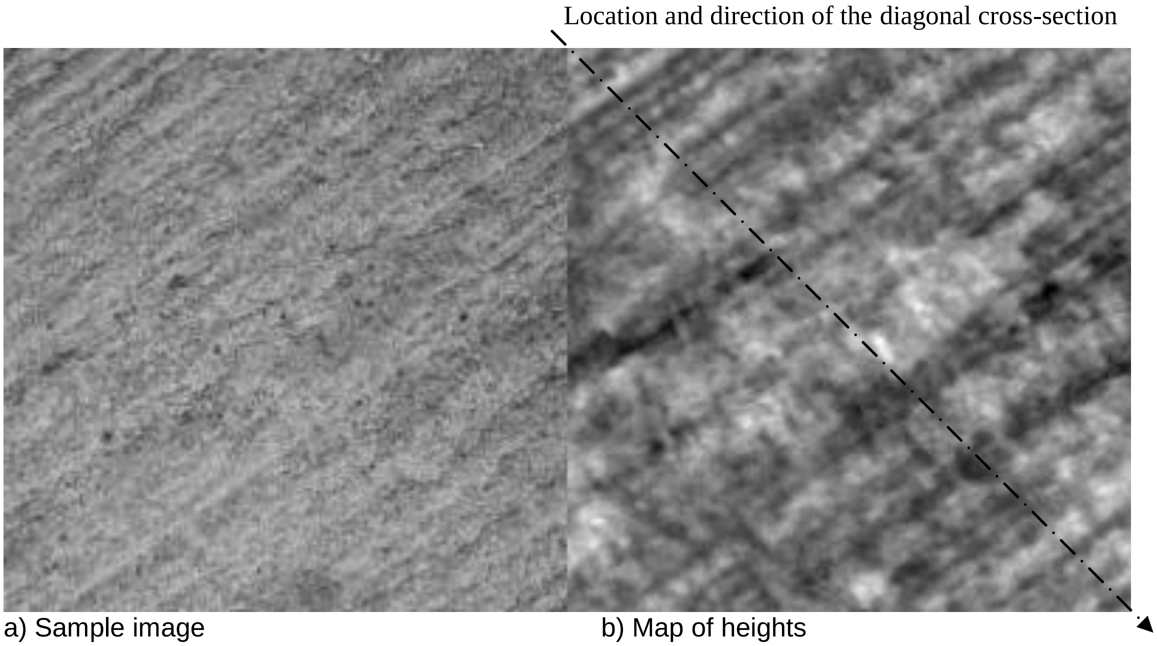
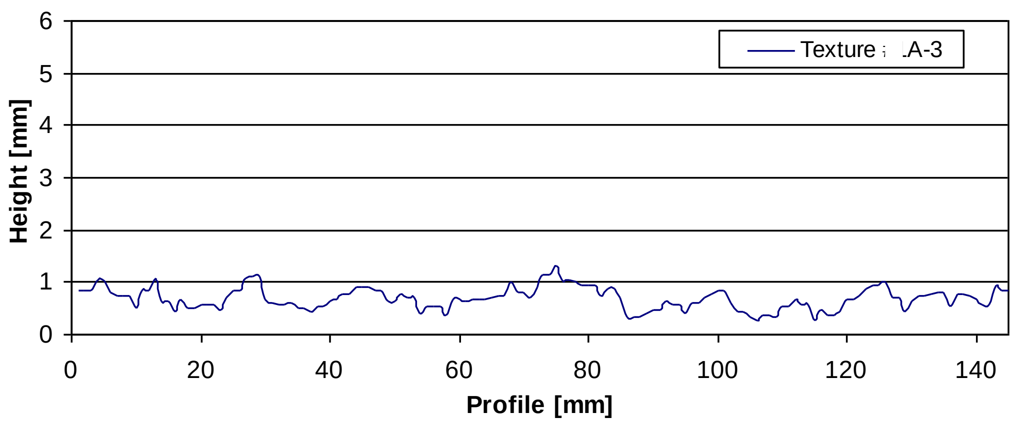


Figure 4 Texturing type (label) on south extension of north-south tollway

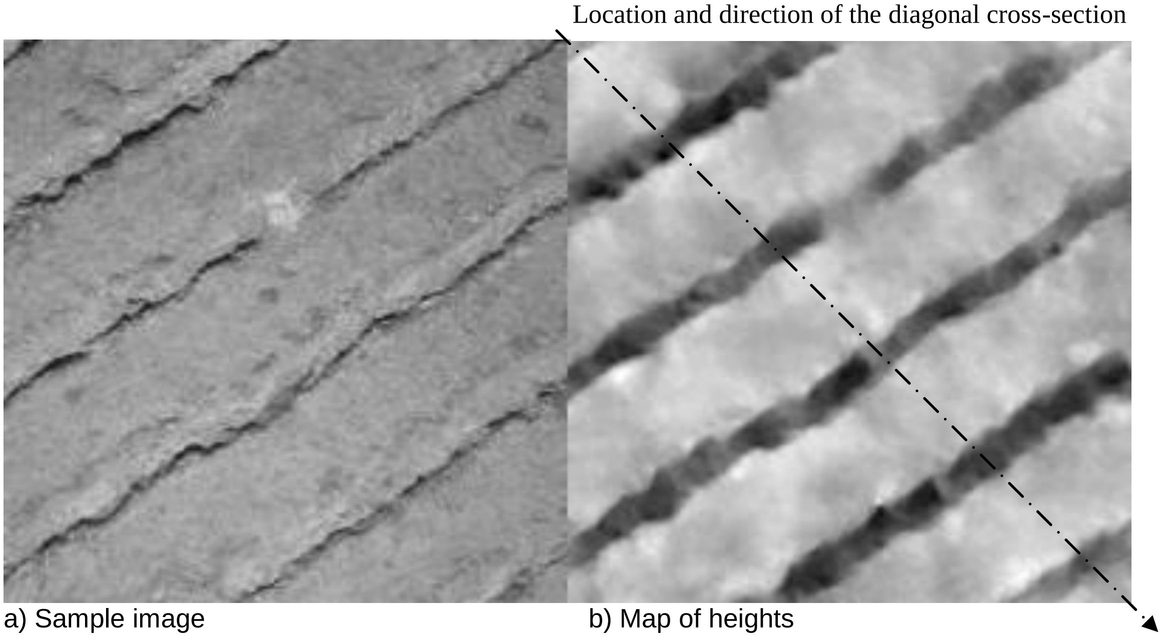


a) Sample image b) Map of heights

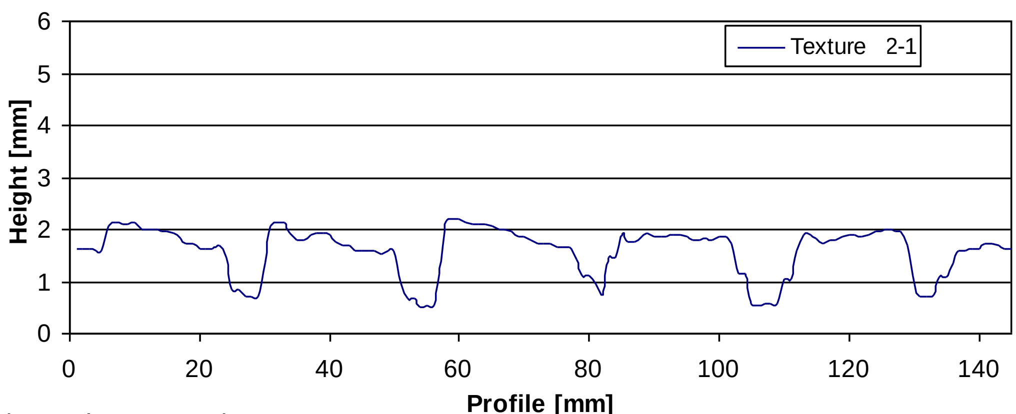


c) Diagonal cross-section

Figure 5 Turf drag texture (Area of 100×100 mm^2)

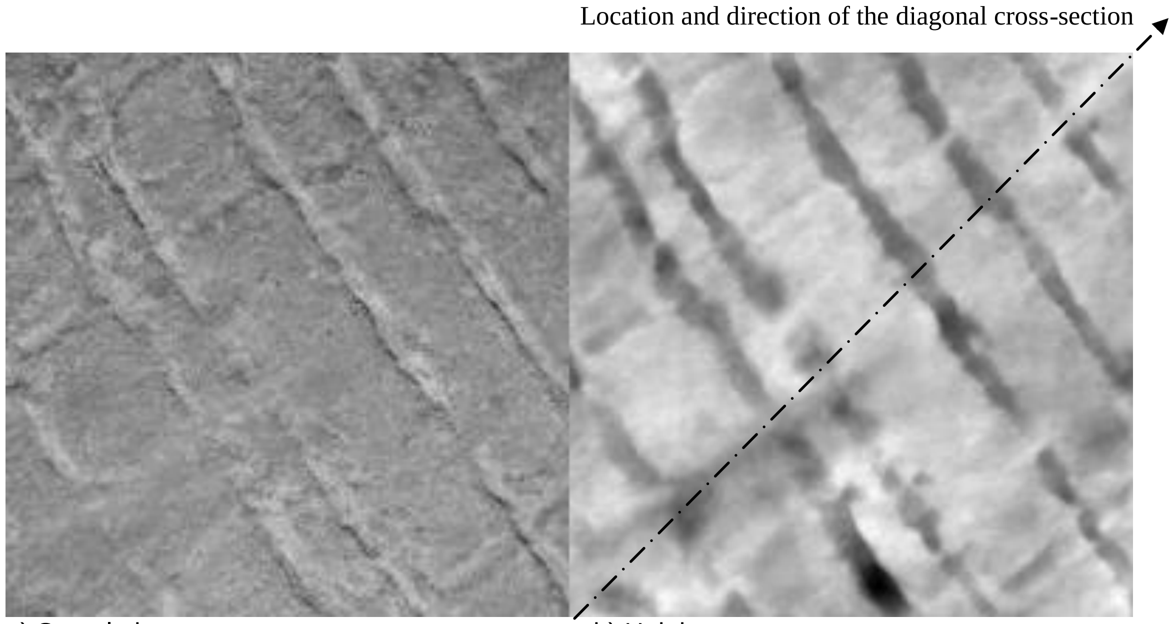


a) Sample image b) Map of heights



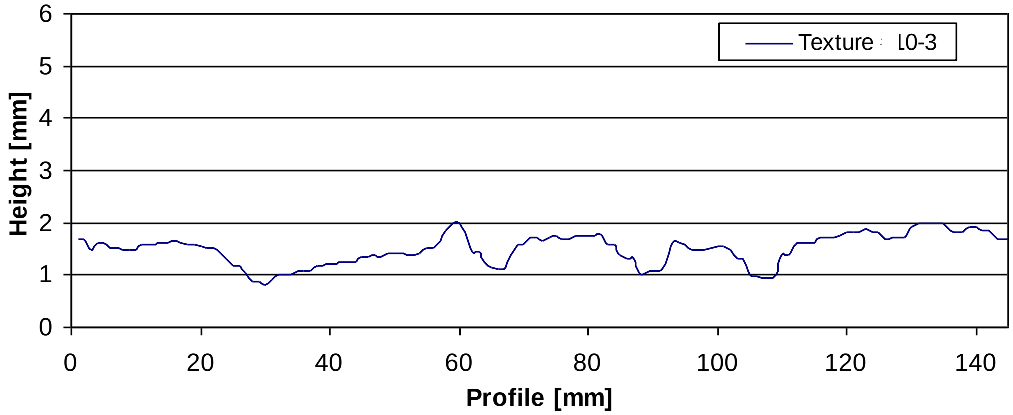
c) Diagonal cross-section

Figure 6 Longitudinal tining (Area of 100×100 mm^2)



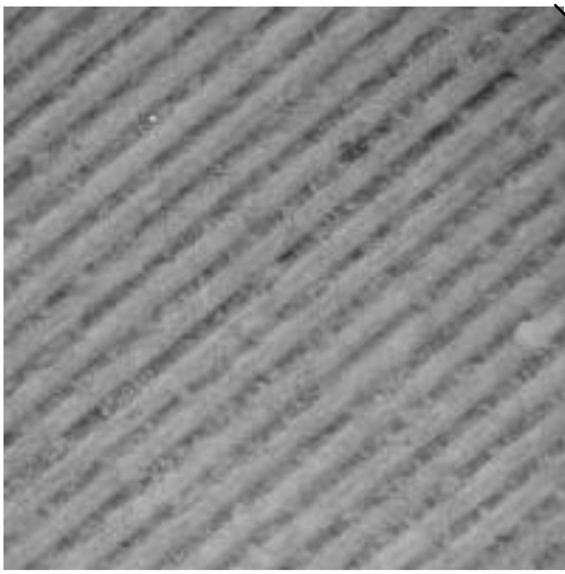
a) Sample image

b) Heights map

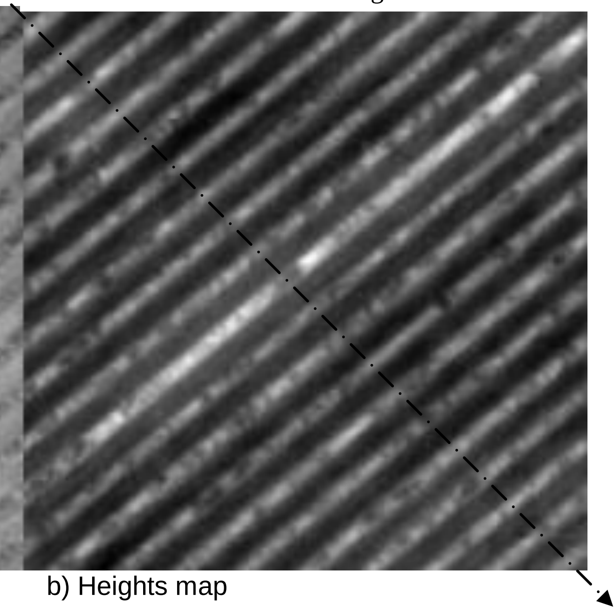


c) Diagonal cross-section

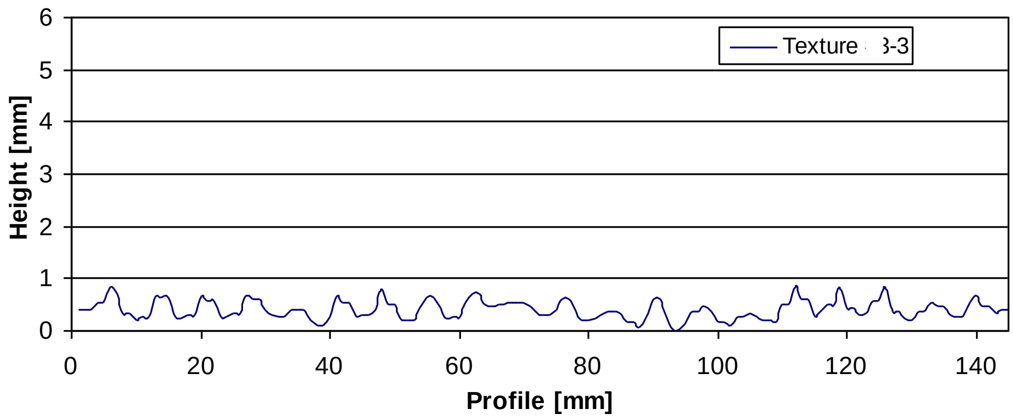
Figure 7 Random tining (Area of 100×100 mm^2)



a) Sample image

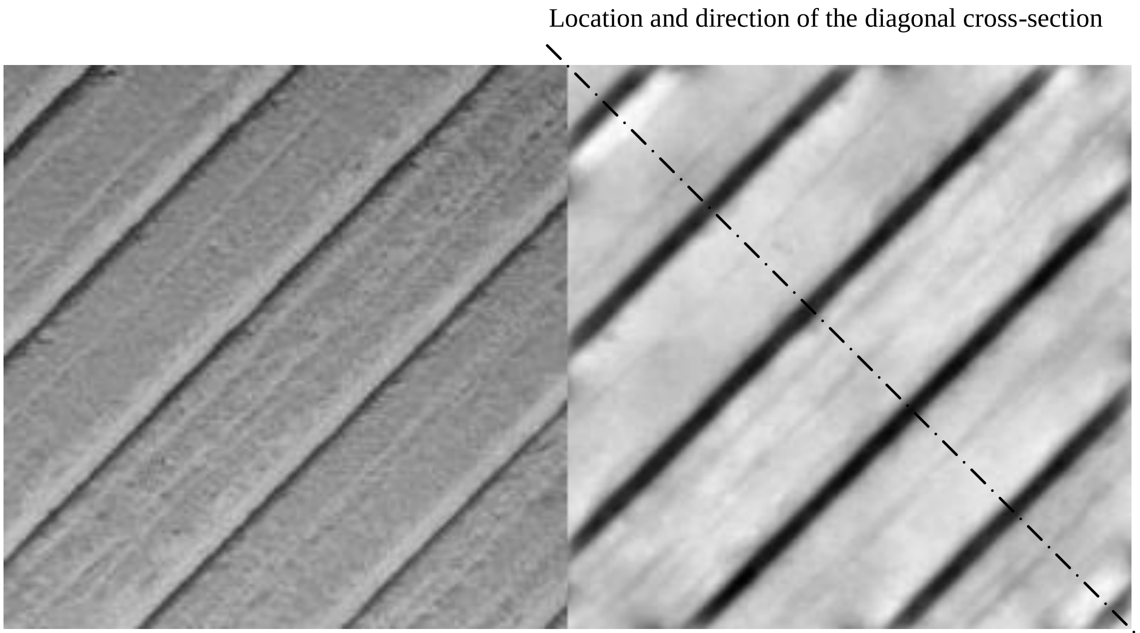


b) Heights map



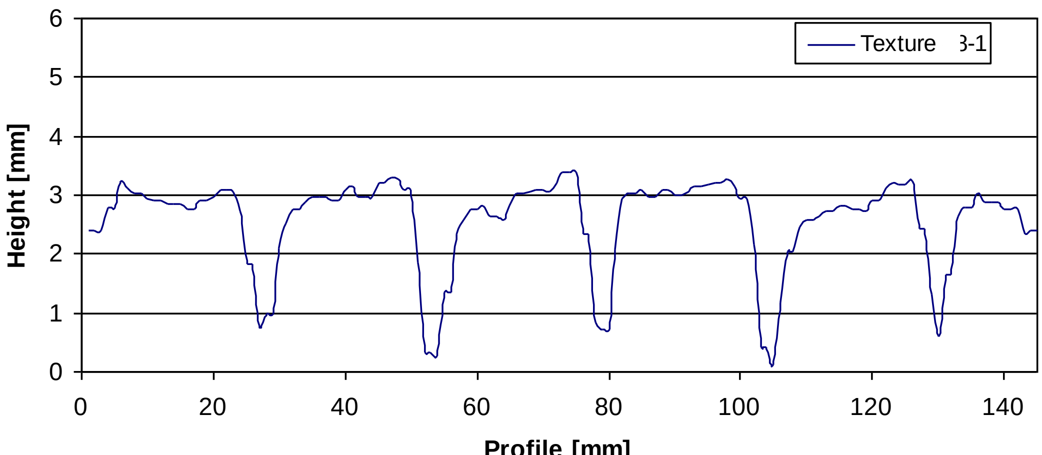
c) Diagonal cross-section

Figure 8 Diamond grinding (Area of 100×100 mm^2)



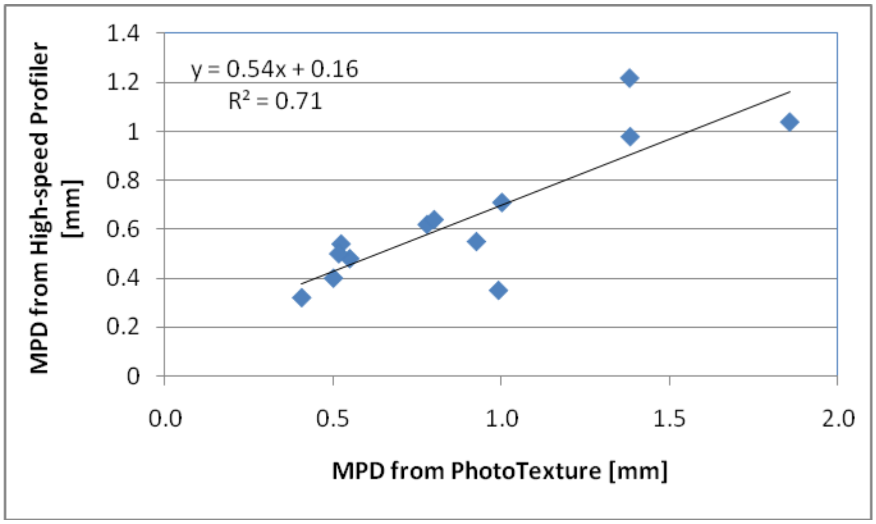
a) Sample image

b) Heights map

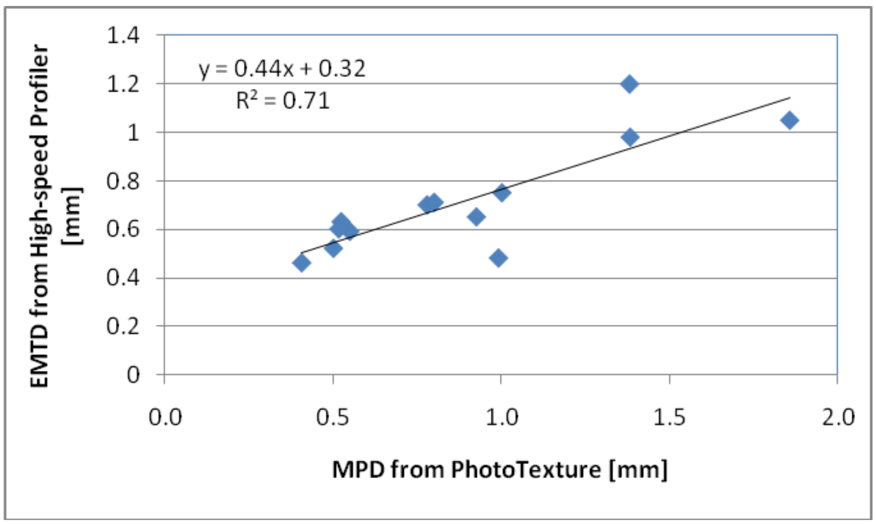


c) Diagonal cross-section

Figure 9 Diamond groove (Area of 100×100 mm^2)

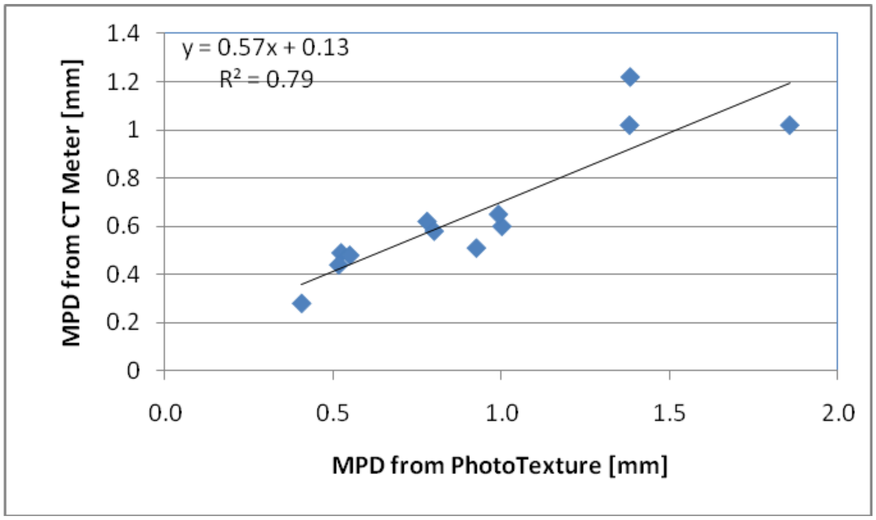


a) MPD from High-speed Profiler

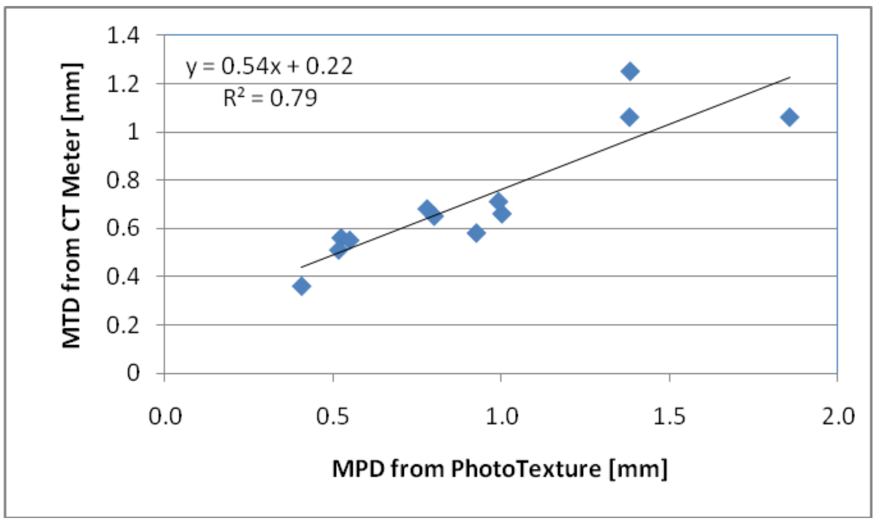


b) EMTD from High-speed Profiler

Figure 10 MPD from PhotoTexture versus high-speed profiler measurements

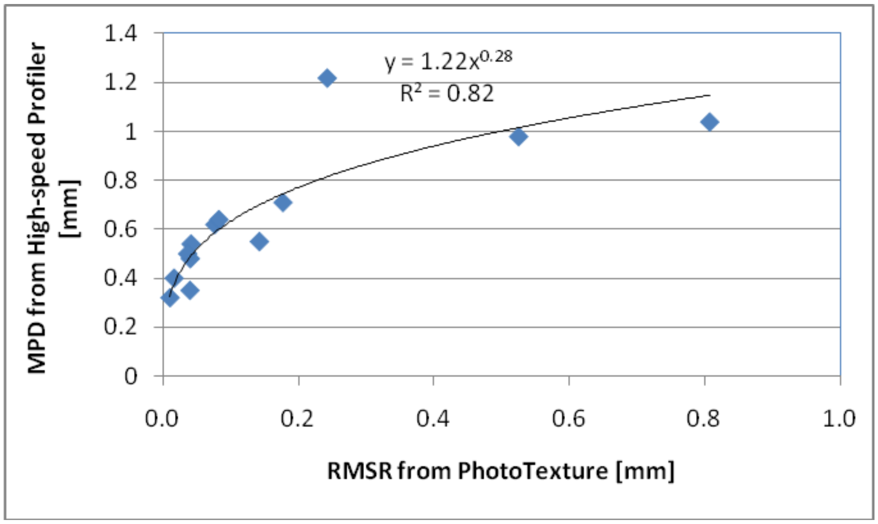


a) MPD from CT Meter

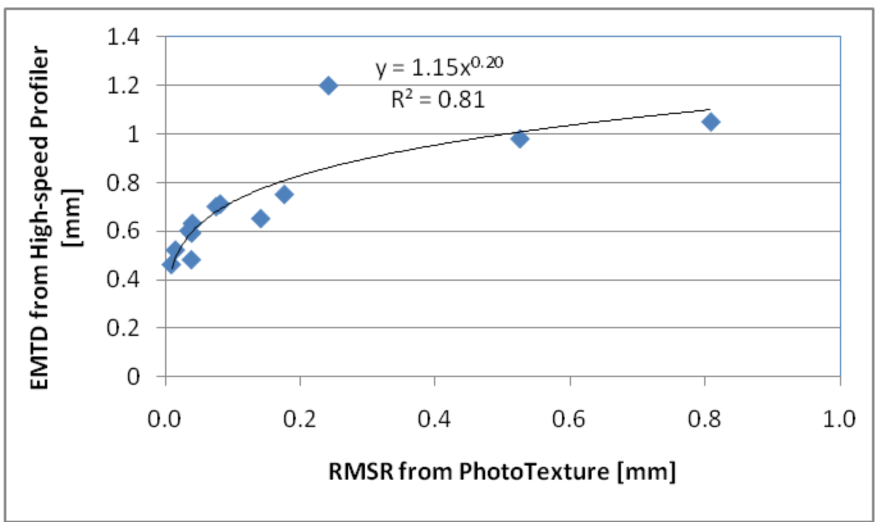


b) MTD from CT Meter

Figure 11 MPD from PhotoTexture versus high-speed profiler measurements

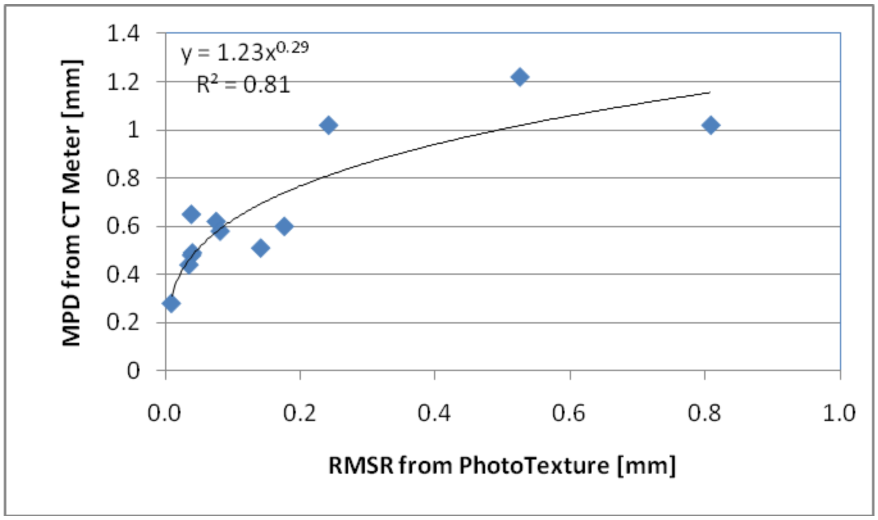


a) MPD from High-speed Profiler

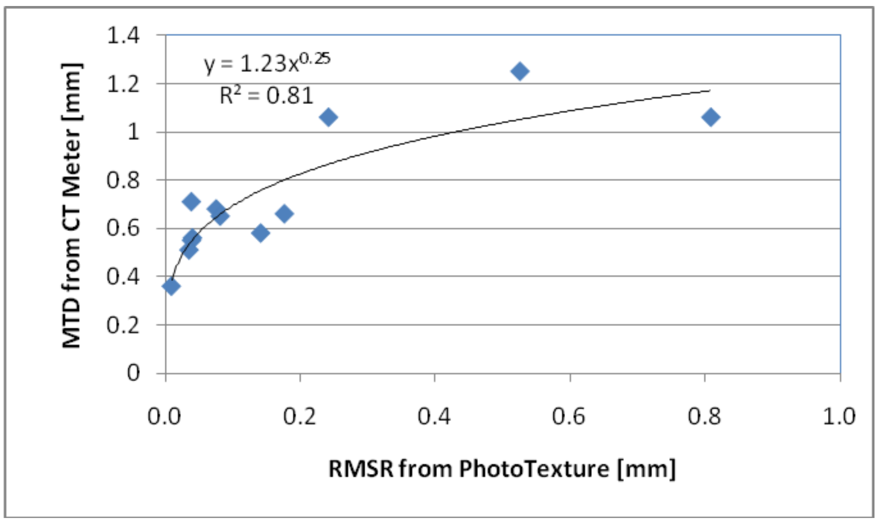


b) EMTD from High-speed Profiler

Figure 12 RMSR from PhotoTexture versus high-speed profiler measurements

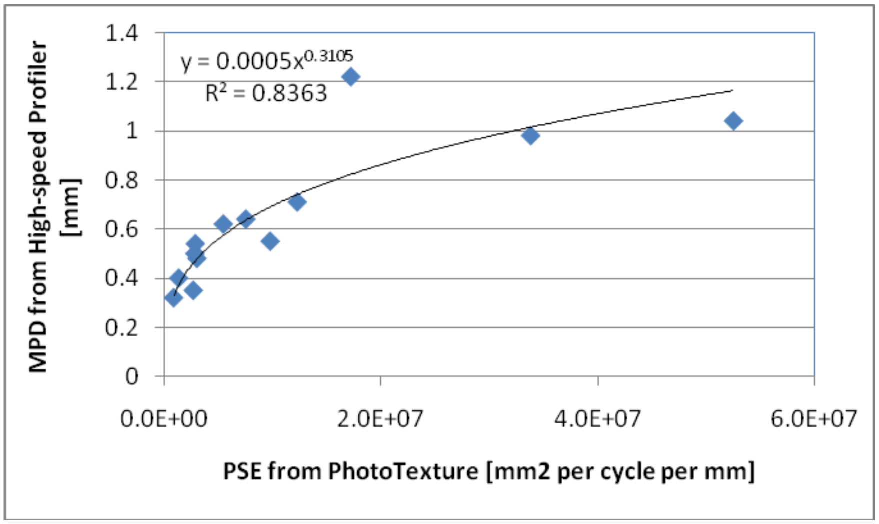


a) MPD from CT Meter

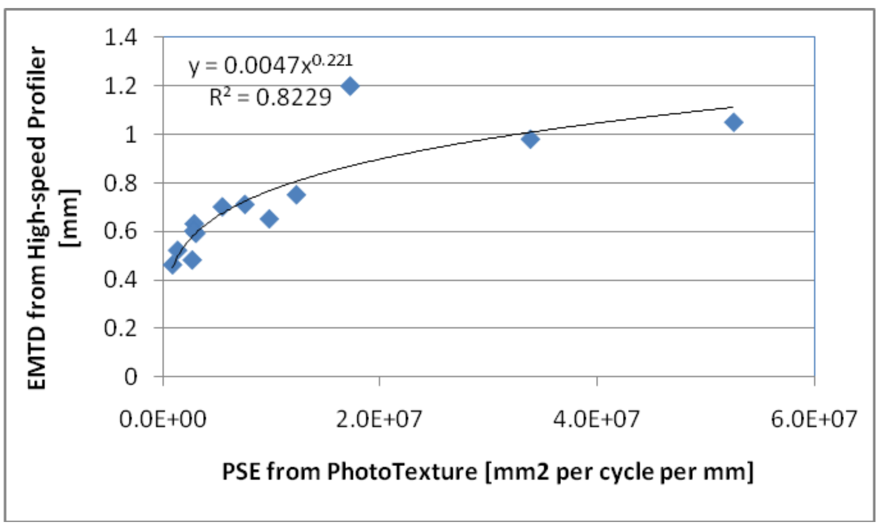


b) MTD from CT Meter

Figure 13 RMSR from PhotoTexture versus high-speed profiler measurements

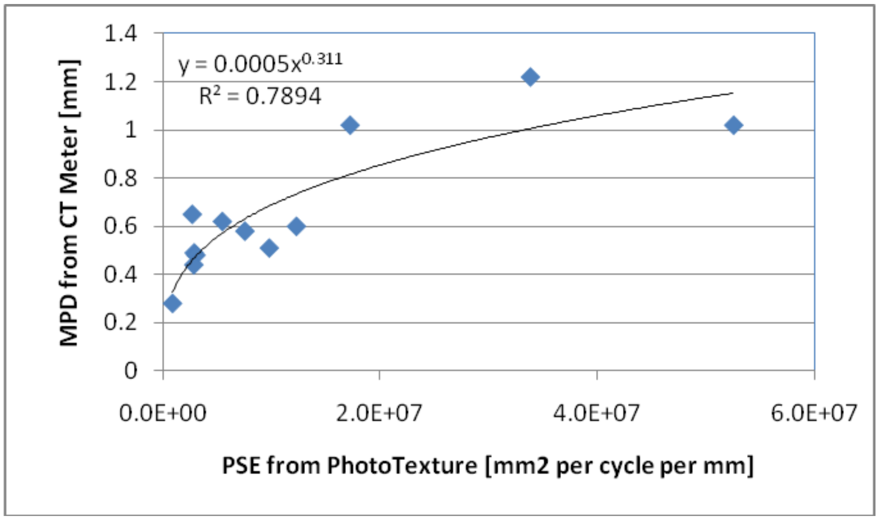


a) MPD from High-speed Profiler

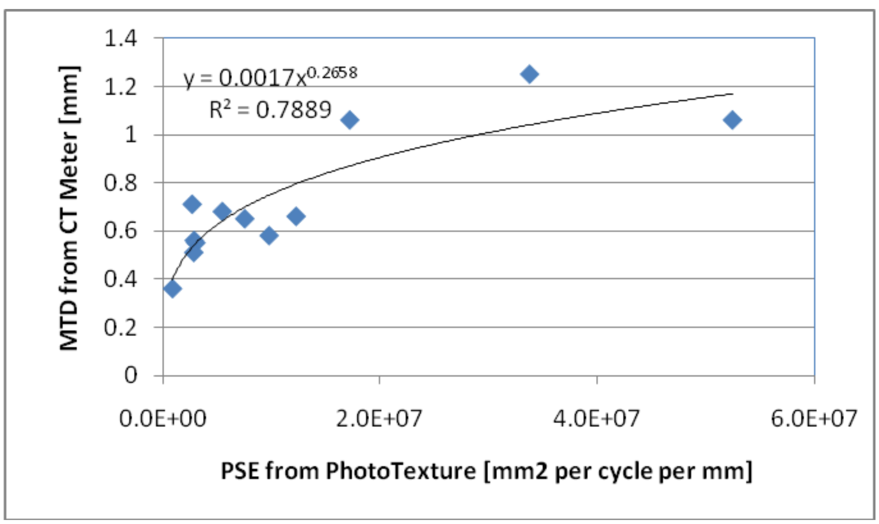


b) EMTD from High-speed Profiler

Figure 14 PSE from PhotoTexture versus high-speed profiler measurements



a) MPD from CT Meter



b) MTD from CT Meter

Figure 15 PSE from PhotoTexture versus high-speed profiler measurements