# Study on the relevance of some description methods for plateau honed surfaces

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**Abstract**

Much work has been undertaken in recent years into the determination of complete parametric description of plateau honed surfaces with the intention to make a link between process conditions, surface topography and the required functional performances. Different advanced techniques (plateau/valleys decomposition using the normalized Abbott-Firestone curve or morphological operators, multiscale decomposition using continuous wavelets transform…) were proposed and applied in different studies. This paper re-examine the current state of developments and addresses a discussion on the relevance of the different proposed parameters and characterization methods for plateau honed surfaces by considering the control loop manufacturing-characterization-function. The relevance of appropriate characterization is demonstrated through two experimental studies. They consider the effect of the most plateau honing process variables (the abrasive grit size and abrasive indentation velocity in finish honing and the plateau honing stage duration and pressure) on cylinder liner surface textures and hydrodynamic friction of the ring-pack system.

Keywords: Plateau honing, surface roughness, surface characterization, friction.

## 1 Introduction

One of the major actual challenges of surface engineering is the identification of the pertinent topographic parameter that describes precisely the functional performance of the surface and also allows to make a link between process and product function [1, 2]. Therefore, an important research work is undertaken to develop surface characterization methods and to define topographic parameters that correlate process to function. Particularly for honed surfaces characterization, the choice of surface parameter was mainly emprirical and differs from one organization to another. In order to find a scientific proof of the choice of the best parameter, many attempts were done to characterize honed surface in correlation with their functional performances [3, 4, 5, 6]. In these studies, surface parameters are derived from three different families of characterization approaches that are standard techniques (Iso 4287, Iso 12085 and Iso 13565-2) [7, 8, 9], multiscale decomposition methods [10] and plateaus/valleys decomposition methods [11, 12, 13]. Nevertheless, at this time, the parameter that correlates strongly process and functionality is still sought [11, 13]. In this paper, the mutual correlation between plateau honing process working variables and resulting surface parameters on the one hand and between topographic parameters and friction performance of cylinder honed surface on the other hand will be investigated. Then, the most influent process variables were considered which are expansion speed and abrasive grit size of the finish honing stage as well as contact pressure and duration of plateau honing stage. Furthermore, a hydrodynamic contact model which takes into account the real surface topography was developed to predict friction in ring-pack tribosystem. Finally, the performance of the various surface parameters was analyzed and the more appropriate characterization approach was identified.

## 2 Characterization approaches of Plateau honed surfaces

### *2.1 Standard methods*

Various parameters derived from ISO standard 4287 and 12085 were used for the characterization of honed surfaces such as the arithmetic roughness Ra [8, 9] or R [7], the skewness and kurtosis parameters, Rsk and Rku [8], which describe the morphology of plateau-honed surfaces that are asymmetrically negative and highly flat. Spk, Sk, and Svk functional parameters based on the bearing curve (or Abbott curve) were introduced by automotive industry and are from ISO 13565-2 standard. It was found that these parameters do not correlate process with functional performances of honed surfaces [3, 4, 13].

### *2.2 Plateau/valleys methods*

The surface profile of a honed surface is mainly composed of smooth plateaus and valleys. Spq and Svq parameters were introduced in order to characterize plateau and valley components respectively. Two methods can be used for that, the Abbot curve linearization method [11] and the morphological filtering approach [12]. The first one is derived from ISO 13565-3 standard. It assumes that the surface after plateau honing is composed of two superposed Gaussian distributions corresponding to the two component plateau and valley. Spq and Svq are determined from the two tangents on the linearized bearing curve. Pawlus in [11] showed that these parameters from this method are correlated with process conditions. The second method uses sequential alternate filters based on the mathematical morphology operators. This method was applied for monitoring surface wear during engine tests [12].

### *2.3 Multiscale decomposition methods*

Various multi-scale techniques for the surface decomposition in a wide range of wavelength from roughness to waviness and then for the quantification of roughness parameters at each surface scales were proposed in literature [7, 14]. A methodology using continuous wavelet transform was applied on cylinder liner surface topography to extract the multiscale process signature of each honing stage [7, 10] and to monitor the influence of honing operating conditions on surface patterns [7, 10]. The correlation between abrasion mechanisms and the multiscale process signature was highlighted in [15].The effect of the various surface scales on its functional performances has been studied by Demirci et al [5] and it was identified that finer scales act positively on elastohydrodynamic friction. Furthermore, El Mansori et al. show that in finish honing, the abrasive grit size is the most important variable that impact surface multiscale behavior [16].

## 3 Experimental procedure

### *3.1 Surface generation*

Honing experiments were carried out on an instrumented vertical honing machine with an expansible tool (NAGEL n° 28-8470). The workpiece consists of cylinder liner of lamellar gray cast iron engine crankcase. These cylinders are typically usable in diesel engine for commercial vehicles. They are produced by an interrupted multistage abrasive finishing process, well known as the plateau-honing process. This very widely used process is a succession of three honing stages (rough, finish and plateau honing) [11, 15]. Four variable process parameters were used such as grit size, expansion speed that represents the indentation impact of honing stones on the cylinder liner during finish honing stage, time of plateau honing stage and contact pressure during plateau honing stage. Three different expansion speed were tested, which are 1.5µm/s, 4µm/s and 8µm/s. The size of grit stone varies from 30µm to 380µm. Plateau honing time varies from 4 to 16 strokes and the used contact pressures are 2.3, 5.5 and 10 bar. Experimental details are available in [3, 6].

### *3.2 Surface measurement and characterization*

The obtained textures are first measured with a tactile rugosimeter for 2D profiles using conventional filters to get ISO standard parameters and specific filters using wavelet transform for multiscale decomposition. Then, negative surface replicas made of a silicon rubber material (Struers, Repliset F5) were used to assess the 3D texture of honed surfaces after the plateau-honing stage at the mid-height of the cylinder bore specimen [3]. Topographical features of replica surfaces were measured in three locations by a three-dimensional white light interferometer, WYKO 3300 NT (WLI). The surface was sampled at 640 × 480 points with the same step scale of 1.94 µm in the x and y directions. Form component is removed from acquired 3D data using least square method based on cubic Spline function. To get plateau/valley morphological decomposition sequential alternate filters are used.

### *3.3 Functional performances prediction*

A deterministic numerical model was developed to estimate the friction generated between rough surfaces. The model considers the real topography of the surfaces from 3D acquisition. The scope of this model is to qualitatively predict the friction coefficient obtained when the texture characteristics of surfaces are varied in order to optimize the performance. Frictional performances are obtained using the ring-pack elastohydrodynamic contact simulation program using Reynolds equations described in [3, 5]. The lubrication regime is assumed mainly elastohydrodynamic with a constant speed.

## 4 Results and discussions

Figure 1 resumes the impact of the most influent operating honing conditions on hydrodynamic friction. It highlights the direct relationship between the honing process variables and friction performance of bore surfaces.
It can be seen that the friction coefficient rises with the increase of the abrasive grit size and the expansion velocity in finish stage. Furthermore, friction decreases considerably with the increase of honing duration or pressure in plateau stage. It means that the reduction of the plateau roughness and by the way of the valley depth enhances the reduction of friction coefficient [6].

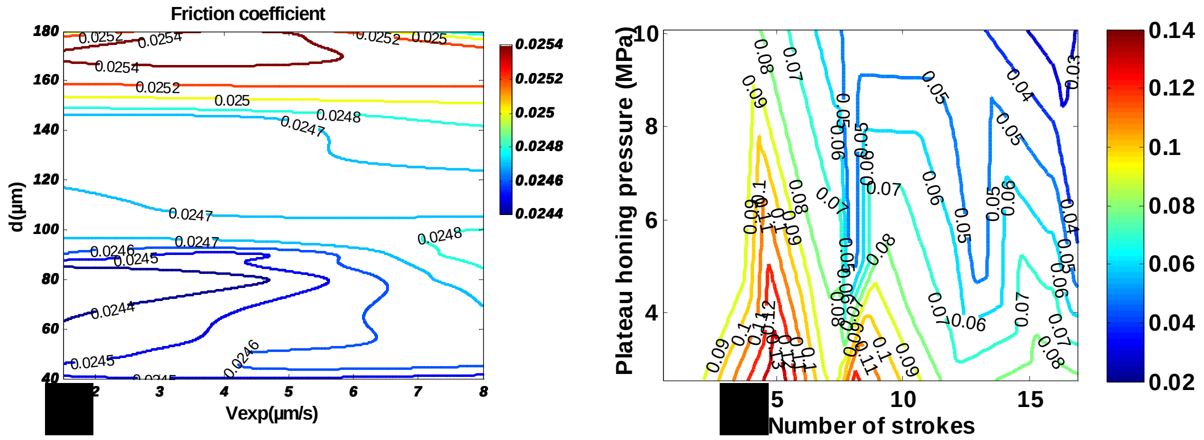


Figure 1: Cartography of the influence of (a) Grit Size and expansion speed in finish honing stage and (b) stroke number and honing pressure in plateau honing stage on frictional performances of plateau honed surfaces of cylinder liners.

The correlation between honing working variables and surface parameters on the one hand, and between surface parameters and friction coefficient on the other hand was investigated. The surface parameters considered are derived from the three characterization approaches mentioned above. Table 1 resumes all the obtained correlation coefficients. It demonstrates that the widely used Rk family surface parameters do not allow to make a link between honing process conditions and friction performance. This is in accordance with previous studies [3, 4, 13].
The evolution of plateau and valley components and their correlation with process and functionality was studied using Sq family surface parameters. Two techniques were applied: the first based on Abbot curve linearization

and the second based on morphological filtering. **Erreur ! Source du renvoi introuvable.** shows that the correlation of these parameters is strong for the majority of conditions.

**Table 1** Process and functionality correlation coefficient for each surface parameter

| | Process variables | | | | Surface parameters | Surface-functionality (friction) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $(D)_f$ | $(V_{exp})_f$ | $(t)_{pl}$ | $(P)_{pl}$ | | $(D)_f$ | $(V_{exp})_f$ | $(t)_{pl}$ | $(P)_{pl}$ |
| Standard parameters | 0.67 | 0.36 | 0.71 | 0.64 | **Ra** | 0.52 | 0.30 | 0.95 | 0.96 |
| | 0.55 | 0.37 | 0.79 | 0.72 | **R** | 0.38 | 0.30 | 0.93 | 0.99 |
| | 0.98 | 0.05 | 0.78 | 0.73 | **AR** | 0.97 | 0.10 | 0.71 | 0.70 |
| | 0.40 | 0.51 | 0.48 | 0.51 | **Rsk** | 0.25 | 0.39 | 0.50 | 0.29 |
| | 0.55 | 0.48 | 0.29 | 0.39 | **Rku** | 0.40 | 0.41 | 0.13 | 0.44 |
| | 0.65 | 0.36 | 0.59 | 0.78 | **Rpk** | 0.49 | 0.29 | 0.85 | 0.22 |
| | 0.63 | 0.42 | 0.69 | 0.61 | **Rk** | 0.48 | 0.34 | 0.96 | 0.92 |
| | 0.60 | 0.30 | 0.64 | 0.72 | **Rvk** | 0.43 | 0.22 | 0.69 | 0.94 |
| Plateau/valley decomposition | 0.84 | 0.73 | 0.47 | 0.55 | **Rpq Abbott** | 0.72 | 0.64 | 0.46 | 0.90 |
| | 0.76 | 0.51 | 0.72 | 0.66 | **Rvq Abbott** | 0.72 | 0.47 | 0.72 | 0.87 |
| | 0.79 | 0.66 | 0.78 | 0.62 | **Rpq morpho.** | 0.7 | 0.58 | 0.97 | 0.91 |
| | 0.75 | 0.51 | 0.86 | 0.82 | **Rvq morpho.** | 0.72 | 0.47 | 0.94 | 0.95 |
| Multiscale method | 0.94 | 0.95 | 0.73 | 0.75 | **Sma for Scale=0.24mm** | 0.65 | 0.29 | 0.77 | 0.95 |

**Table 2** Comparison between Abbot and Morphological plateau/valley decomposition concerning their correlation with process and function

| | Process-Surface correlation | | | | Surface-functionality (friction) correlation | | | |
|---|---|---|---|---|---|---|---|---|
| **Initial Ra (µm)** | **(t)pl 0.38** | **(t)pl 0.70** | **(P)pl 0.38** | **(P)pl 0.70** | **(t)pl 0.38** | **(t)pl 0.70** | **(P)pl 0.38** | **(P)pl 0.70** |
| **Rpq Abbott** | 0.60 | 0.84 | 0.96 | 0.78 | 0.25 | 0.98 | 0.68 | 0.93 |
| **Rvq Abbott** | 0.90 | 0.81 | 0.77 | 0.96 | 0.78 | 0.98 | 0.99 | 0.84 |
| **Rpq morphological** | 0.78 | 0.87 | 0.92 | 0.84 | 0.99 | 0.96 | 0.58 | 0.96 |
| **Rvq morphological** | 0.86 | 0.89 | 0.99 | 0.99 | 0.96 | 0.96 | 0.82 | 0.96 |

However, a difference is noticed between morphological and Abbott parameter in which the correlation is weak for smoother surfaces in plateau stage honing. The weakness of the Abbott curve linearization method is explained by computational difficulties that exist for the research of the intersection point that differentiates the two tangents (that represent Spq and Svq) of the linearized Abbott curve [11]. Table 2 shows that correlation coefficients decrease with a lower initial roughness (Ra=0.38µm) in plateau stage honing.
Finally, this study has shown that the morphological method is the most robust method between those shown in relationship with both process condition and functional performances. Concerning multiscale analysis, the correlation is not established for all the scales and it is necessary to define the range of scales that correlate the best with both process and functional performances. In our case, a scale equal to 0.24mm is used because it is included in the range of scales (from 0.05 to 0.4mm) in which the correlation between surface, process and

function is the best compared to other scale ranges (see **Erreur ! Référence non valide pour un signet.**). It is shown that for the studied conditions the correlation is generally good between this method and both process and functionality, except for the correlation with functionality concerning the variation of expansion speed that is not established for all the characterization parameters.

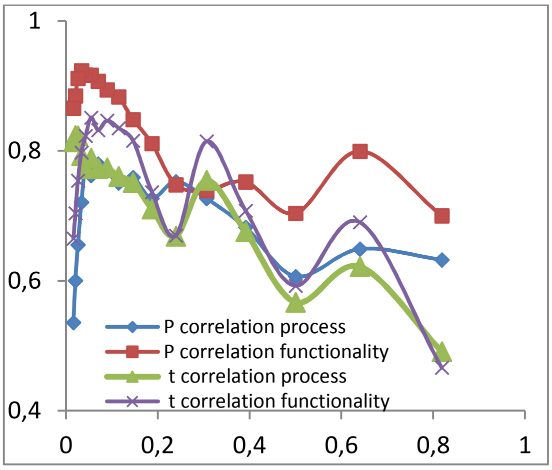


Figure 2. Correlation between SMa Multiscale parameter, process and functionality for each scale concerning plateau stage honing. (a) for the global range of scales; (b) for the lowest scales.

## 5 Conclusion

This study addresses a comparison between various surface texture characterization techniques (standard approaches, multiscale techniques and plateau/valleys methods) to make a link between honing process operating conditions and surface functionalities of cylinder engines. The effects of the most influent process parameters (finish honing indentation velocity, abrasive grit size, plateau honing time and pressure) on friction were studied. The conclusions of the study are as follows:

- Standard methods are inefficient to make a link between process variables and frictional performances;
- Plateau/valley decomposition parameters allow to link process conditions at plateau stage and functional performances. However, the morphological decomposition method is more robust than Abbott curve linearization method, particularly for smoother honed surfaces.
- Multiscale decomposition is an efficient approach that permits making a link between process and functionality via surface roughness spectrum.

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