Functional correlation surface texture / grip of a deposit : case of NiP

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Abstract. This work studies a functional correlation between different texture parameters and the adherence of NiP coating on a metal substrate. Multiple surfaces with different milling feed rate and coated with NiP went through a pull-off adhesion test. This study determined through texture analysis functional correlation between characterization of surface topographies and the strength measured during the test. In order to study if a multi-scale approach improve the correlation, a "conventional" method based on ISO 25178 procedure and a multi-scale method based on wavelet filtering are compared,

Keywords: Surface Metrology ; Multiscale ; wavelet ; Surface analysis ; coating adhesion, ISO 4287-4288; ISO 25178

1 Introduction

With the development of new techniques of machining, the surfaces resulting from those process have characteristics different from conventional machining such as milling. In order to develop conventional correlation between specific function and characteristics, analysis methods had to take into account these changes. The multi-scale approach is an approach that results from the progress made in surface metrology. Engineered surfaces with characteristics that differs from conventional machining or more complex geometry are reasons for these changes [1]. In this study the first problematic was to find functional correlations between the pull-off adhesion test stress and different parameters used for the analysis of surface's topography. We hope to observe a good correlation between stress and some texture parameters and we wish to optimize this correlation using a multi-scale method. We will first present the analysis methods used (conventional and multi-scale) and then focus on the results obtained.

2 Methods of analysis

A surface can be characterized through linear analysis or surface analysis. With the development of new measuring devices such as non-contact profilometers or matrix devices, we have access to more ways to characterize a surface. Linear analysis is still widely used in the industry. However, surface analyses are increasingly used because they can characterize surfaces more accurately.
In this study we focus on areal measurement and analysis but linear analysis is presented for comparison. Measurements are made using an Alicona InfiniteFocus microscope

2.1 Linear Analysis ISO 4287/4288

Linear surface analysis is standardized by ISO 4287 GPS [2] and ISO 4288 GPS [3]. The profile is retrieved by:

- suppressing the form profile by associating with a nominal form (circle or polynomial);
- suppressing the microroughness by using a high pass filter;
- separating the roughness (high pass filter) and waviness (low pass filter).

The procedure to obtain roughness and waviness, is defined by the standards and is illustrated Figure 1.a

2.2 Surface Analyses Based on ISO 25178 Standard

Surfaces are 3-dimensional, it seems logical to study them in 3 dimensions. With surface analyses one can think of a better functional correlation. New machining processes result in surfaces that may be non-isotropic thus the need for new analytical tools.

Figure 1.b represents the steps to analyze a surface based on ISO 25178 [4]. The procedure and values of the filters chosen for each sample are not detailed here

2.3 Multiscale Analysis

Surface topographies are influenced by manufacturing processes and are included in different size of physical features. The multiscale consideration comes from how these topographies seems different depending on the scale of observation. “Scale” can have various meanings in metrological studies. In this paper, we refer to it as a segment of wavelengths or spatial frequencies. Brown gives a very good overview Multiscale analyses and characterizations of surface topographies [5]

In this study we want to see if the use of a multi-scale method can improve the correlation between the pull-off stress and some texture parameters, or even find new parameters that do not correlate with a conventional approach but correlate with a multi-scale method.

There are multiple ways to execute a multiscale analysis. The surface can be decomposed in scales with different methods such as wavelet or sliding bandpass filtering.

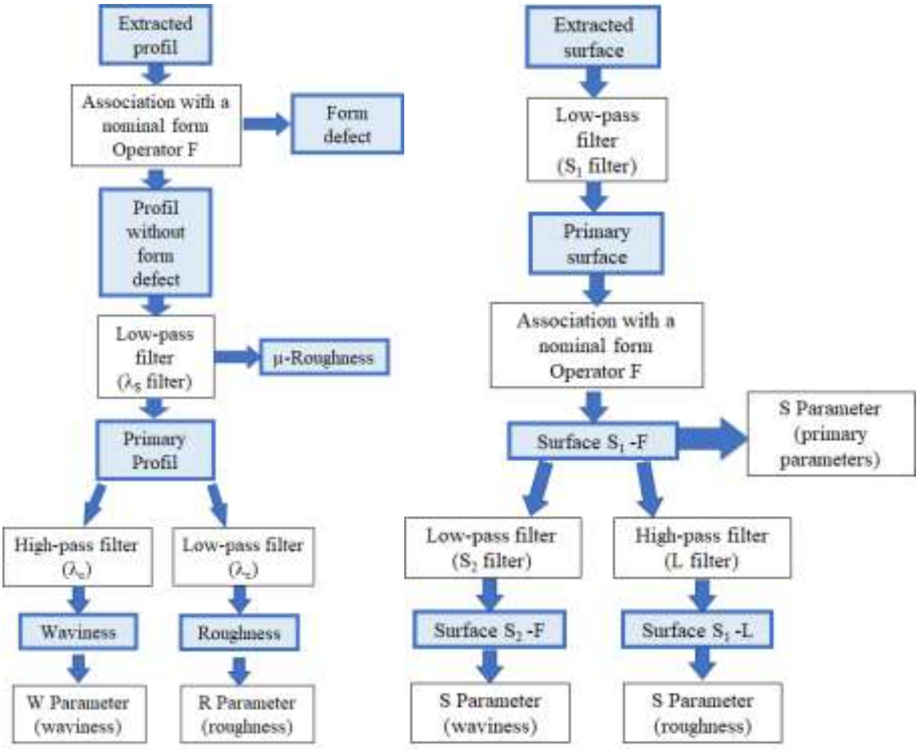

Fig. 1. a) Steps for a profile study ISO 4287-4288 profil procedure . b) Steps for an areal study ISO 25178 analysis procedure

Wavelet

. We used wavelet in the multiscale analysis in this study that is shown further on in this paper.

Compared to Fourier transformation, which shows infinite sinusoidal functions, wavelet represents finite duration. Wavelets can analyze the characteristic of a signal at a particular space region compared to Fourier transform thanks to its bandpass characteristic in the frequency domain. Wavelets are representation that carry time and frequency information. They can be compared to Fourier transform but without its limitations. [6]

Chang et al., used the Daubechies wavelets for non-contact surface roughness assessment of specimens by shaping, grinding, and polishing processes [7]. J. Mahashar Ali et al., used the wavelet transform to analyze electrical discharge machined surfaces [8].

In this study the arbitrary choice is done to use Daubechies wavelets (Index n°6). This wavelet is illustrated Figure 2. For each milled surface 10 scale levels are studied.

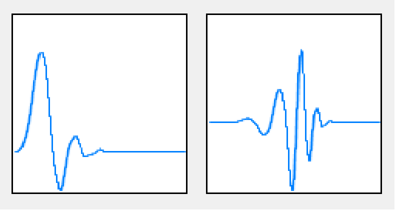

Fig. 2. Daubechies wavelet Index 6 : Scale function and Wavelet function (DigitalSurf Mountains Maps software).

3 Application

This study focused on finding correlations between the stress used to pull off the coating of the mould, table 1, and the surface texture.

Different substrates (same material but different textures) were coated with NiP. Parts of specified diameters were used to measure the force required to pull the coating away from its substrate, Figure 3 The substrates were manufactured by milling with different feed rate/tooth (Fz mm/tooth). [9]. The pull-of tests were performed several times each, the average measurements are presented in Table 1.

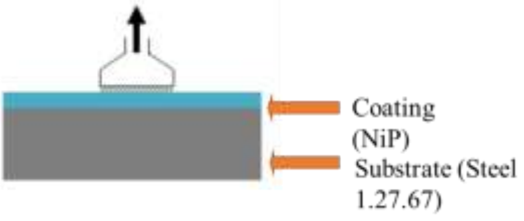

Fig. 3. Crash coating test schematic [8]

Table 1. Pull-of Stress in tension averaged values

Fz (mm/tooth)	Pull-of Stress (MPa)
0,02	1,75
0,04	2,4
0,06	2,75
0,08	4,75
0,1	7,25

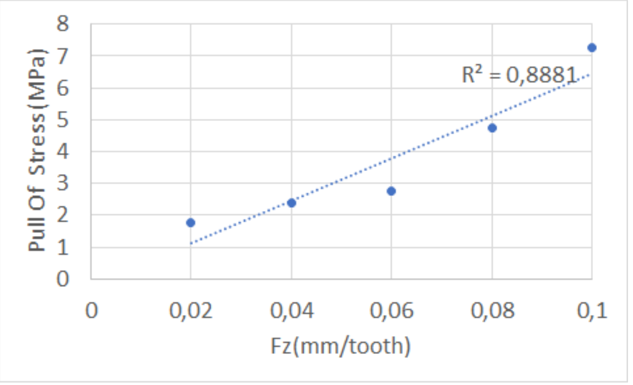

Fig. 4. Pull of stress evolution with Fz

3.1 Linear Results

The different analyses (linear, surface and multiscale) presented in this study are performed using the software MoutainsMap8 from the DigitalSurf company.

Multiple measurements were done using an InfiniteFocus Alicona topo-microscope with a 100nm resolution. Each measured surface was used to extract more than 2000 profiles and to obtain the minimum, maximum, average and standard deviation values for each parameter. Not all results are shown here but some can be seen in Figure 5 and Figure 6. After having obtained these roughness parameters, we tried to make a functional correlation with the pull-off stress. The correlation coefficients obtained are presented in Table 2 and illustrated in Figure 7.

In this study, we limited ourselves to these parameters for comparison with the previous study [9]. The linear analysis is presented for comparison with the surface results. We observe that for these 4 parameters the correlation is rather good and goes from 0.81 for Rt to 0.98 for Rz.

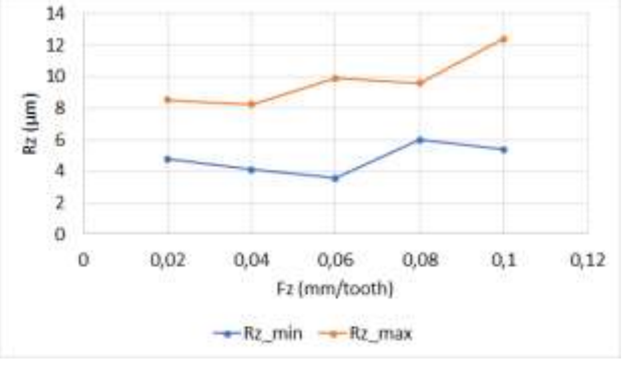

Fig. 5. Rz evolution with Fz

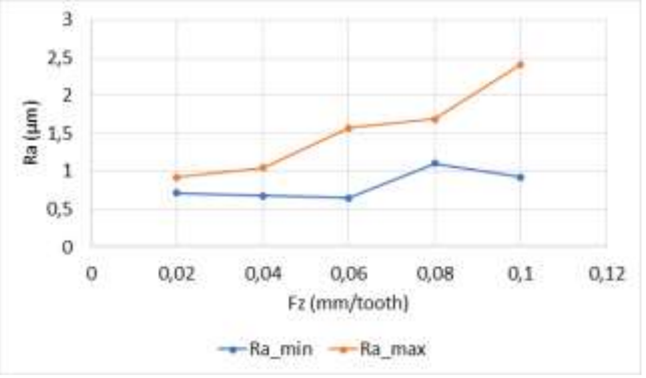

Fig. 6. Ra evolution with Fz

Table 2. Correlation coefficient of each parameter.

Parameters	Correlation coefficient (R^2)
Ra	0,8355
Rt	0,8104
Rz	0,9896
Rsm	0,8906

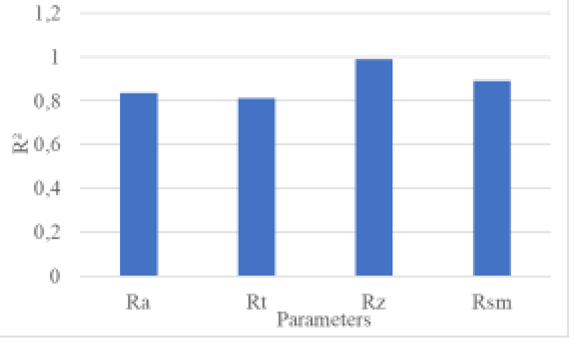

Fig. 7. Correlation coefficient for each parameter

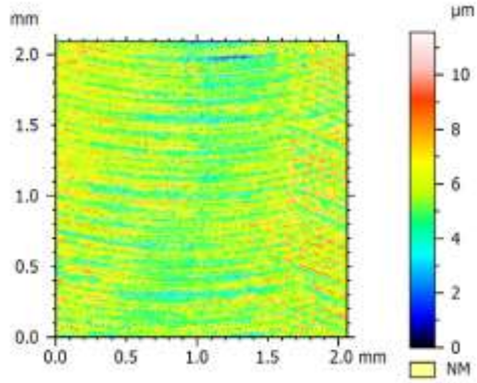

Fig. 8. FIGURE 9 : Example of a raw studied surface

4 Surface Analyses Results

4.1 Conventional method

An areal analyses allows us to have parameters that represent better the 3-dimensional aspect of the surface. Thus, the aim of these analyses is to really understand the impact of the surface topography on the adhesive function of the coating. A second objective is to compare the correlations results of these parameters of a conventional analysis and a wavelet approach. An example of the studied surface is given in figure 9. The parameters studied in the surface analyses were parameters that could explicitly give us an idea of the topography. We calculated of the surface Sq, Ssk, Sku, Sa, Sxp, Sal, Str, Vmp, Vmc, Vvc, Vvv..

The correlations coefficients obtained from these analyses are high as shown on figure 9.

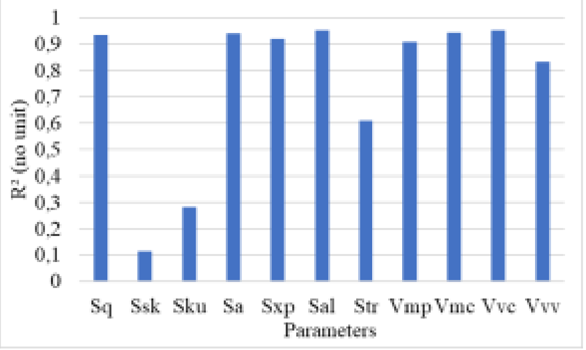

Fig. 9. Correlation coefficient for each parameter

The lowest correlated coefficients, Ssk and Sku, correspond to the asymmetry and geometry of the crests and valleys. Str represents the aspect ratio of the texture, i.e.

whether the surface has the same characteristics in all directions or whether the surface has a preferred texture direction.

Therefore, there is a significant correlation for the parameters that represent the material volumes and void volumes as well as the height differences and the maximum height of the surface. We can underline that the correlations obtained are almost as good as for the linear study.

4.2 Wavelet analyses

For the wavelet decomposition of surfaces, the Daubechies type of wavelet was used. Each surface was decomposed into 10 wave levels and the roughness levels were recovered. The parameters calculated are the same as for the conventional analysis. The interest was therefore to observe whether the parameters that are poorly correlated with a conventional decomposition have a more efficient scale allowing to find a better functional correlation.

Finally, the wavelet approach allowed to find high correlations for all parameters (figure 10). For the parameters with low correlation with the conventional method, a scale was found to give much higher correlations. We can notice that whatever parameter is used, the correlation coefficient is better with the multi-scale approach than with the conventional approach. We can also notice that for the parameters Str, Ssk and Sku whose level of correlation was weak with the conventional approach we can find a study scale giving a good level of correlation but this level (scale 4 and 5) is quite different from the scales allowing to optimize the other parameters (scale 8 and 9).

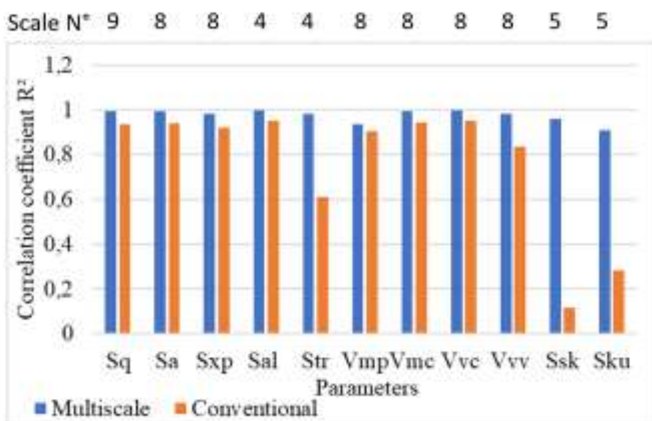

Fig. 10. Correlation coefficient for each parameter with wavelet decomposition and conventional approach

5 Conclusion

In conclusion, we were able to evaluate correlations between the pull of stress and the texture parameters of the substrate in several ways. We found strong correlations with the volume of void and material or the height differences on the surface. Furthermore, the comparison between the conventional surface analysis method and the multiscale wavelet decomposition method showed that the scale impact the correlation that can be found. Indeed, some parameters, with an adapted scale, could be correlated with the function. It would be interesting to carry out the same study with a different type of machining, such as electric discharge machining, which is not as anisotropic as milling. Furthermore a discrimination study needs to be carried out to definitively validate the results.

References

1. . X. Jane Jiang, David J. Whitehouse, Technological shifts in surface metrology, CIRP Annals, Volume 61, Issue 2, 2012, Pages 815-836, ISSN 0007-8506, https://doi.org/10.1016/j.cirp.2012.05.009.
2. ISO. Spécification géométrique des produits (GPS) — État de surface : Méthode du profil — Termes, définitions et paramètres d'état de surface. ISO 4287 GPS. 1997-04, 25
3. ISO. Spécification géométrique des produits (GPS) — État de surface : Méthode du profil — Règles et procédures pour l'évaluation de l'état de surface. ISO 4288 GPS. 1996-08, 8
4. ISO. Spécification géométrique des produits (GPS) — État de surface : Surfacique. ISO 25178 GPS. 2017-05, 25
5. Brown CA, et al. Multiscale analyses and characterizations of surface topographies. CIRP Annals - Manufacturing Technology (2018), https://doi.org/10.1016/j.cirp.2018.06.001
6. X. Jiang, P. Scott, D. Whitehouse, Wavelets and their applications for surface metrology, CIRP Annals, Volume 7, Issue 1, 2008, Pages 555-558, ISSN 0007-8506, https://doi.org/10.1016/j.cirp.2008.03.110.
7. S.I. Chang, J.S. Ravathur, Computer vision based non-contact surface roughness assessment using wavelet transform and response surface methodology, Qual. Eng. 17 (2005) 435–451.
8. Mahashar Ali, J., Siddhi Jailani, H., & Murugan, M. (2020). Surface roughness evaluation of electrical discharge machined surfaces using wavelet transform of speckle line images. Measurement, 149, 107029. https://doi.org/10.1016/j.measurement.2019.107029
9. V. Lambert. Crash-coating. Master Génie Mécanique Procédés et matériaux. Besançon : UFC, 2021, 28