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The authors: Constance MOREL[1]
Maxence BIGERELLE[2]

Mechanically Nanostructured Surfaces Analyzed By A 3D Roughness-Based Method

W Abrasives®

[1]Winoa, 528 avenue de Savoie BP 3, 38570 Le
Cheylas, France

[2]LAMIIH, UMR CNRS 8201, Université de
Valenciennes, France

E-mail: constance.morel@winoagroup.com

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Introduction

It is widely known that projection-based processes such as blasting, shot-peening… tend to roughen the treated surfaces. It may be the very purpose, like in the case of grit blasting, which is a surface preparation technique aiming at creating a specific roughness to ensure good adhesion of the painting or other coating to be applied. In some cases however, the rough surface finish is rather an undesirable side effect.

NanoPeening® is a projection-based, surface nanostructure technology process developed and patented by Winoa [1-2]. The technique leads to such a refining of the top metallic grains that the surface becomes nanostructured on a depth ranging from 30 to 70µm and the underlayer is still much finer than the bulk down to 200 to 250µm. This change results in various properties such as strong hardness, enhanced surface reactivity… which in turn find applications for instance in wear protection. However, the surface finish generated by the NanoPeening® process can be a brake or an obstacle to its development and its implementation on production lines. This is the reason why investigations are running on techniques to reduce the created roughness. On the other hand, some interesting information could be drawn from this surface state: to a certain extent, it might for instance reflect the process performance (thickness of the nanostructured layer, surface hardness...).

The question was addressed using a method developed within a laboratory of the University of Valenciennes (France) called LAMIIH (French acronym for Laboratory of Industrial and Human Automation Control, Mechanical Engineering and Computer Science). The method relies on a mathematical program that points out, for a given system, relevant 3D roughness parameter(s). These are the ones to be followed up to highlight possible relationships between the surface state and the transformations induced by the NanoPeening® process. For the present study, the method was used to initiate a model able to link the final surface state to the underlying nanostructure.

Experimental procedure

Two sets of metallic surfaces were provided:
- 10 of steel grade A,
- 10 of steel grade B

Within each series, five conditions of NanoPeening® (each one applied to 2 surfaces) were processed in order to get 5 different intensities, resulting in a total of 10 settings. The nomenclature (1 a/b → 10 a/b) was established to facilitate the identification of relationships between surface finish and treatment intensity. The difference in material between the two series had not been communicated to the laboratory.

The 3D roughness of the treated surfaces was then analyzed with a white light interferometer (NewView 7300, from Zygo) equipped with optical objectives from Mirau.

Its very high resolution (0.1 nm in height, 50 nm in lateral) allows for a spatial elementary sampling as fine as 351*263 µm (on the basis of the 0.55µm pixels of the camera).

The effective inspected areas of 4500*4500 µm were then built up by stitching, assembling 16 x 24 = 384 elementary samples with an overlap of 20% (Figure 1)

To insure a robust statistics, for each surface 20 areas - randomly taken on it - were measured. In other words, the total number of single measurements required by each metallic surface amounted to 20 x 384 = 7680.

Mountain software (version 7) was used for data processing.

The LAMIIH uses a procedure that involves the measurement of 3D parameters, then their computing is done by a program internally developed to identify a "relevant factor".

According to the procedure, as many as 56 3D parameters are considered: 30 defined by ISO 25178, 18 by EUR 15178N, 7 by ISO 12781 (related to surface flatness) and 1 by ASME B46.1. They are measured following a multiscale approach, i.e. using various values of cut-off (ranging from 45 to 4000 µm - Figure 2) and applying various filters (high-pass/low-pass/band-pass - Figure 3). This makes it possible to get different kinds of information. For instance, a low-pass filter only returns

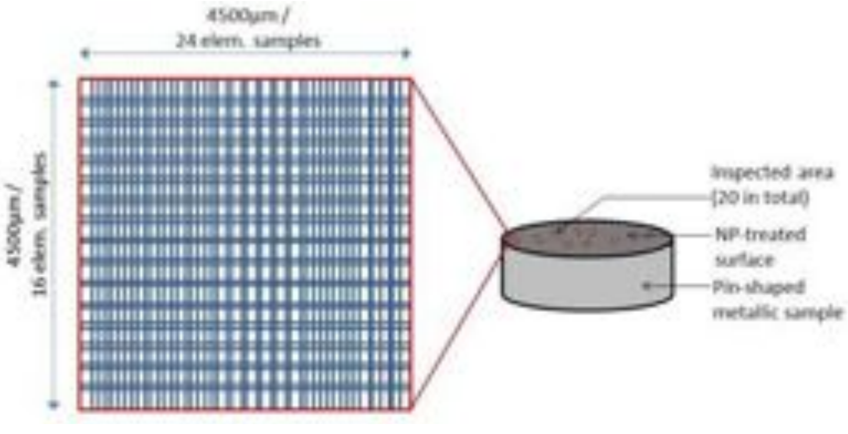

Figure 1: schematic illustration of the inspected surface reconstitution by stitching (384 overlapping elementary samples)

the information of low frequency (but still in the domain of roughness, without falling in the range of waviness). The filtering is performed by Fourier Transformation using a Gaussian filter. The multiscale decomposition of the surface is particularly appropriate to analyze machining processes [3] and the multiscale topography lends itself very well to the characterization of sandblasted surfaces [4].

Finally, the mathematical program is run to identify the most relevant parameter to be followed in order to study a given system, i.e. the one showing the best correlation with the property of interest.

Results and discussion

In the present case, the program highlighted the parameter S_k, low-pass filtered, as the most representative of the NanoPeening® intensity level. S_k characterizes the linear portion of the Abbott-Firestone curve as illustrated in Figure 4.

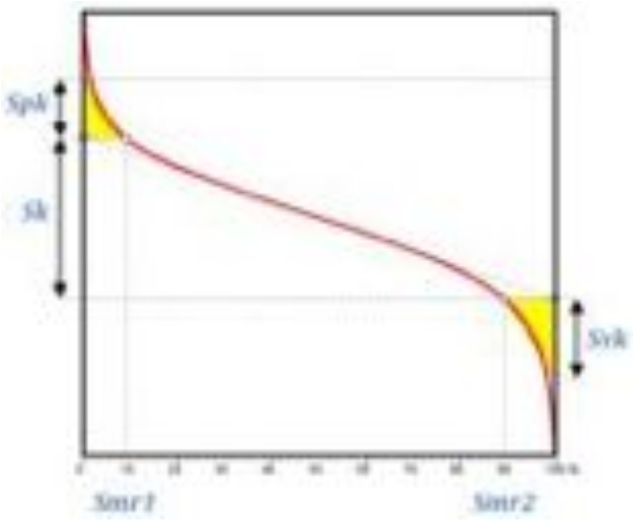

Figure 4: meaning of S_k parameter on the Abbott-Firestone curve (or bearing area curve)

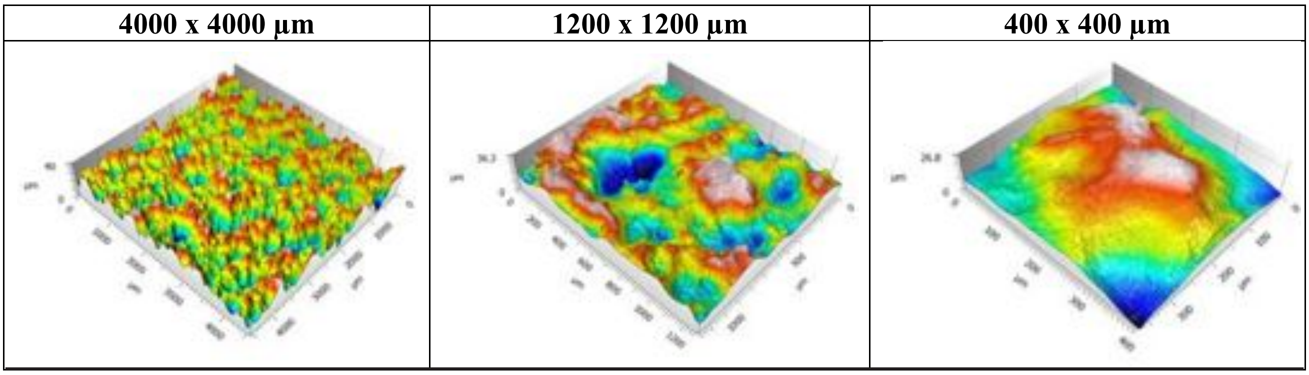

Figure 2: High Definition measurements of surface 2b topography observed at different zoom levels with white-light interferometer

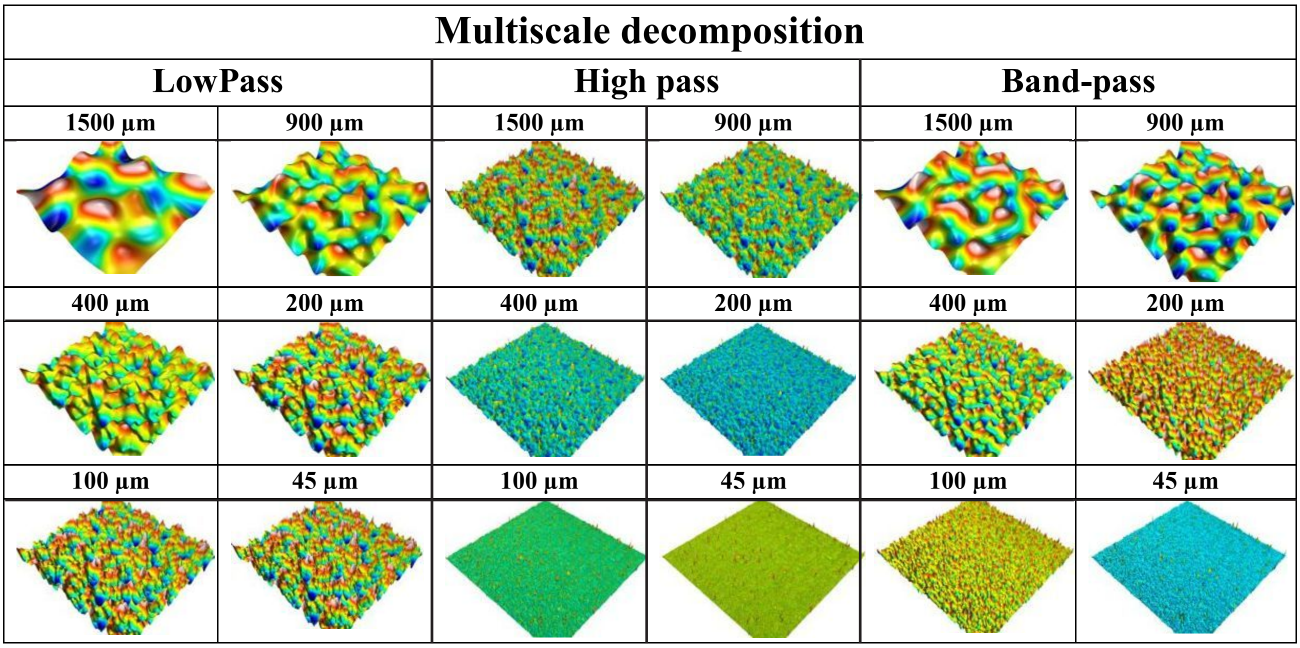

Figure 3: evidence of the filter importance for the original surface shown in Figure 1 filtered at low-pass/high-pass/band-pass

As can be seen in the graph of Figure 4, the low-pass filtered S_k parameter distinguishes the two populations of samples and perfectly reflects the increasing treatment intensity within each group (with stabilization on the last 2 points).

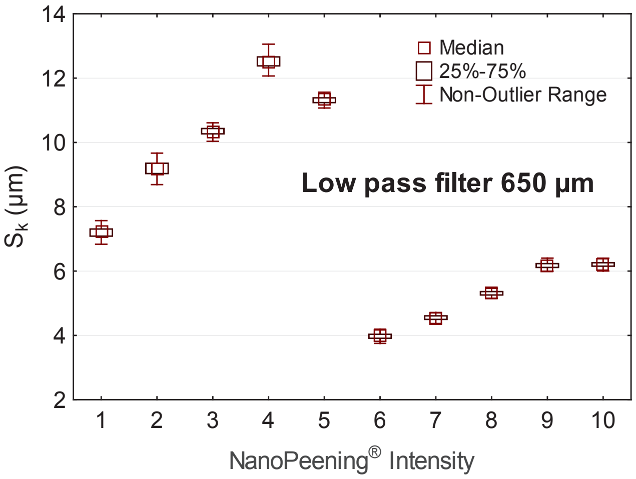

Figure 4 (graph): low-pass filtered S_k parameter for the two sets of surfaces

This first result showed that it is possible to differentiate the two series, that is to say, the presence of 2 materials. The parameter that stresses out the most distinction is then sought. This time the S_{ha}, low-pass filtered, came out. It is associated with the so-called "motifs segmentation method" originally developed for 2D roughness then adapted to 3D.

Only accessible through the Mountain software [5], this method relies on a highly complex algorithm, but can be basically described as an approach that compares the surface to a landscape: when the valleys are filled with water, the streams end up connecting, forming a network; it makes up a patchwork of patterns or cells called "motifs". The mountains (motifs having a high altitude) are referred to as *hills* while those at a low altitude (the valleys) as *dales*.

Graphically, the method results in mappings such as those shown in Figures 5 and 6. Then, statistics and analyses can

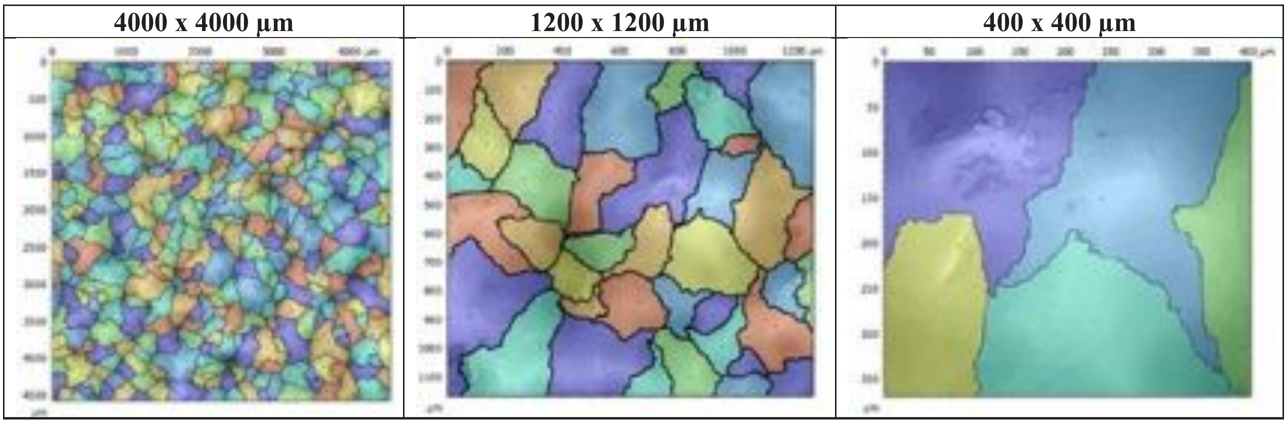

Figure 5: the Wolf Pruning decompositions of the surface 2b (only three scales are displayed)

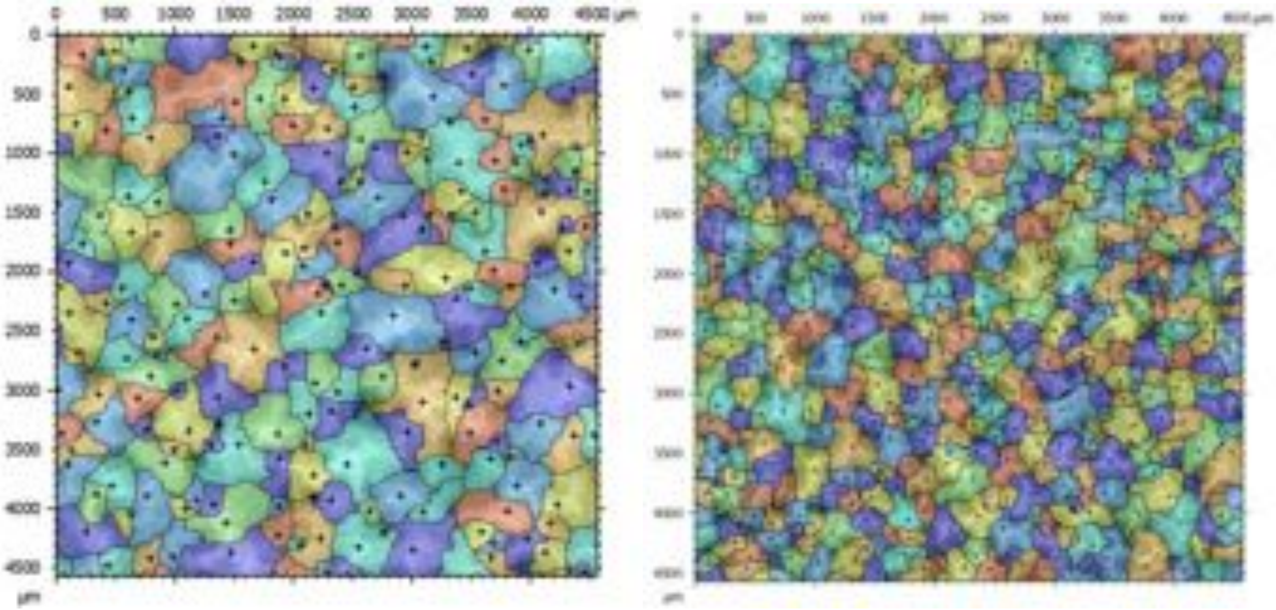

Figure 6: illustration of the motifs method for one sample from series 1 (left) and one from series 2 (right). The colors have no meaning: they only serve to better observe the patterns

be done: for instance it is possible to count the number of patterns within a given surface area which allows for the deduction of the motifs mean area. It is also possible to measure the mean area of the hills and dales: the corresponding parameters are S_{ha} and S_{da} respectively. Alike for the topographies, the multi-scale approach (called in this case "Wolf Pruning decomposition") with the different filters was adopted (Figure 5). In this study, the method clearly distinguishes the two series: the first one (grade A) has generally much larger motifs than the second one (grade B), as can be clearly observed in Figure 6. Nevertheless, the best differentiation is given by the S_{ha} (mean area of the hills), low-pass filtered. Some of the mentioned parameters are displayed in Table 1.

Motifs Parameters	Series 1 (samples 1 to 5)	Series 2 (samples 6 to 10)
Number of motifs	231	474
Spd - Peak density (/mm²)	11.4	23.4
Mean height (µm)	5.06	4.42
Mean area (µm²)	90523	44116

Table 1: Some results obtained by applying the motifs method to the samples shown in Figure 4

However, another kind of parameter accessed by the motifs method, the density of furrows, seems on the contrary not to be influenced by the steel grade. This parameter, low-pass filtered, exhibits a fairly good correlation with the intensity of the NanoPeening® and exhibits a smooth continuum between the two series. It somehow makes sense because the pleats are due to the plastic deformation caused by the process in the material, which are directly linked to the material's mechanical properties.

The motifs method [6] approach shows that the parameters related to the peaks' height such as S_a, S_z... are not the only ones to consider; the patterns also provide interesting information.

In order to further improve the fit and find a model that would raise no distinction between the two sets, a study was conducted involving no longer only one but two parameters. After testing all combinations, the best match was found with the peak density – S_{pd} – low-pass filtered at 2 different levels. With a correlation coefficient of 0.99 (Figure 7), this relationship could pave the way to the elaboration of a predictive model of the nanostructured thickness on the basis of the final surface state.

Conclusion

Samples treated by NanoPeening® were characterized by 3D roughness using a mathematical program to analyze the measured parameters. It confirmed that this approach is particularly well adapted to the study of blasted surfaces. So, as complex as it is, the motifs method can provide very interesting information. The association of two parameters (or one parameter addressed with different filters) could lead to a model able to give data on the properties of the underlying material, resulting from the nanostructural process.

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[5] http://www.digital-surf.com/fr/guideareal featureparameters.html

[6] ISO 25178-2:2012 Geometrical product specifications (GPS) - Surface texture: Areal - Part 2: Terms, definitions and surface texture parameters

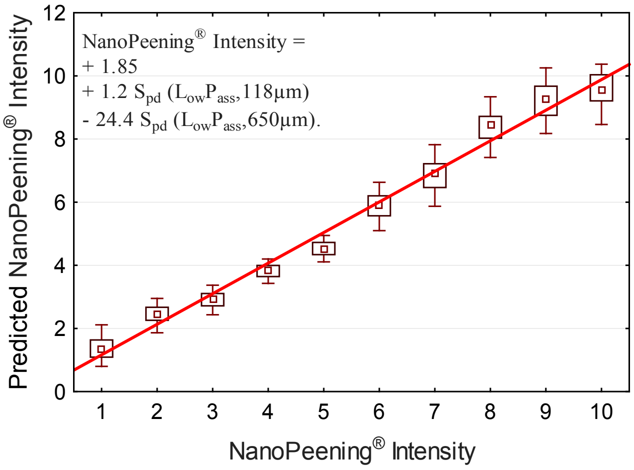

Figure 7: fit between the peak-density based model and the process growing intensity

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Maxence BIGERELLE[2]

[1]Winoa, 528 avenue de Savoie BP 3, 38570 Le Cheylas, France

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