Title:
**Geometrical Verification of Turned Surfaces using 3D Roughness Parameters**

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Introduction:
Design and verification represent the beginning and the end of product manufacturing: they respectively define the product characteristics and confirm their actual compliance [17]. The geometric control has a direct effect on the cost and quality of a product. The surface texture is a key factor that affects the functionality and reliability of mechanical components [5], and roughness is a crucial parameter for evaluating the material surfaces, because it directly affects the optical and mechanical properties of the materials. Roughness determines the characteristics of wear, friction, lubrication, corrosion [6-13] heat transfer, optical properties, fluid flow, measuring surfaces [2], adhesion [9-10], fracture toughness, and fatigue resistance [16], among others. Roughness represents one of the most important factors in tribology and it can be used to evaluate the quality of a machining operation [2].

There are several parameters that can be used to characterize the surface roughness. However, regardless of the application of the evaluated surface, classical roughness parameters for instance Ra, Rt, and Rmax have been widely used. In this paper, an extensive study was conducted to identify which 3D roughness parameters best characterize turned surfaces. Samples were made considering four cutting conditions. For this purpose, a full factorial design $2^2$ was proposed. The statistical analysis was carried out by using software STATISTICA® 7.0. For comparing multiple samples, the Kruskal-Wallis test was performed.

Materials and Methods:
To identify which roughness parameters best characterize surfaces obtained by turning, a wide roughness evaluation was performed. A factorial design $2^2$ was proposed considering different cutting conditions, as shown in Table 1. The factors cutting depth (f) and feed rate (ap) were assumed as (0.5 mm and 1.0 mm) and (0.1 mm/rot and 0.2 mm/rot), respectively.

| *Test* | *f (mm) Factor 1* | *ap (mm/rot) Factor 2* |
|---|---|---|
| 1 | - 1 (0.5) | -1 (0.1) |
| 2 | +1 (1.0) | -1 (0.1) |
| 3 | -1 (0.5) | +1 (0.2) |
| 4 | +1 (1.0) | +1 (0.2) |

Tab. 1: Factorial design $2^2$ proposed to make the turned samples.

In accordance with Table 1, four conditions were investigated, and three samples were made for each condition. All samples were made of gray cast iron. The face turning operation was performed using a CNC lathe, Multiplic 35D, manufactured by ROMI, with tip distance of 1500 mm and maximum rotation of 3000 rpm. A ISO SPUN 12 03 08 H1P hard metal square insert, with a face support at 75° model CSKPR 2525 M12, was used as a turning cutting tool. During the turning process, the cutting speed was kept constant (80 m/min). A vegetable-base fluid Vasco 1000 with a concentration of 95 % was used as cutting fluid.

Roughness was measured using an interferometer in white light mode (CLA). This equipment has 0.01 µm vertical resolution. Measurement management and data collection were performed through the Talysurf CLI 2000® software. The calibration certificate states an expanded uncertainty of 0.05 % associated with the interferometer calibration, for a coverage factor k of 2.00 and a coverage probability of 95 %. Effective topographies were obtained from an area of 1 $mm^2$. 2001 points were collected along each line, spaced at 0.5 µm, where 251 lines were considered. For turned surfaces, the Operator Leveling was applied for primary extracted topographies followed by the robust Gaussian filter. Three measurement cycles were performed for each sample.

Several 3D roughness parameters covered by ISO 25178 standard [11], divided into three categories were collected: (a) area amplitude parameters, (b) functional and (c) feature parameters. The parameters of each category are listed as follows:

a. Area amplitude parameters are arithmetic mean deviation (Sa), root mean square height (Sq), skewness (Ssk), kurtosis (Sku), maximum peak height (Sp), maximum pit height (Sv), and maximum height (Sz).

b. Volume parameters are material volume (Vm), void volume (Vv), peak material volume (Vmp), core material volume (Vmc), core void volume (Vvc), and valley void volume (Vvv).

c. Feature parameters include density of peaks (Spd), arithmetic mean peak curvature (Spc), ten-point height (S10z), five-point peak height (S5p), five-point pit height (S5v), closed dale area (Sda), closed hill area (Sha), closed dale volume (Sdv), and closed hill volume (Shv).

The standard uncertainty associated with all measurands was estimated by applying the GUM method put forward on [3]. The statistical analysis was carried out by using software STATISTICA® 7.0. For comparing multiple samples, the Kruskal-Wallis test was performed.

## Results and Discussion:

The 3D effective topographies obtained from turned surfaces for all evaluated conditions are shown in Fig. 1. In this figure it is observed that changes in the values of feed rate produced more pronounced differences on the obtained topographies than those produced by the cutting depth changes. Figures 2 and 3 corroborate these results.

Figures 2 and 3 represent the average of amplitude and functional parameter values for all investigated conditions, respectively. The values of feature parameters are not presented. The standard uncertainty is also shown, as error bars. Figure 2 represents that the effect of the feed rate was more significant than that produced by the cutting depth rate for all evaluated amplitude parameters. This behavior was also observed for almost all functional parameters (Fig. 3). An increase in the feed rate during the turning tended to increase the height of the peaks and the depth of the valleys because a single-point tool was used. On the other hand, an increase in the cutting depth (keeping constant the other cutting parameters) during the turning can result in an increase in the machining forces and, consequently, in the mechanical vibration of the system, producing a worse surface finish [8]. According to [9], gray cast iron contains up to 3 % silicon responsible for increasing the amount of graphite (solid lubricant). However, the removal of material during the machining causes the release of the graphite present in its composition, deteriorating the machined surface finish and, consequently, the roughness [7-10].

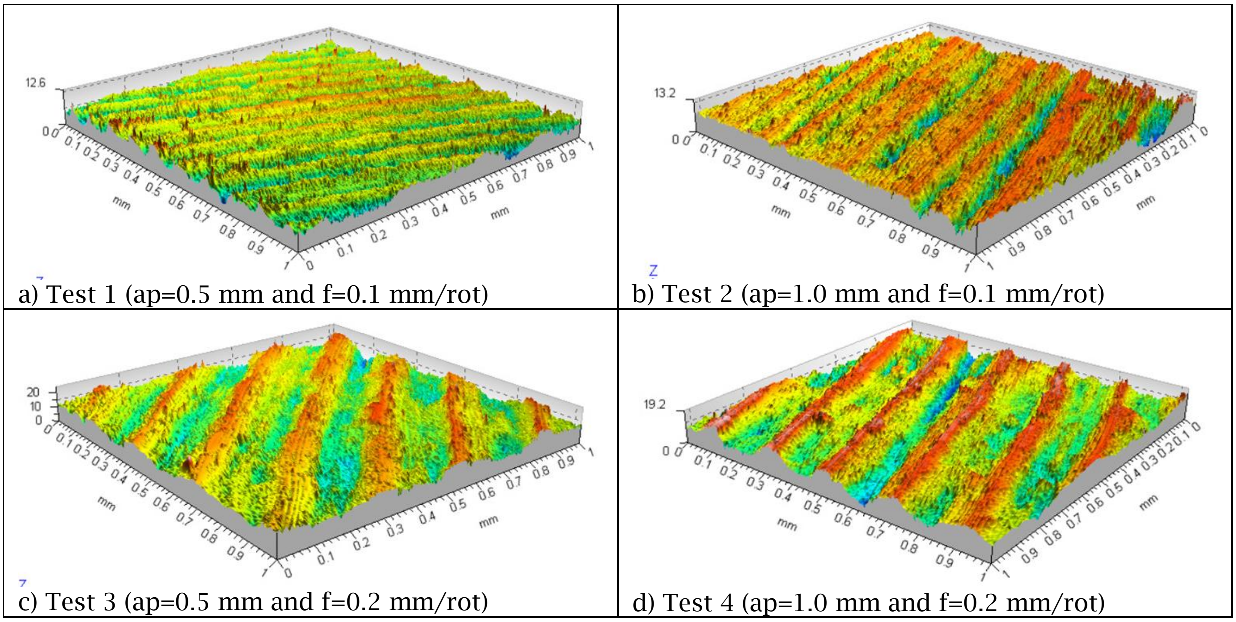


Fig. 1: 3D effective topography of turned sample for all tested conditions.

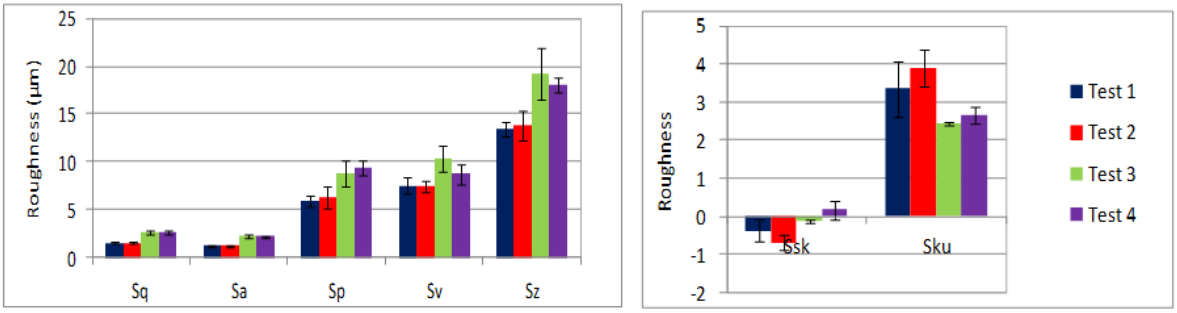


Fig. 2: Average of amplitude parameter values. Standard uncertainty is shown as error bars.

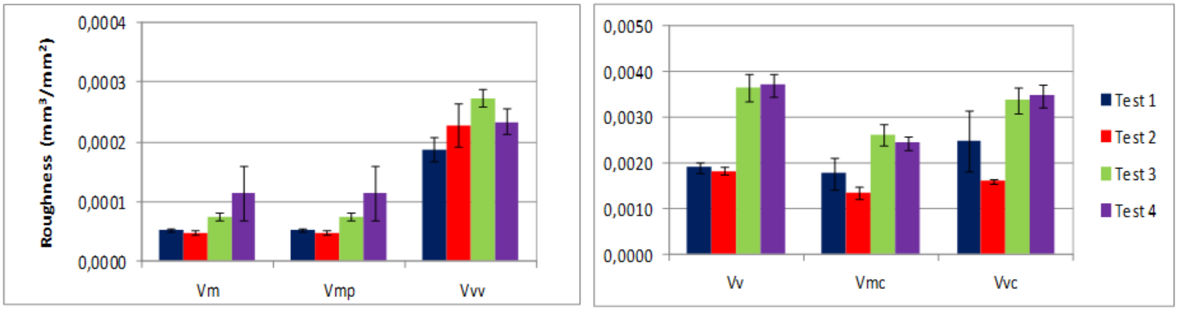


Fig. 3: Average of functional parameter values. Standard uncertainty is shown as error bars.

The Kruskal-Wallis test was applied for comparing multiple samples. The p-value less than 0.05 were obtained for four parameters (Sq, Sa, Vv and Vmp). These results were corroborated by the box plot shown in Fig. 4. This fact indicates that at least one experiment exhibited a mean value different than others.

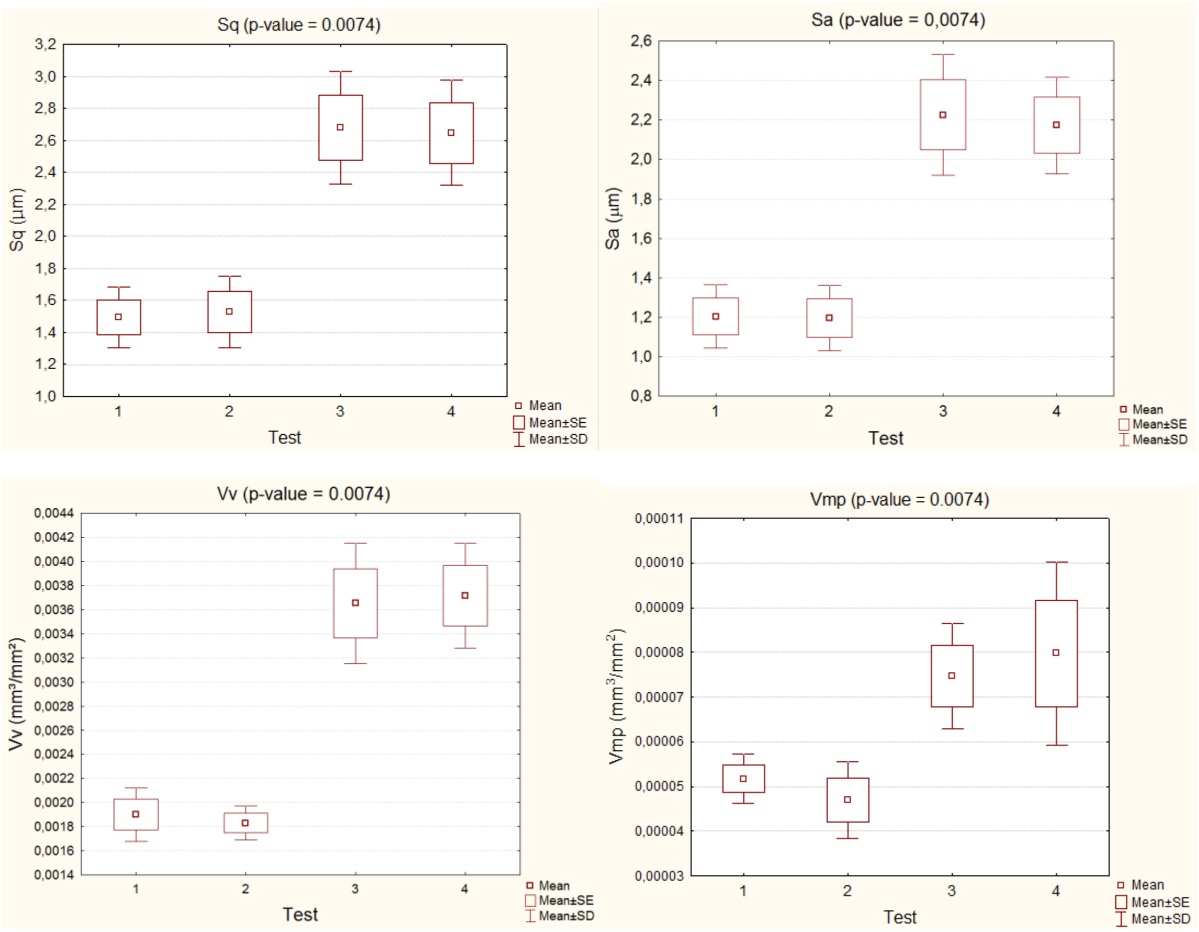


Fig. 4: Box plots of parameters whose p-value was less than 0.05.

Sq and Sa amplitude parameters represent average roughness, and they do not provide any information about the predominance of peaks or valleys, for instance as about the presence of atypical peaks or valleys. The values of both parameters may be strongly influenced by the valley and peaks amplitude. The volume of the peaks (Vmp) is essential to assess the evolution of wear [16]. The volume of the voids in the valleys (Vv) represents the surface capacity to maintain the lubricant film that is necessary to prevent metal-metal contact in several practical applications [1].

<u>Conclusions:</u>
Under the evaluated experimental conditions, the parameters Sq, Sa, Vv and Vmp can be used to characterize the turning surfaces. All other evaluated parameters were unable of detecting the changes caused on the surface by different cutting conditions investigated.

The results presented in this paper can be useful for operators who perform the roughness measurement in production lines of parts, contributing to the choice of the appropriate roughness parameters to be evaluated.

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