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INVESTIGATION OF 3D SURFACE ROUGHNESS ON ENVIRONMENTALLY FRIENDLY WAY MILLED SURFACES

There were significant developments in the machining processes till now which goal were improvement of accuracy and productivity of machining. Next to it todays the protection of the environment is very important too. It can be executed on different ways. One of them is the reduction of coolants and lubricants. Implementation of dry cutting cannot be accomplished by simply turning off the lubricant supply [1]. In fact, the coolant performs several important functions, which, in its absence, must be taken over by other machining process components. This paper shows the execution and evaluation of milling cutting experiment.

1. INTRODUCTION

In the up-to-date intensified economic relations, the most important requirements against the product producers are: good quality, high productivity, economic efficiency, effective environment protection [1]. Although, next to the imperishable advantages of coolants and lubricants – which aim is to achieve the aims mentioned above - have several disadvantageous effects as well. There are efforts for reductions of these effects all over the world. In order to promote these things, researchers have to investigate qualitatively new methods, procedures and solutions. In the recent years a lot of investigations have been done to avoid the cutting fluids from the manufacturing [2], [3], [4], [5], [18]. Nowadays the so called ―Green manufacturing" is dealing with this as well. Allen at.al. discussed the status of environmentally conscious manufacturing in Europe, in Japan and in the USA [6]. Sheng at. al. have addressed specific parts of the manufacturing process – e.g. minimum quantity lubrication and dry cutting - in more details with success [7], [9] which is now being realized in numerous manufacturing operations internationally. A schematic of green elements of design and manufacturing is shown in Fig. 1. [8].

The aim of present research was to examine the effect of technological parameters and the applied method of cooling and lubricating on 3D parameters of surface roughness. We examined peripheral milling procedure. During our experiments and evaluations the machine tool (PERFECT-JET MCV-M8) and the 3D surface roughness measuring equipment (AltiSurf®520) were procured from European Union TIOP-1.3.1-07 project.

2. SURFACE FINISH AND INTEGRITY

The goal in any three-dimensional characterisation of surface topography is to integrate the surface features in a representative manner as accurately as possible. Many methods have been utilised to obtain a degree of surface visual characterisation, with notably the best technique at present being to describe the surface condition by a predefined series of parameters which can be quantifiably measured then related to practical operational performance [10]. In the framework of application of the European Union [Directorate of the EC (DG12)] the work done at the University of Birmingham [11] contributed to a large extent to development of 3D visualisation technics an determination of 3D surface features. In the final report of the project Prof. Stout and his co-workers worked out the „basic parameter set" the so called „Birmingham 14 parameters" [12], [13], [14].

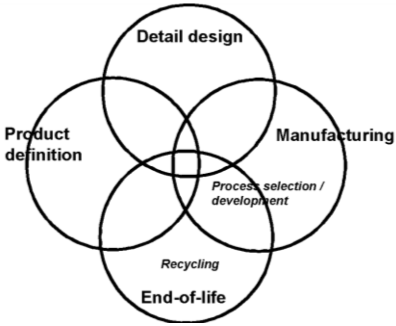


Figure 1 – Schematic relationships among the elements of green manufacturing [8]

Generally, they can be broken down into distinct groups:

• amplitude parameters - which are measures of the vertical characteristics of the surface deviations;

• spacing parameters - being measures of the horizontal characteristics of the surface deviations;

• hybrid parameters - are some combination of amplitude and spacing parameters;

• statistical parameters - amplitude heights treated as statistical data sets.

Later, the European project SurfStand [15], [16] improved these parameters by working on the correlation with functional specifications, and prepared the basis for a draft ISO standard [17].

ISO 25178 is the first international standard dealing with areal surface texture [17]. it contains several parts among which part 2 defines a set of areal parameters. Areal parameters are named with a capital S or V letter. Five main parameter groups are: “height parameters”, “spatial parameters”, “hybrid parameters”, “functional parameters”, and “feature parameters”. They are summarised in Fig. 2 [17]. As in this paper only some elements of the height parameters (Sq and Sa) will be examined, that is why the abbreviation and denomination of parameters belong to it is shown on Fig. 3.

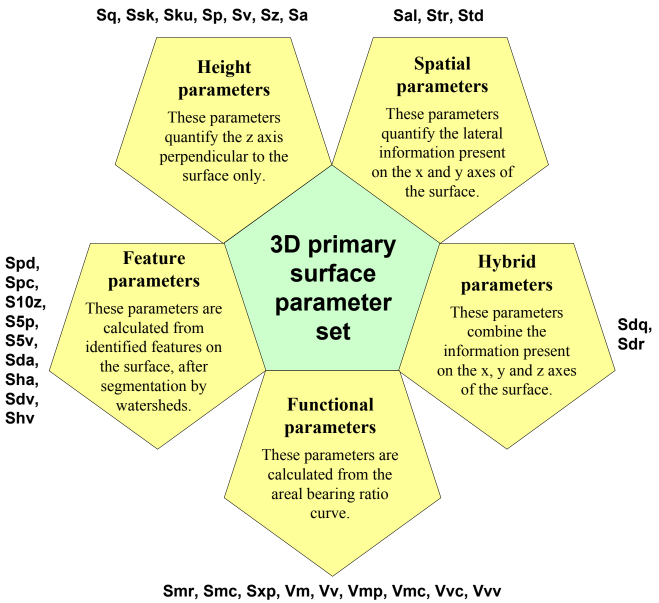


Figure 2 – Basic primary 3D surface parameter set in ISO 25178

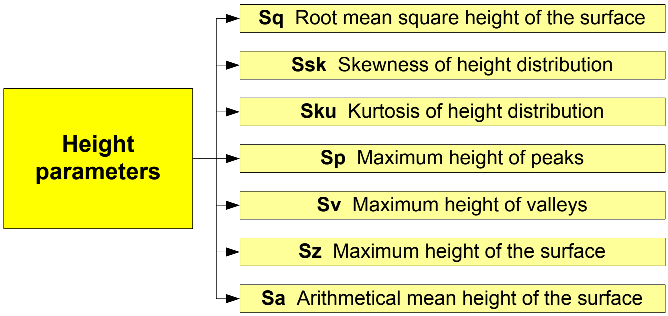


Figure 3 – Height parameters in ISO 25178

3. Research CONDITIONS

The type of milling cutter used in the experiment: Ø11.582 mm long solid carbide end mill, produced by Karnasch, number of teeth is 4 without coating. Type of the applied machine tool is PERFECT-JET MCV-M8. The workpiece materials are Steel AISI 1045 (Tensile stress 770 MPa) wherein we made 27 mm long outer cylindrical surfaces Ø29 mm (Fig. 4). During experiments dry machining, was executed without using coolants. On the milling centre the possible maximum volume of coolants and lubricants could set to 44 ℓ/h. At our experiments we set only 1.17 ℓ/h, so we pretend this as minimum quantity lubrication (MQL). The 3D surface roughness measurements were executed on the AltiSurf®520 equipment (Fig. 5).

Figure 4 – Clamping of the machined specimen

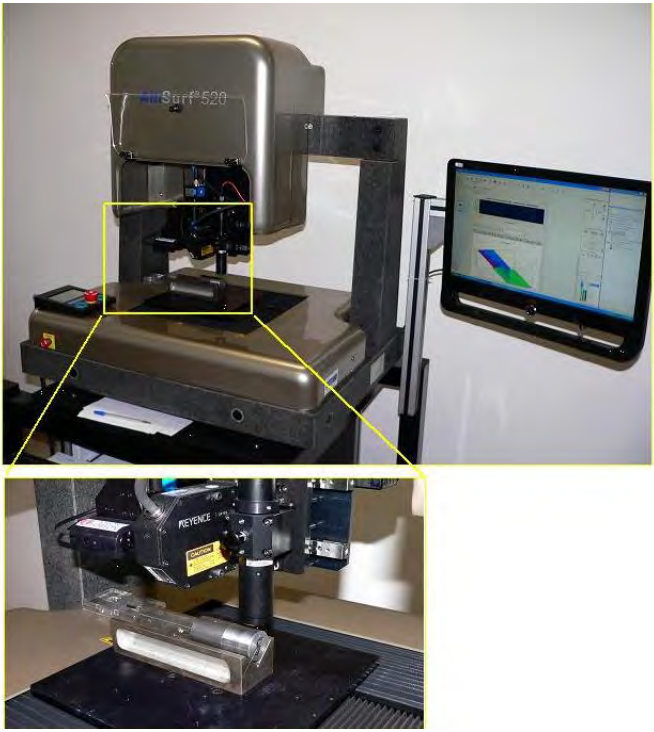


Figure 5 – AltiSurf®520 3D surface roughness measuring equipment

4. 3D SURFACE ANALYSIS OF MILLED SPECIMEN

By using of Factorial Experiment Design a great number of experiments were elaborated. We have chosen 8 experiments among them in order to show the results of 3D surface analysis. The measured area was 1 mm x 1 mm on the milled surface. In this paper let us consider how the cutting speed (v_c), feed rate (v_f), and the volume of coolants and lubricants ($\dot{V}_{Emulsion}$) has effect on milling process related the 3D surface characters. The experiment plan is shown in Table 1.

Characterized 3D views of measured surfaces.

For each groups a featuring 3D view of surfaces are summarized in the book Blunt & Jiang [16]. The 3D picture of one measured surfaces are shown in Fig. 5.

The seven height parameters (Fig. 3) are used for characterizing the amplitude property of surfaces. They are classified into four categories, i.e. dispersion, extreme, asymmetry of the height distribution and sharpness of the height distribution. Among them are the Sa (arithmetical mean height of the surface) and the Sq (Root-Mean-Square Deviation of the Surface).

Table 1 – Adjusted technological parameters and the number of experiments

Number of experiments	Feed rate, m/min	Cutting speed, m/min	Volume of emulsion, ℓ/h
1	0,3	54.55	0.0 (dry)
2	0,5	54.55	0.0 (dry)
3	0,3	65.46	0.0 (dry)
4	0,5	65.46	0.0 (dry)
5	0,3	54.55	1.17
6	0,5	54.55	1.17
7	0,3	65.46	1.17
8	0,5	65.46	1.17

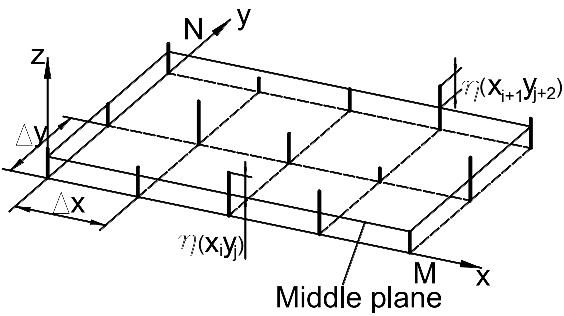


Figure 5 – Basic dimensions for 3D evaluation

The Roughness average is the arithmetic mean of the absolute values of the surface departures from the mean plane [17].

$$Sa = -\frac{1}{M \cdot N}\sum_{j=1}^{N}\sum_{i=1}^{M}\left|\eta\left(x_i, x_j\right)\right| \tag{1}$$

where, *M* is a number of points of per profile, *N* is the number of profile. **Sa** is normally used to describe the roughness of machined surfaces. It is useful for detecting variations in overall surface height and for monitoring an existing manufacturing process. A change in **Sa** usually signifies a change in the process.

Root-Mean-Square Deviation of the Surface Sq

The root mean square (RMS) roughness, obtained by squaring each height value in the dataset, then taking the square root of the mean [15], [16].

$$Sq = \sqrt{\frac{1}{M \cdot N}\sum_{j=1}^{N}\sum_{i=1}^{M}\eta^2\left(x_i, y_j\right)} \tag{2}$$

This is a dispersion parameter defined as the root mean square value of the surface departures within the sampling area. Sq cannot detect spacing differences or the presence of infrequent high peaks or deep valleys. *Sq* is a very general and widely used parameter. In statistics, it is the sample standard deviation.

The measured surface on the milled surface was 1 mm x 1 mm volt. Along the generatrix of the cylinder we made 3 measurements in different sections: at the beginning, at the middle, and at the end of the cylinder (Fig. 6.) and we made 5 measurements at each sections (Fig. 7). Average values were calculated in every sections and along the generatrix. The result of measurements are shown in Table 2 and 3, and Figure 8 and 9.

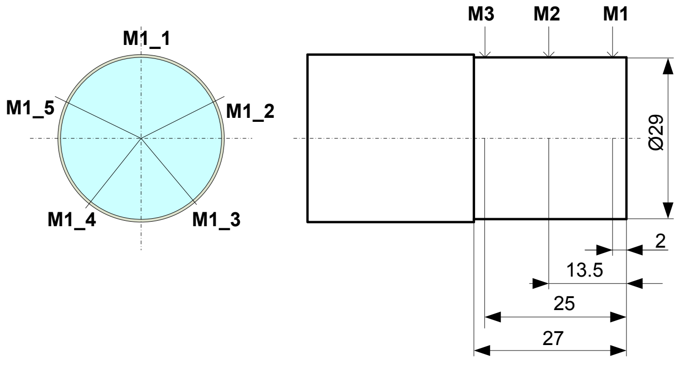


Figure 6 – Geometric data of specimen and places of measurements

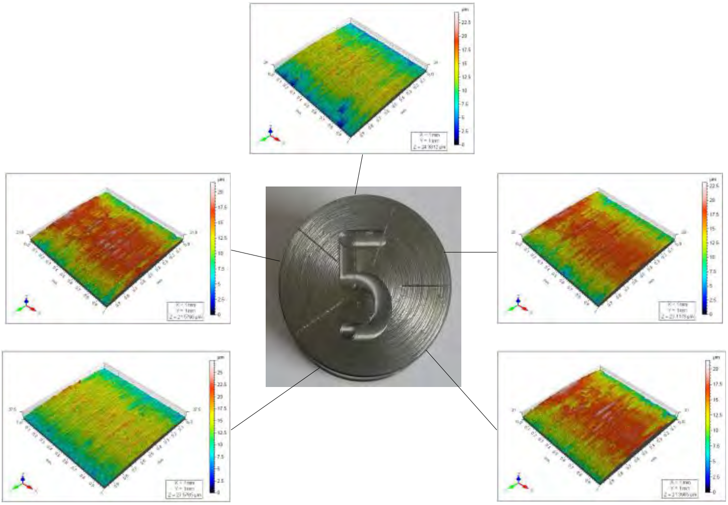


Figure 7 – Measurement results at the case of specimen 5 (experiment 5)
at the beginning of the specimen

Table 2 – Measuring results of Arithmetic mean height of the surface

Sa	v_{f1}= 0,3 m/min	v_{f2}= 0,5 m/min
v_{c1}=54.55 m/min	2.896 μm	2.794 μm
v_{c2}=65.46 m/min	3.050 μm	2.719 μm

a) in case of dry milling
($V_{emulsion\ 1}$ = 0.0 ℓ/h)

Sa	v_{f1}= 0,3 m/min	v_{f2}= 0,5 m/min
v_{c1}=54.55 m/min	2.822 μm	2.760 μm
v_{c2}=65.46 m/min	2.980 μm	2.654 μm

b) when using coolant and lubricant
($V_{emulsion\ 2}$ = 1,17 ℓ/h)

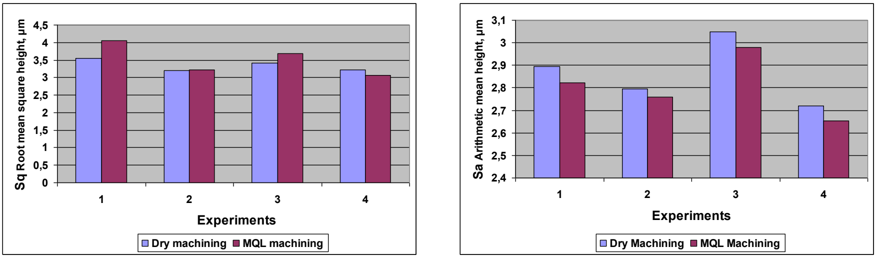
Table 3 – Measuring results of Root-Mean-Square Deviation of the Surface

Sq	v_{f1}= 0,3 m/min	v_{f2}= 0,5 m/min
v_{c1}=54.55 m/min	3.546 μm	3.200 μm
v_{c2}=65.46 m/min	3.419 μm	3.213 μm

a) in case of dry milling
($V_{emulsion\ 1}$ = 0.0 ℓ/h)

Sq	v_{f1}= 0,3 m/min	v_{f2}= 0,5 m/min
v_{c1}=54.55 m/min	4.062 μm	3.214 μm
v_{c2}=65.46 m/min	3.695 μm	3.064 μm

b) when using coolant and lubricant
($V_{emulsion\ 2}$ = 1,17 ℓ/h)



a) b)

Figure 8 – Comparing of measuring results of amplitude parameters between dry and cooled milling (bar chart)

Empirical formulas can be determined from experiments by using factorial experimental design. Equation (3) shows the calculated empirical equation valid for the range of parameters: Cutting speeds: v_{c1} = 54.55 m/min; v_{c2} = 65.46 m/min; Feed rates: v_{f1} = 0.3 m/min, v_{f2} = 0.5 m/min; Volume of emulsion: $V_{emulsion\ 1}$ = 0 *l*/h; $V_{emulsion\ 3}$ = 1.17 *l*/h.

$$Sa = k_0^{Sa} + k_1^{Sa} \cdot v_f + k_2^{Sa} \cdot v_c + k_3^{Sa} \cdot \dot{V}_{Emulsion} + k_{12}^{Sa} \cdot v_f \cdot v_c + \\ + k_{13}^{Sa} \cdot v_f \cdot \dot{V}_{Emulsion} + k_{123}^{Sa} \cdot v_f \cdot v_c \cdot \dot{V}_{Emulsion} + k_{123}^{Sa} \cdot v_f \cdot v_c \cdot \dot{V}_{Emulsion} \quad (3)$$

where:

$k_0^{Sa} = 0.562$ $k_1^{Sa} = 5.215$ $k_2^{Sa} = 0.046$ $k_3^{Sa} = -0.356$

$k_{12}^{Sa} = -0.105$ $k_{13}^{Sa} = 0.919$ $k_{23}^{Sa} = 4.427x10^{-3}$ $k_{123}^{Sa} = -0.014$

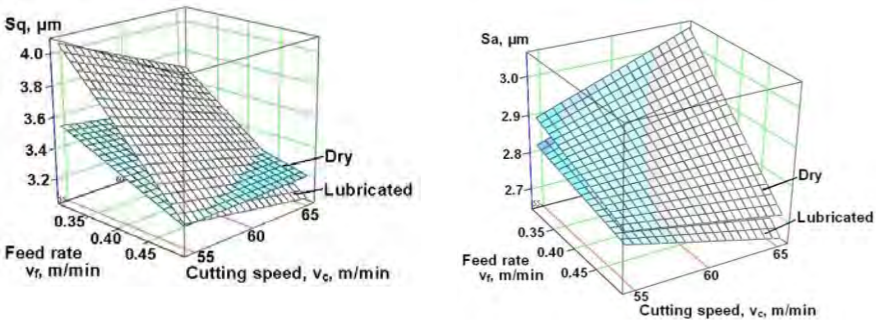
and

$$Sq = k_0^{Sq} + k_1^{Sq} \cdot v_f + k_2^{Sq} \cdot v_c + k_3^{Sq} \cdot \dot{V}_{Emulsion} + k_{12}^{Sq} \cdot v_f \cdot v_c + \\ + k_{13}^{Sq} \cdot v_f \cdot \dot{V}_{Emulsion} + k_{23}^{Sq} \cdot v_c \cdot \dot{V}_{Emulsion} + k_{123}^{Sq} \cdot v_f \cdot v_c \cdot \dot{V}_{Emulsion} \quad (4)$$

where:

$k_0^{Sq} = 5.750$ $k_1^{Sq} = -5.230$ $k_2^{Sq} = -0.031$ $k_3^{Sq} = 2.604$

$k_{12}^{Sq} = 0.064$ $k_{13}^{Sq} = -3.791$ $k_{23}^{Sq} = -0.028$ $k_{123}^{Sq} = 0.030$



a) b)

Figure 9 – Comparing of measuring results of amplitude parameters between dry and cooled milling (3D diagram)

The value of ―Arithmetic mean height of the surface (**Sa**)" is higher in dry machining than in the case of using minimum volume of coolants and lubricants. However the change of nature of Sa and its value and is different in lower and higher feed rates whe changing the cutting speed.

- In case of dry cutting the increase of cutting speed by 20% (from v_{c1} to v_{c2}) caused 5.3% reduction in in the value of **Sa** at the smaller feed rate (v_{f1}) while at the larger feed rate (v_{f2}) the increase of **Sa** was only 2.7%. In case of applying minimum volume of coolants and lubricants when increasing the cutting speed the value reduction of **Sa** was 5.6% at smaller feed rate (v_{f1}) and 3.8%- at higher feed rate v_{f2}. Consequently almost unchangeable.
- When examamination is done in the function of feed rate from v_{f1} to v_{f2} by 66.7% it can be stated that in dry cutting the increase of feed rate caused 9.7% decrease in the value of **Sq** when smaller cutting speed (v_{c1}), while 6.0% at higher cutting speed (v_{c2}). When using minimum volume of coolants and lubricants the decrease of **Sq** value was 20.9% at v_{c1} and 17,0% at v_{c2}.

5. CONCLUSIONS

The paper showed how the 3D surface roughness values of milled workpieces are changing in case of environmentally friendly cutting of AISI 1045 steel. Dry milling and milling with high volume coolants ($V_{emulsion}$ = 1.17 ℓ/h) were examined. The most important conclusions are summarised below:

in case of higher values of feed rate and cutting speed milling, when using minimum volume of coolants and lubricants, showed better - that is smaller - values related to Sa and Sq parameters.

The smallest values of Sa and Sq parameters could be get when applying the minimum volume of coolants and luricants at higher cutting speeds and feed rates.

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