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# DESIGNATION OF EVALUATION AREA IN MEASURING 3D SURFACE ROUGHNESS

**Abstract.** *In the automotive industry surface topography is an important issue. The working surfaces of the components require high precision machining. In this paper the minimum 3D roughness evaluation areas were determined to decrease the time and cost of measuring the components.*

**Keywords:** *surface roughness; Sa, Ssk;, hard turning; grinding.*

## 1. INTRODUCTION

With the appearance of super hard materials and single-point tools (turning tools) produced from these materials, it became possible to machine hardened materials (HRC>50). To apply these machining procedures for finishing, numerous research projects were necessary, e.g. analyzing tool-wear [1], describing tool-life as a function of the cutting data [2], designing machine tools with greater rigidity, etc. These preliminary conditions facilitated the analysis methods, whose aim was comparing the surfaces machined by the new technologies with those machined by grinding or substituting the grinding by the new technologies. The foci of these analysis methods were the accuracy and surface quality of the machined components [3].

Table 1 – Examples for 3D evaluation areas

| Applied technology | Evaluation area [mm × mm] |
|---|---|
| Grinding | 1.5×1 [4], 2.5×2.5 [5], 0.5×0.5 [11], 1.2×0.9 [13] |
| Turning | 0.705×0.528 [6] |
| Hard turning | 0.8×0.8 [7], 0.5×0.5 [11], 2.5×2.5 [12] |
| Milling | 5×5 [8], 2.5×2.5 [9], 1.2×0.9 [13] |
| Rolling | 0.7×0.525 [110] |
| Burnishing | 2.5×2.5 [12] |
| Direct Laser Deposition | 1.2×0.9 [13] |

In this paper the reliability of 3D surface roughness testing is analyzed. Parameters for height (Sa) and area (Ssk) are measured and analyzed in different evaluation areas, and minimum areas were determined by applying descriptive statistical parameters. The reason for such a study was that there are many 3D topography research studies available but there is no exact advice for the evaluation area of the surface. Some studies are cited in Table 1 as examples; it can be stated that the evaluation area varies in quite a random manner and there is no significant relationship between the area and the applied technology or the technological data compared to the 2D roughness test, where the evaluation length is offered by a standard.

There is another problem in 3D roughness analysis: in several studies important data are neglected, therefore the repeatability of the experiment or analysis cannot be realized. Some examples of poorly reported studies:

- Missing evaluation area [14],
- Missing cut-off and filtering method [15],
- Missing cutting data, evaluation area and cut-off [16, 17].

## 2. EXPERIMENTAL SETUP AND THE MEASURED ROUGHNESS DATA

In the experiment the bores of two gear wheels were machined and the surfaces of the bores were analyzed. The main data of the hardened component are:

- Material: 16MnCr5
- Hardness: 62 HRC
- Diameter (d): 38 mm
- Bore length (l): 29.85 mm
- Accuracy: IT5
- Allowance (Z): 0.15 mm

Table 2 – Cutting data of the experiment and data of the roughness test

| | | Hard turning | | Grinding | |
|---|---|---|---|---|---|
| Machine tool | | EMAG VSC 400 DS | | SI-4/A | |
| Applied tools | | CNGA 120408S-LO CBN (R)<br>CNGA 120408 7020 (S) | | 40×20×16-9A80-K7V22 | |
| Cutting | Roughing | $v_{c,R}$ | 180 m/min | $v_{c,R}$ | 30 m/s |
| | | $f_R$ | 0.24 mm/rev | $v_{w,R}$ | 18 m/s |
| | | $a_{p,R}$ | 0.1 mm | $v_{f,L,R}$ | 2.2 m/min |
| | Smoothing | $v_{c,S}$ | 180 m/min | $v_{c,S}$ | 30 m/s |
| | | $f_S$ | 0.12 mm/rev | $v_{w,S}$ | 18 m/s |
| | | $a_{p,S}$ | 0.05 mm | $v_{f,L,S}$ | 2 m/min |
| Measuring machine | | | Altisurf 520 | | |
| Standard applied for the evaluation | | | ISO 25178-2:2012 | | |
| | | | Axe X | Axe Y | |
| Evaluation area | Length | | 1.5 mm | 1.5 mm | |
| | Size | | 1501 points | 1501 points | |
| | Spacing | | 1 µm | 1 µm | |

The internal cylindrical surface of one component was machined by hard turning in roughing and smoothing passes. The bore of the other was hard turned in the roughing pass and ground in the smoothing. The machine tool, other cutting tools applied, and cutting data are summarized in Table 2. After machining roughness tests were carried out by a 3D roughness measuring machine.

The main data of the setup are summarized in Table 2. As measured surfaces 2.3×2.3 mm$^2$ squares were designated on the components. Gauss filter was applied for filtering the surface waviness. The cut-off (basis of evaluation) was determined according to the standard ISO 25178-2:2012. Its value was 0.8 in case of both surfaces. This resulted in 1.5×1.5 mm$^2$ evaluation areas.

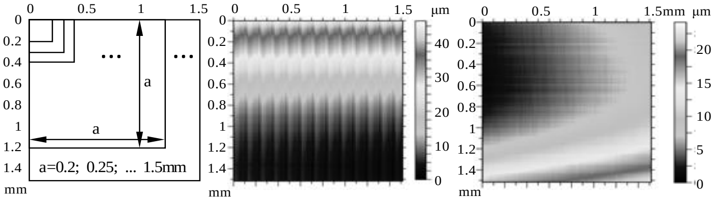

Figure 1 – Designation of the evaluation areas (left), 3D views of the surface topographies (hard turned (middle); ground (right))

Table 3 – Data of the roughness test

| Hard turning | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| a | **1.5** | **1.45** | **1.4** | **1.35** | **1.3** | **1.25** | **1.2** | **1.15** | **1.1** |
| Sa | 0.7221 | 0.7204 | 0.7277 | 0.7182 | 0.7241 | 0.7191 | 0.7272 | 0.7158 | 0.7244 |
| Ssk | 0.0114 | 0.0069 | 0.0112 | -0.0034 | 0.0171 | 0.0055 | 0.0128 | 0.0146 | -0.018 |
| a | **1.05** | **1** | **0.95** | **0.9** | **0.85** | **0.8** | **0.75** | **0.7** | **0.65** |
| Sa | 0.7128 | 0.7164 | 0.7229 | 0.7055 | 0.7303 | 0.7107 | 0.7217 | 0.716 | 0.7131 |
| Ssk | 0.0282 | 0.0119 | 0.0306 | 0.0387 | -0.0014 | 0.0408 | -0.007 | 0.0364 | 0.0254 |
| a | **0.6** | **0.55** | **0.5** | **0.45** | **0.4** | **0.35** | **0.3** | **0.25** | **0.2** |
| Sa | 0.7337 | 0.7125 | 0.7327 | 0.6996 | 0.7101 | 0.7322 | 0.6739 | 0.7405 | 0.674 |
| Ssk | -0.0029 | 0.0125 | -0.0428 | 0.0534 | -0.0039 | 0.0534 | 0.0659 | -0.0845 | -0.0243 |
| **Grinding** | | | | | | | | | |
| a | **1.5** | **1.45** | **1.4** | **1.35** | **1.3** | **1.25** | **1.2** | **1.15** | **1.1** |
| Sa | 0.2005 | 0.2024 | 0.1997 | 0.2018 | 0.2008 | 0.2009 | 0.2056 | 0.1981 | 0.1982 |
| Ssk | -0.0334 | -0.0627 | -0.0497 | -0.0432 | -0.0615 | -0.0421 | -0.08 | -0.0828 | -0.0583 |
| a | **1.05** | **1** | **0.95** | **0.9** | **0.85** | **0.8** | **0.75** | **0.7** | **0.65** |
| Sa | 0.1994 | 0.1999 | 0.2013 | 0.1962 | 0.1964 | 0.1945 | 0.1938 | 0.1919 | 0.192 |
| Ssk | -0.058 | -0.056 | -0.0417 | -0.0066 | 0.004 | -0.0167 | -0.0215 | -0.0119 | 0.0036 |
| a | **0.6** | **0.55** | **0.5** | **0.45** | **0.4** | **0.35** | **0.3** | **0.25** | **0.2** |
| Sa | 0.1906 | 0.1873 | 0.1884 | 0.1837 | 0.1865 | 0.1812 | 0.1799 | 0.1719 | 0.1596 |
| Ssk | -0.0287 | -0.0682 | -0.0916 | -0.0867 | -0.0749 | -0.0734 | -0.0978 | -0.1569 | -0.0475 |

The main goal of the study is to determine the minimum evaluation area in the case of the two chosen roughness parameters. Based on the data obtained by scanning the original area, further smaller areas were designated and evaluated (side lengths of the areas are from 1.5 mm to 0.2 mm). A total of 27 areas of different sizes were evaluated. The scheme of this is demonstrated in Fig. 1. In Fig. 2 the 3D-views of the hard turned and the ground surfaces are demonstrated. In Table 3 the Sa and Ssk 3D surface roughness parameter values are summarized.

## 3. RESULTS AND DISCUSSION

In Fig. 2 values of the Sa parameters of the hard turned and ground surfaces are demonstrated. A reference value was designated for the analysis: the arithmetic average of the first 5 roughness values. The standard deviations of these data points for the two surfaces are close to zero: 0.0036 μm and 0.0011 μm, respectively. As the evaluation area decreases, the difference between the actual roughness values and the reference values increases. However, the increase in the Sa data of the ground surface is less than in case of the hard turned surface. In addition to that, the values show a slight decrease.

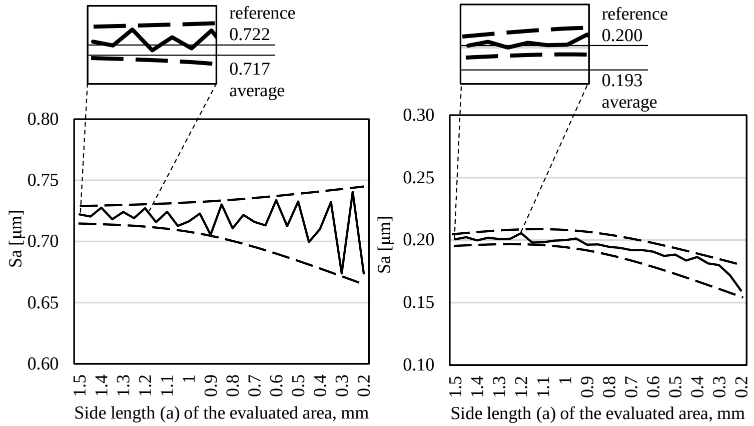

Figure 2 – The Sa parameter values of the hard turned (left) and the ground (right) surfaces

In Fig. 3 the Ssk roughness values of the hard turned and ground surfaces are demonstrated. Here, the standard deviations of the first 5 data points for the two surfaces are 0.0076 and 0.0124, respectively. As the evaluation area decreases the difference between the actual roughness values and the reference values increases.

The bias, which is the difference between the reference value and the average of the 27 parameter values, was also calculated. The biases of the Sa parameters of the hard turned and ground surfaces are -0.005 μm and -0.007 μm, respectively. In the case of the Ssk parameter they are 0.002 and -0.004, respectively. These relatively low values provide the information that the roughness values deviate in a quite symmetrical manner around the reference values, which are considered as reliable roughness values due to the area being large enough for the evaluation.

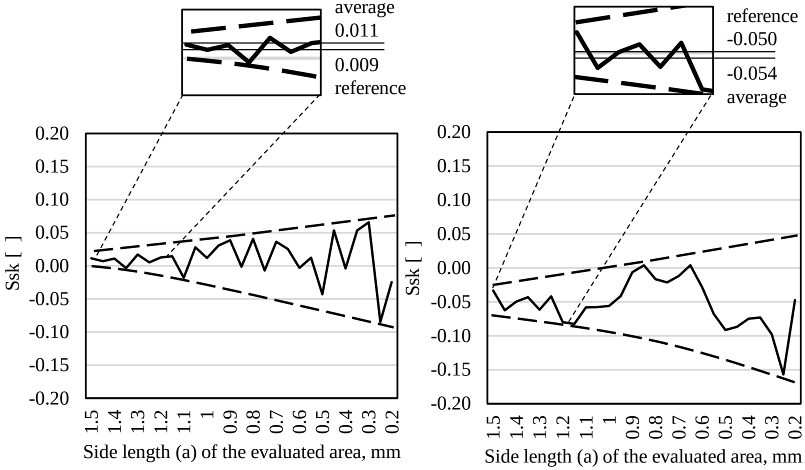

Figure 3 – The Ssk parameter values of the hard turned (left) and the ground (right) surfaces

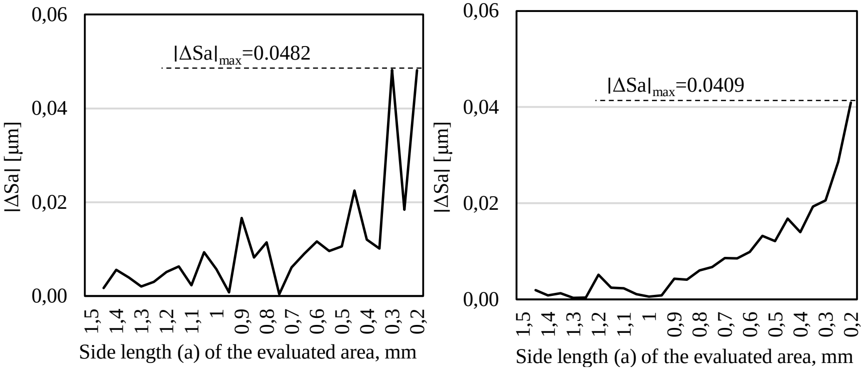

Figure 4 – Absolute differences in the Sa values of the hard turned (left) and the ground (right) surface – basis: Sa values of the 1.5×1.5 mm areas

The roughness values of the decreasing areas were compared to those of the 1.5×1.5 mm area. The absolute values of these differences are plotted in Figs. 4 and 5. Compared to the 1.5×1.5 area in the case of hard turning, the Sa parameter values show less than 1% difference from the areas 1.45×1.45 to 1.1×1.1. The actual Ssk values are closer to 0 than the Sa values, and therefore the percentage differences are greater.

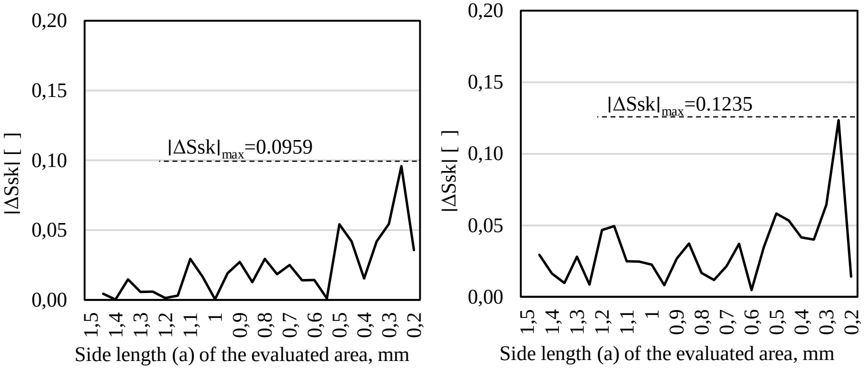

Figure 5 – Absolute differences in the Ssk values of the hard turned (left) and the ground (right) surface – basis: Ssk values of the 1.5×1.5 mm areas

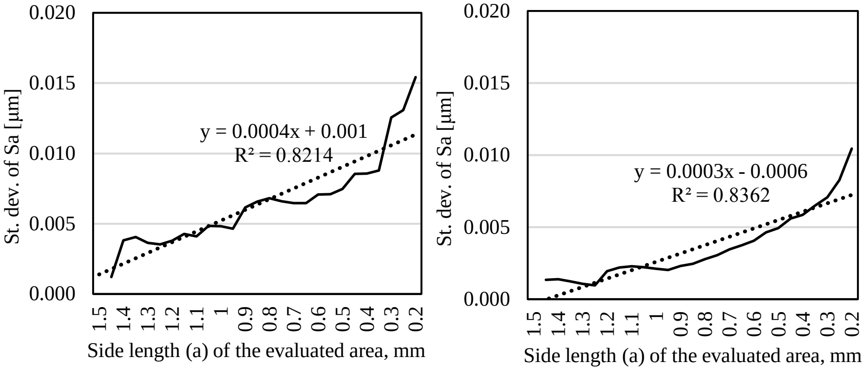

Figure 6 – Standard deviations of the Sa values of the hard turned (left) and the ground (right) surfaces

The parameter values show a less than 100% difference from the area 1.45×1.45 to 1.4×1.4. The 100% difference can be considered as normal. In the case of grinding, the differences of the Sa parameter values are less than 1% from the area 1.5×1.5 to the area 1.2×1.2. The differences of the Ssk parameters are less than 100% from the area 1.5×1.5 to 1.25×1.25. It is seen that the smaller the evaluation area, the greater this difference is. The relatively low levels of percentage differences help in designating a limit area that can be considered as a reliable minimum for the evaluation of the roughness areas.

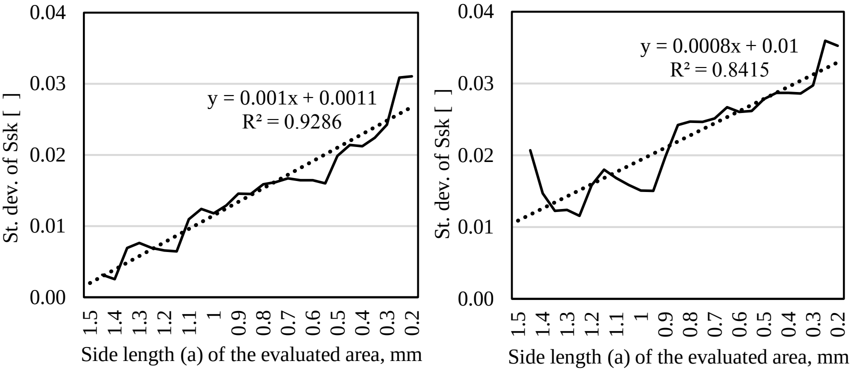

Figure 7 – Standard deviations of the Ssk values of the hard turned (left) and the ground (right) surfaces

Similarly to the analysis of the absolute differences, the change in standard deviations were calculated. The decreasing evaluation area leads to the distortion of the roughness values. This phenomenon is followed by the increased deviation of the data. If the standard deviations of roughness data of more areas are calculated, these values show an increasing tendency (Figs. 6 and 7). The deviation data correspond to the percentage differences data in the designation of minimum evaluation areas, because the first few deviation values can be considered as low enough. This finding is summarized in Table 4. In the case of grinding, the standard deviation limit is significantly greater than that of hard turning but it is still acceptable.

Table 4 – Data of the roughness test

| | | Sa | Ssk |
|---|---|---|---|
| Hard turning | %Δ, Area | 1%, 1.5×1.5-1.1×1.1 | 100%, 1.5×1.5-1.4×1.4 |
| | St. dev., Area | 0.005, 1.5×1.5-0.95×0.95 | 0.005, 1.5×1.5-1.4×1.4 |
| Grinding | %Δ, Area | 1%, 1.5×1.5-1.2×1.2 | 100%, 1.5×1.5-1.25×1.25 |
| | St. dev., Area | 0.005, 1.5×1.5-0.5×0.5 | 0.02, 1.5×1.5-0.9×0.9 |

## 4. SUMMARY

Hard surfaces were machined by hard turning and grinding and evaluated after 3D surface measurement in order to determine a minimum roughness evaluation area which is still acceptable based on a designated reference value. This reference can be the first or the first few measurement on surfaces which are considered large enough for technical evaluation. The reliability of the measurements was demonstrated by calculation of the standard deviation of the values of various (smaller and smaller) evaluation areas When precision components are machined in the automotive industry, surface topography and within that surface roughness are determining parameters whose measurement requires a considerable amount of time by the measuring organizational unit, particularly if 3D parameters are required for the qualification of the surface. The size of the measured area is in a nearly linear function with the measuring time. Therefore, finding the minimum evaluation area is crucial. It was found that in the case of the surface finished by hard turning, the minimum ‘a’ side length of the evaluation area is 1.1 mm and 1.4 mm based on the Sa and the Ssk roughness parameters, respectively. The minimum length in case of the surface finished by grinding is 1.2 mm and 1.25 mm, respectively. An important limitation of the study is that only two parameters were analyzed. In further studies the remaining 20 or so parameters have to be analyzed. Furthermore, other typical surfaces and machining operations would be useful to analyze.

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# ПОЗНАЧЕННЯ ОБЛАСТІ ОЦІНКИ ПРИ ТРИВИМІРНОМУ ВИМІРЮВАННІ ШОРСТКОСТІ ПОВЕРХНІ

**Анотація.** *В деталях для автомобільної промисловості важлива топографія поверхні. Робочі поверхні деталей вимагають високоточної обробки. У цій статті були визначені мінімальні області оцінки 3D шорсткості, щоб зменшити час і вартість вимірювання компонентів та аналізується надійність тривимірних випробувань шорсткості поверхні. Параметри висоти (*$S_a$*) і площі (*$S_{sk}$*) вимірюються і аналізуються в різних областях оцінки, а мінімальні площі визначалися із застосуванням описових статистичних параметрів. Виміряні поверхні становили 2,3 × 2,3 мм*$^2$*. Для фільтраціії хвилястості поверхні застосовувався фільтр Гаусса. Граничне значення (підстава для оцінки) було 0,8 для обох поверхонь. В результаті були отримані оціночні площі 1,5×1,5 мм*$^2$*. Основна мета дослідження - визначити мінімальну область оцінки в разі двох обраних параметрів шорсткості. На основі даних, отриманих при скануванні вихідної області, були визначені і оцінені подальші менші області (довжина сторін областей становила від 1,5 мм до 0,2 мм). Всього було оцінено 27 ділянок різного розміру. Коли прецизійні компоненти обробляються, топографія поверхні і в межах цієї шорсткості поверхні є визначальними параметрами, вимірювання яких вимагає значного кількість часу, необхідне для проведення вимірювань організаційною одиницею, особливо якщо для оцінки поверхні потрібні 3D-параметри. Розмір вимірюваної області майже лінійно залежить від часу вимірювання. Тому дуже важливо знайти мінімальну площу оцінки. Було виявлено, що в разі поверхні, обробленої гострінням, мінімальна довжина сторони «a» області оцінки становить 1,1 мм і 1,4 мм на основі параметрів шорсткості *$S_a$* і *$S_{sk}$* відповідно. Мінімальна довжина поверхні при шліфуванні становить 1,2 мм і 1,25 мм відповідно.*

**Ключові слова:** *області оцінки 3D шорсткості; статистичні параметри; топографія поверхні; мінімальна площа оцінки.*