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Original scientific paper *

INVESTIGATION OF THE CUTTING PARAMETERS INFLUENCE ON SURFACE ROUGHNESS IN TURNING AISI 1045 STEEL

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Abstract. *With surface roughness being one of the main quality requirements of machining, it is important to know how different machining parameters influence it. This paper presents experimental results of measured surface roughness values at different parameter combinations in external turning of AISI 1045 steel. Parameters that were used (cutting speed, depth of cut and feed rate) were varied in their selected ranges at three levels. Measurements were performed on the MahrSurf-XR1 surface roughness measuring machine, with the precision of 0.001µm. It was concluded that feed rate has the largest influence on surface roughness, followed by depth of cut and cutting speed. With an increase in feed rate, surface roughness increases, and with an increase in cutting speed and depth of cut, surface roughness decreases.*

Key words: *Surface roughness, Turning, AISI 1045, Cutting parameters.*

1. INTRODUCTION

A major focus of academic and industrial research, related to the improvement of the machining industry, is on creating new machining processes or optimizing and improving the existing ones. Creating „green machining" operations, optimizing machining parameters, creating mathematical models for prediction of different machining aspects, etc., are some of the paths for research in this area. In addition, turning processes, processes used for creating cylindrical parts, are a major part of the machining industry, and as such are often being improved.

As surface roughness is one of the major requirements of the machining industry and turning operations, it is important to know how different parameter combinations can influence it. Research has already been done in this area regarding different machining

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systems (machine tools, cutting tools, cooling and lubrication environment, workpiece materials).

Guo et al. [1] presented a two-step approach for minimizing energy consumption for specified surface roughness in finish turning by optimizing cutting parameters. They used steel (11SMnPb30) and aluminum (AlCuMgPb) as workpiece materials in the experiments. It was concluded that with an increase in depth of cut and feed rate, surface roughness increases, while with an increase in cutting speed, surface roughness decreases. Camposeco-Negrete [2] concluded that feed rate was the biggest factor in minimizing surface roughness in machining of AISI 6061 T6 aluminum. Surface roughness was mostly influenced by feed rate (with decreasing feed rate, surface roughness increased), and less by cutting speed and depth of cut. Bagaber and Yusoff [3] concluded that feed rate contributed with 53.8% to surface roughness, followed by cutting speed (11%), in turning of AISI 316 austenitic stainless steel. Su et al. [4] determined that for turning an AISI 304 austenitic stainless steel part, optimal parameters for decreasing surface roughness (Ra) and specific energy consumption, and increasing material removal rate were: depth of cut of 2.2 mm, feed rate of 0.15 mm/rev, and cutting speed of 90 m/s. Senthilkumar et al. [5] experimented with surface roughness (among other parameters) of a turned AISI 1045 steel part, by using different machining parameters, such as depth of cut, cutting speed and feed rate. The range of depth of cut was 0.3 - 0.6 mm, which is not too excessive for this material. The obtained optimal parameter combination was: depth of cut of 0.3 mm, feed rate of 0.203 mm/rev and cutting speed of 256 m/min. Iqbal et al. [6, 7] also considered turning of AISI 1045 steel material, but only investigated the effect that cutting speed has on different performance characteristics. Sangwana and Kanta [8] investigated energy consumption and surface roughness in machining of AISI 1045. The authors concluded that feed rate is the most significant parameter for the reduction of energy consumption and surface roughness, followed by depth of cut and cutting speed.

Abbas et al. [9] investigated the impact of various cooling and lubrication techniques on surface roughness and power consumption. Optimization methods were used to find the optimal parameter combination for each cooling and lubrication condition. Bhattacharya et al. [10] determined the effects that feed rate, cutting speed and depth of cut have on surface roughness and power consumption while turning AISI 1045 material. Cutting speed was the most significant parameter for surface roughness, followed by feed rate and depth of cut. The optimal values of surface roughness were found to be for the cutting speed of 240 m/min and the feed rate of 0.125 mm/rev.

The goal of this study is to investigate the effect of cutting parameters on surface roughness in external longitudinal turning of AISI 1045 steel. This steel was selected for its good machinability and wide application in the industry. In the experiment, three cutting parameters, namely, cutting speed, depth of cut and feed rate were varied at three levels. Upon conducting the machining experiment a suitable measurement system was used for data acquisition upon which the analysis of the cutting parameters influence on the resulting surface roughness was performed.

2. EXPERIMENTAL SETUP

The experiment was done in two phases. The first phase was the machining of workpieces on a CNC lathe machine, with different parameter combinations. In the second phase, the surface roughness of the previously machined workpieces was measured by a surface roughness measuring device.

2.1 First phase of the experiment

The first phase of the experiment was conducted on the Gildemeister NEF 520 CNC lathe machine, with a CNMG120408-PM cutting insert in wet conditions (cutting oil – FAM SG 15 N (ISO 6743-7, L-MHE; ISO/TS 12927)). Three workpieces of initial dimensions Ø60 x 500 mm were used. All three workpieces were pre-machined to ensure an elementary cylindrical shape and straightness, reduce circular runout and to create proper fixture surface (Fig. 1).

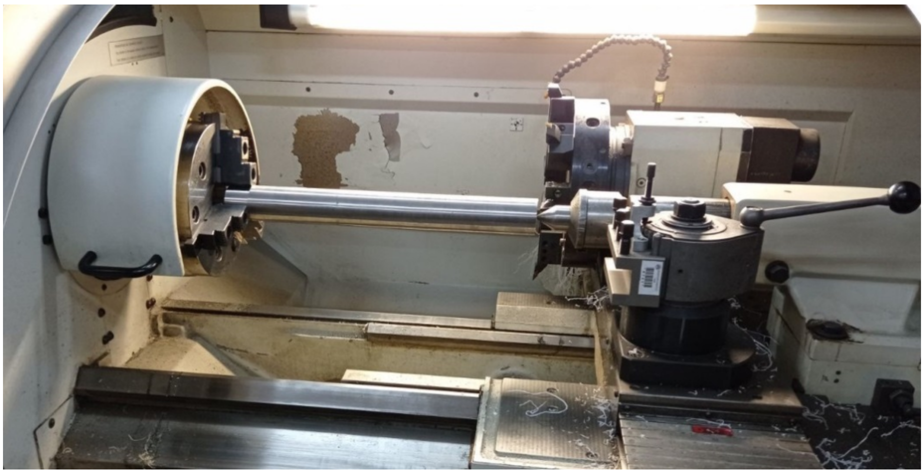

Fig. 1 Experimental setup

The geometrical and dimensional tolerances were checked after pre-machining so no irregularities or differences in workpieces would occur. Basic information about the machine, cutting tool and workpieces are given in Table 1.

Table 1 Machine, cutting tool and workpiece details

Machine	**Power [kW]**	**Max. rev [min^{-1}]**	**Control Unit**		
Gildemeister NEF 520	12	3000	Heidenhain Manual Plus 4110		
Toolholder	**Insert**		**Grade**		**Insert manufacturer**
DCLNL 2020K 12 Cutting edge angle 95°	CNMG120408-PM Le=12 [mm] Re =0.8 [mm]		YBC252* (P10-P35) (P10-P35)**		ZCC CT
Workpiece Material	**HB**	**k_c [N/mm2]**	**m_c**	**Starting diameter [mm]**	**Length [mm]**

AISI 1045	206	2000	0.15	58	500

*YBC252 comprises of thick layer of TICN and Al2O3 in CVD
**(P10-P35) is written on the tool manufacturer's box, but does not fully comply to the ISO standard mark (P20-P35)

Cutting speed (v_c), feed rate (f) and depth of cut (a_p) were the input parameters chosen for the experiment, as they are the most often used parameters in the reviewed literature. 27 different combinations of parameters were created from the following parameter values: a_p = {1, 1.675, 2.5} [mm]; f = {0.1, 0.2, 0.3} [mm/rev]; v_c = {240, 270, 300} [m/min]. Three workpieces were used, one for each depth of cut. Workpiece 1 had the depth of cut equal to 1 mm, workpiece 2 had the depth of cut equal to 1.675 mm, and workpiece 3 had the depth of cut equal to 2.5 mm. Fig. 2 illustrates the parameter combination positioning on workpieces (all workpieces had the same positioning of parameter combinations, just different depths of cut). L1 – L9 are segments that correlate to given parameter combinations, and surface roughness measurements were conducted on these segments. I1 – I8 are segments used for getting the needed cutting speed between two consecutive L segments (for example, I7 is between L7 and L8, which is used for getting the cutting speed of 240 - 270 m/min).

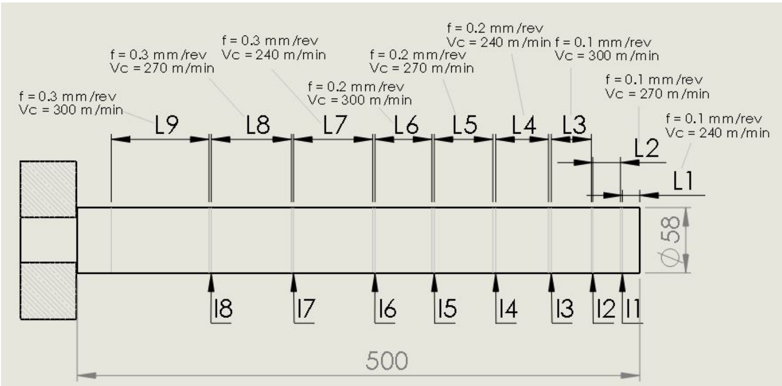

Fig. 2 Cutting parameter combinations used on the workpieces

After conducting all 27 experimental trials on the three workpieces, the first phase of the experiment was done. Fig. 3 illustrates the roughness of machined surface for the first three experiments with the depth of cut of 2.5 mm.

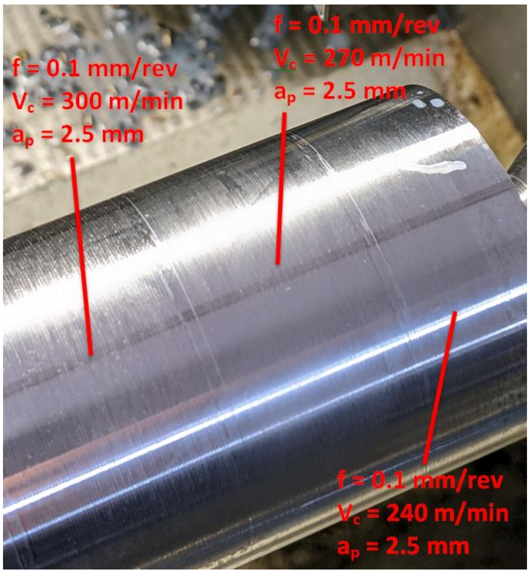

Fig. 3 Roughness of the machined surface

2.2 Second phase of the experiment

Surface roughness was assessed in terms of the arithmetic mean roughness (R_a), the average maximum peak to valley length (R_z), and the largest single roughness depth within the evaluation length (R_{max}). Surface roughness measurements were performed on the Mahr MarSurf XR 1 roughness measuring station (Fig. 4) using a skidless probe system BFW 250. The example of the obtained results can be seen in Fig. 5. The results obtained are twofold, firstly, profile of surface roughness can be seen, and secondly, the values of measured parameters are displayed (R_a, R_z, R_{max}).

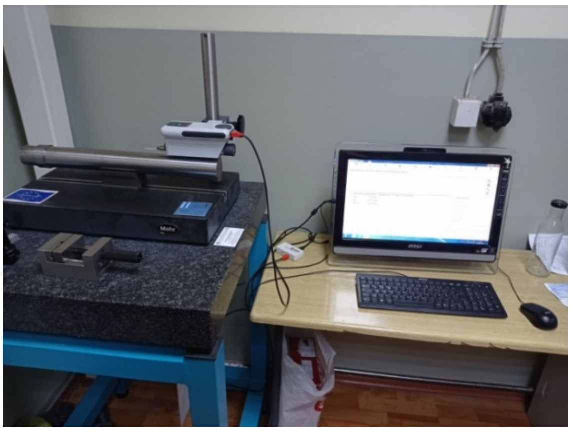

Fig. 4 MahrSurf-XR1 - Surface roughness measuring machine setup

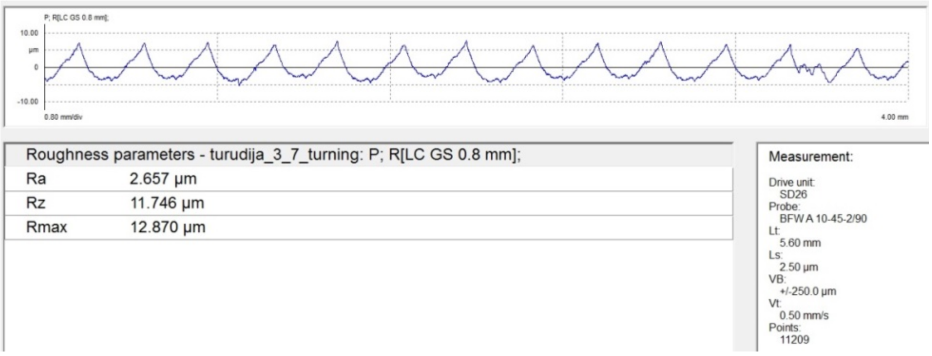

Fig. 5 Results for one segment - surface roughness profile and R_a, R_z, R_{max} values

The measurement conditions were chosen to meet the following roughness definition standards: reference length λc = 0.8 mm, number of repetitions of reference length n = 5, which means that the total test length is 5.6 mm. Measurement profile R and results are passed through the Gauss filter. The accuracy of the surface roughness-measuring device is 1 nm.

3. Results and Discussion

Fig. 6 displays trends for R_a, R_z and R_{max} measurement. In Fig. 6 one can notice some instabilities of the results when the feed rate is f = 0.1 mm/rev. These instabilities will be later discussed, but first some observations regarding parameter influence on surface roughness will be presented.

3.1 Feed rate effect on surface roughness

Surface roughness is, as it is expected, mostly affected by feed rate. The change of R_a can be clearly noticed, especially for the depth of cut of a_p=*2.5 mm*. (Fig. 7). In Fig. 6, a pattern can be noticed where R_a, R_z and R_{max} values with the feed rates of f = 0.2 mm/rev are always smaller than R_a values for the feed rates of f = 0.3 mm/rev. This means that with a smaller feed rate, surface roughness is better, which is in line with the reviewed literature.

It should also be noted that the achieved R_a values were lower than the theoretical values of surface roughness. For example, the calculated R_a value for the external turning operation with the insert geometry of r_e=0.8 mm, κ=95°, $κ_1$=5° and the feed rate of 0.2 mm was calculated at 1.6 µm but the achieved R_a value was 1.228 - 1.522 µm, depending on what cutting speed and depth of cut was used.

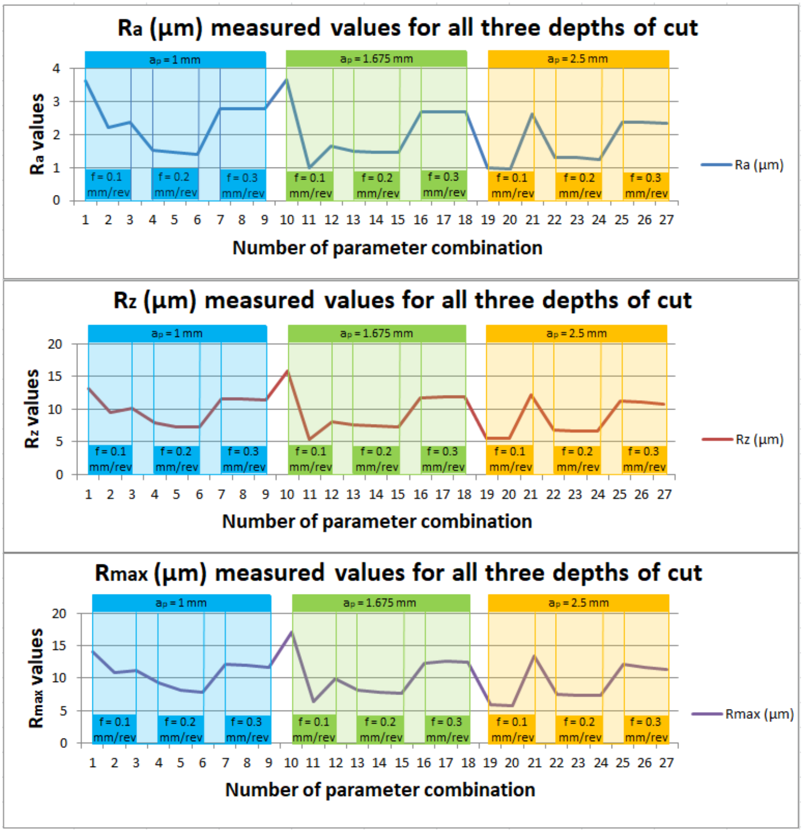

Fig. 6 Trends for R_a, R_z, R_{max} measurements

3.2 Cutting speed effect on surface roughness

From Fig. 8, it can be noted that there is some minor influence of cutting speed on surface roughness for the feed rates of f = 0.2 mm/rev and f = 0.3 mm/rev. It is not significant, but nevertheless it exists. For example, when looking at surface roughness when a_p = 1.675 mm and f = 0.2 mm/rev, R_a value dropped by about 1 % for the cutting speed of 270 m/min, and by about 1.5 % for the cutting speed of 300 m/min compared to the initial cutting speed of 240 m/min. Only two relatively larger changes can be seen, with a_p = 1 mm and f = 0.2 mm/rev. For these parameter combinations R_a value dropped by 3.68 % for the cutting speed of 270 m/min, and by 8.15 % for the cutting speed of 300 m/min. All the comparisons are presented in Table 2. Overall, higher cutting speeds yielded lower R_a values, which confirmed that surface roughness decreases with higher cutting speeds.

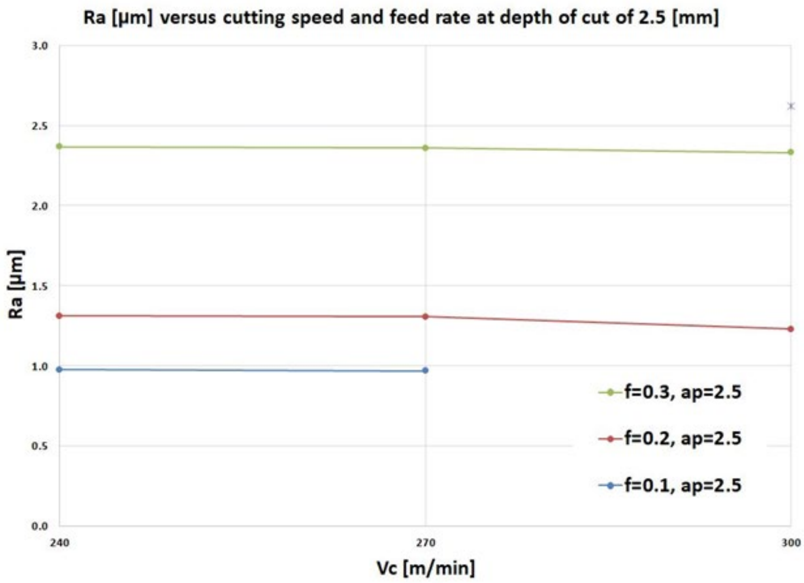

Fig. 7 Influence of feed rate on R_a when a_p = 2.5 mm

Table 2 Difference in R_a values for different cutting speeds (displayed in percentages)

	Compared cutting speeds (m/min)	a_p = 1mm	a_p = 1.675 mm	a_p = 2.5 mm
f = 0.2 mm/rev	240 -> 270	↓ 3.679%	↓ 1.073%	↓ 0.388%
	240 -> 300	↓ 8.147%	↓ 1.543%	↓ 6.474%
f = 0.3 mm/rev	240 -> 270	↓ 0.789%	↓ 0.148%	↓ 0.338%
	240 -> 300	↓ 0.502%	↓ 0.482%	↓ 1.520%

* ↓ - decreasing of R_a value

3.3 Depth of cut effect on surface roughness

With an increase in depth of cut, R_a values decrease, i.e., surface roughness decreases. This can be observed from Fig. 9, where for every same combination of cutting speed and feed rate, surface roughness is lower for higher depths of cut. There are two deviations from this trend. From Table 3, one can observe that R_a values for f = 0.2 mm/rev and v_c = 270 m/min with a_p = 1.675 mm increased by 0.61% compared to a_p = 1mm, with the same cutting speed and feed rate. This is also the case for parameter combinations of v_c = 300 m/min, f = 0.2 mm/rev, a_p = 1mm and v_c = 300 m/min, f = 0.2 mm/rev, a_p = 1.675 mm, where bigger depth of cut actually increased the value of R_a by 4.99%, resulting in the surface roughness increase. This may be caused by the unwanted vibrations during the turning process due to higher radial force at low depth of cuts or due to inadequate depth of cut and insert radius ratio in unstable cutting conditions.

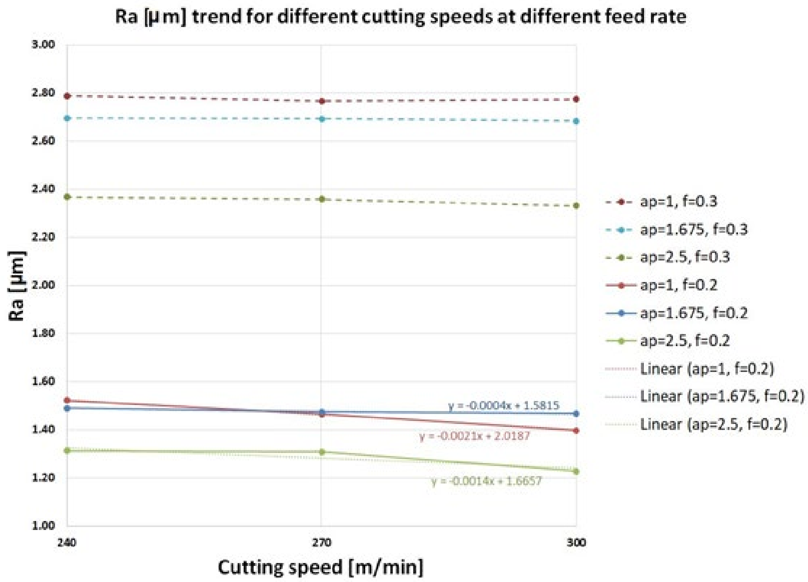

Fig. 8 Influence of cutting speed on R_a

Table 3 Difference in Ra values for different depths of cut (displayed in percentages)

	Compared depths of cut (mm)	v_c = 240 m/min	v_c = 270 m/min	v_c = 300 m/min
f = 0.2 mm/rev	1 -> 1.675	↓ 2.037%	↑ 0.614%	↑ 4.985%
	1 -> 2.5	↓ 13.712%	↓ 10.778%	↓ 12.158%
f = 0.3 mm/rev	1 -> 1.675	↓ 3.299%	↓ 2.685%	↓ 2.989%
	1 -> 2.5	↓ 15.095%	↓ 2.36%	↓ 15.721%

* ↓ - decreasing of R_a value, ↑ - increasing of R_a value

3.4 Instabilities regarding measured results for f = 0.1 mm/rev

For some reason, when the feed rate is f = 0.1 mm/rev, as shown in Fig. 10, the values of R_a are instable (trembling). For example, when looking at the chart that illustrates surface roughness when the feed rate is 0.1 mm/rev, cutting speed 240 m/min and depths of cut are 1 mm, 1.675 mm and 2.5 mm, which is the leftmost blue chart box, it can be seen that the surface roughness ranges from 1 µm to almost 4 µm, which is high, and these results are characterized as trembling. One can assume that the cause of measured surface roughness trembling could be the vibrations occurring on the farthest side of the workpiece, close to the tailstock, since the workpiece was 500 mm long, and according to the experimental plan, the first applied feed rate was 0.1 mm/rev. This vibration may cause such instable results as the ones that were obtained. In addition, the possible explanation for this phenomenon may lie in low axial forces which may stem from the workpiece bending, vibrations and poor chipping due to the unfavorable chip cross-section area.

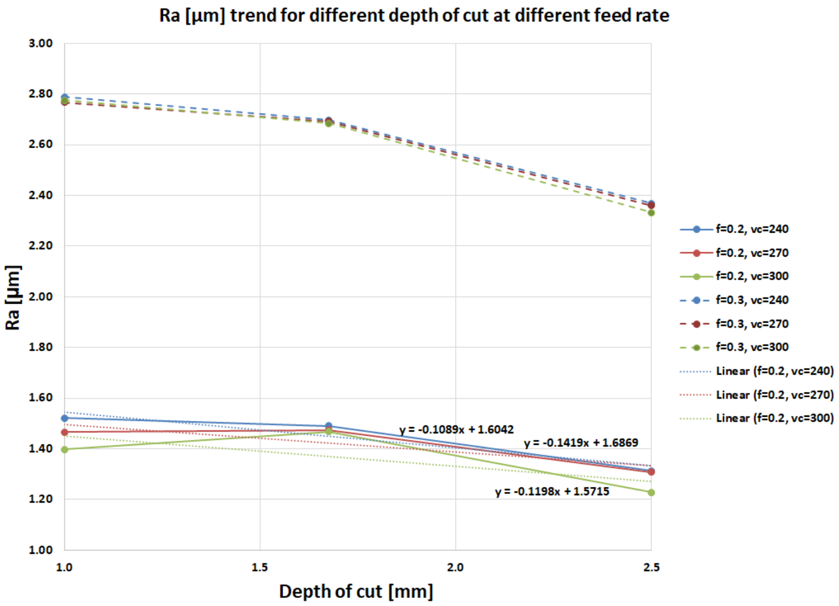

Fig. 9 Influence of depth of cut on R_a

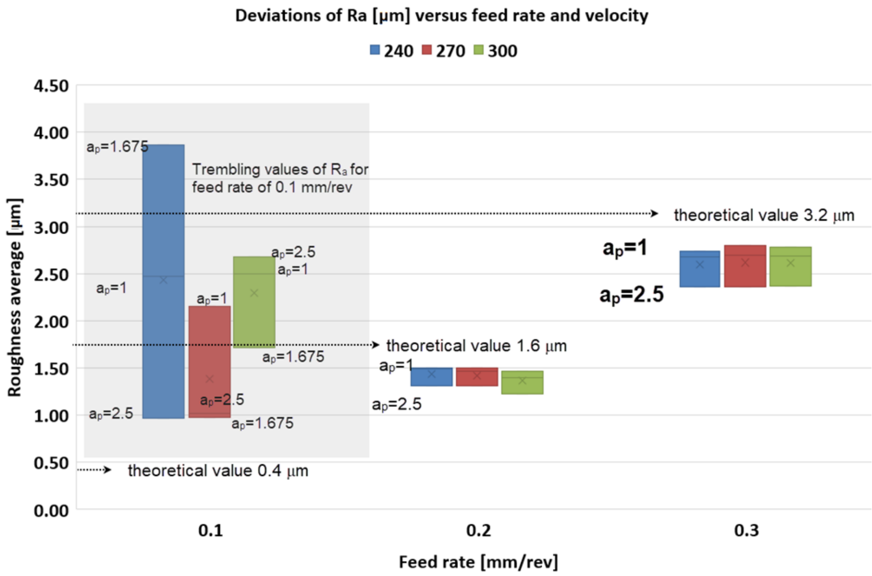

Fig. 10 Theoretical values of surface roughness in comparison to obtained results, as well as trembling values of surface roughness due to vibrations

CONCLUSION

Getting the best possible surface roughness is one of the major concerns of the machining industry. Because of this, the goal of the present paper was to investigate how different turning parameters affect surface roughness. The turning experiment was done using AISI 1045 steel workpiece material on Gildemeister NEF 520 with a CNMG120408-PM cutting insert. First, parameter ranges were selected within their recommended ranges and the experiment setup was established (experimental matrix, experimental setup with positioning of the workpieces, etc.). When the turning of each parameter combination was finished, surface roughness was measured with the Mahr MarSurf XR 1 roughness measuring station. As in the reviewed literature, it can be concluded that feed rate had the biggest influence on surface roughness, followed by depth of cut and cutting speed. Lower R_a values than the theoretical values of surface roughness were achieved. Adequate examples are presented.

Feed rate has the highest impact on surface roughness, and with an increase in feed rate, surface roughness also increases. Measurements showed that with an increase in depth of cut, surface roughness decreases in our experiments, which may not agree with the results from the literature. And even though depth of cut has a very small impact on surface roughness in relation to feed rate, it cannot be avoided to conclude that this phenomenon exists. It may be the case that with an increase in depth of cut, dynamic stability of the system of the machine, tools and workpiece also increases, which results in a decrease in surface roughness. Cutting speed has the lowest impact on surface roughness, and with its increase, surface roughness decreases. There were two deviations from this trend, the first being when the feed rate was 0.2 mm/rev and cutting speed was 270 m/min, and when a_p = 1.675 mm actually increased the value of R_a by 0.61% compared to a_p = 1mm, with the same cutting speed and feed rate. The second one was for parameter combinations of v_c = 300 m/min, f = 0.2 mm/rev, a_p = 1mm and v_c = 300 m/min, f = 0.2 mm/rev, a_p = 1.675 mm, where a bigger depth of cut actually increased the value of R_a by 4.99%, resulting in an increase in surface roughness.

Some observed instabilities regarding the resulting surface roughness in turning of AISI 1045 steel workpieces were observed when the feed rate was 0.1 mm/rev. These instabilities and root causes will be further investigated in more detail in the future work.

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