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An Experimental Based Approach Using Artificial Intelligence Algorithm for Determining the Surface Roughness by Milling Process

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Abstract

Surface roughness plays an important role in the machining area. This work aims to investigate surface roughness with the use of main machining parameters. Steel C35 is used as workpiece material while performing experimental work with twenty-one experiments, and coolant is taken as constant. The experimental model considers two ways to analyze the surface roughness using Artificial Intelligence. The first is the measurement of surface roughness after machining, and the second is to compare the measurement in a theoretical way.

Disciplinary: Mechanical Engineering.

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1 Introduction

The purpose of the experiment is to verify the coefficients and exponents based on the Taylor expression, for the surface roughness during the milling process in universal milling machines. In this way, it is possible to determine the optimal main machining parameters for conducting the experiment. The workpiece material for the case of our research will be investigated for steel C35.

The most influential factors in the research of surface roughness for prismatic workpieces are: v - cutting speed, f - working step and a - cutting depth, as influencing factors of the process. Other factors such as the refrigerant, the geometry of the metal cutting tool, and the rigidity of the processing system, and so these parameters in this paper are kept at a constant level because they are not the subject of their research [1-4].

Two models are developed for surface roughness depending on main machining parameters where one of the models is based on the regression model while the other model was developed with the help of artificial intelligence such as Neural Network and error of validations for this case are obtained with values 4.01% [5]. The authors present the predictive models for surface roughness Ra during the ball-end milling process which were developed using RSM, GA, and GWO algorithms. After that the validity of the model was confirmed using ANOVA methods, so the model accuracy for surface roughness was around 10% due to the setup of the experiments [6].

The authors have developed the predictive models for surface roughness both for metal and aluminum using high-speed milling operation [7], also other research has used artificial intelligence to predict the surface roughness into deep drilling for some steel components [8]. Effect of Various Microstructures Obtained from Heat Treatment on Machinability Behavior of Ti-6Al-4V Alloy, by drilling process [9]. This study investigates the surface roughness properties of specimens that were machined mechanically in a different way before the measuring in order to achieve a different roughness. Workpiece materials and research methods by milling machining are determined to choose the milling tool, main machining parameters, positioning of the workpiece, analytical model to compare the results and to predict the best surface roughness Ra with utilize of Neural Network.

2 Methods and Material

The realization of the experiment procedure is described as follows step by step as seen in Figures 1 and 2. These experiments are included the type of material, equipment for testing the hardness of the material, saw machine, milling machine, the main machining parameters, the equipment for measuring the surface roughness, as well as Matlab software for comparing theoretical and practical results and validation of the experiment. The dimensions of the workpiece are bxhxl (62x16x200) mm, the type of material is C35, it is also determined through the device SADT Hartip 300 as in Figure 1.

Figure 1: Portable hardness tester HARTIP 3000.

Table 1 shows the chemical composition of steel C35.

Table 1: chemical composition of workpiece material C35.

Elements	Symbols	Percent [%]
1	C	0.32 – 0.39
2	Si	Max 0.4
3	Mn	0.5 – 0.8
4	Ni	Max 0.4
5	P	Max 0.045
6	S	Max 0.045
7	Cr	Max 0.4
8	Mo	Max 0.1

During the experimental approach of milling process emulsion, it is used as coolant regarding in the experiment setup. The setup experiment of surface roughens is presented step by step as follows (see Figure 2).

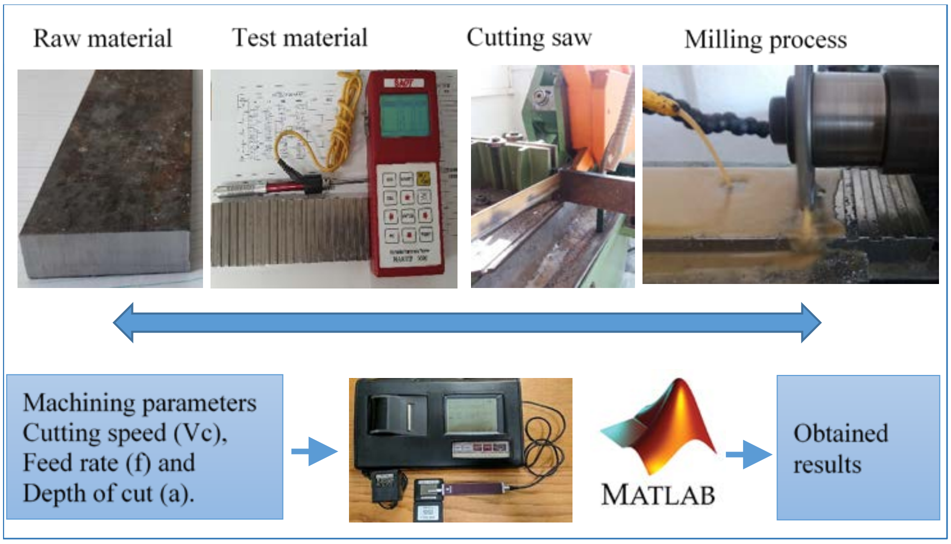

Figure 2: Setup experiment for surface roughness

The type of milling tool is staggered-tooth side milling cutters HSSECo5, with dimensions 80x5x27 (mm), and 32 cutting teeth. These cutting tools are utilized for slot milling and parting off, or when only the sides of the workpiece are to be machined in straddle setups, which are described in their characteristics in Table 2 [11, 12].

Table 2: Cutting tool characteristics.

Type	N
Milling cutter design standard	DIN 1834
Cutting tool material	HSSE Co5
Cutting edge diameter	80 [mm]
Number of teeth Nz	32
Bore diameter	27 [mm]
Width of cutting edge	5 [mm]

Artificial intelligence such as Neural networks is used for our experiment to determine the surface roughness for the milling process based on the main machining parameters (cutting speed v, feed rate f, and depth of cutting a). The diagram of surface roughness using Artificial Intelligence AI, based on the number of inputs, hidden layers, and till output functions for our case Ra (see Figure 3).

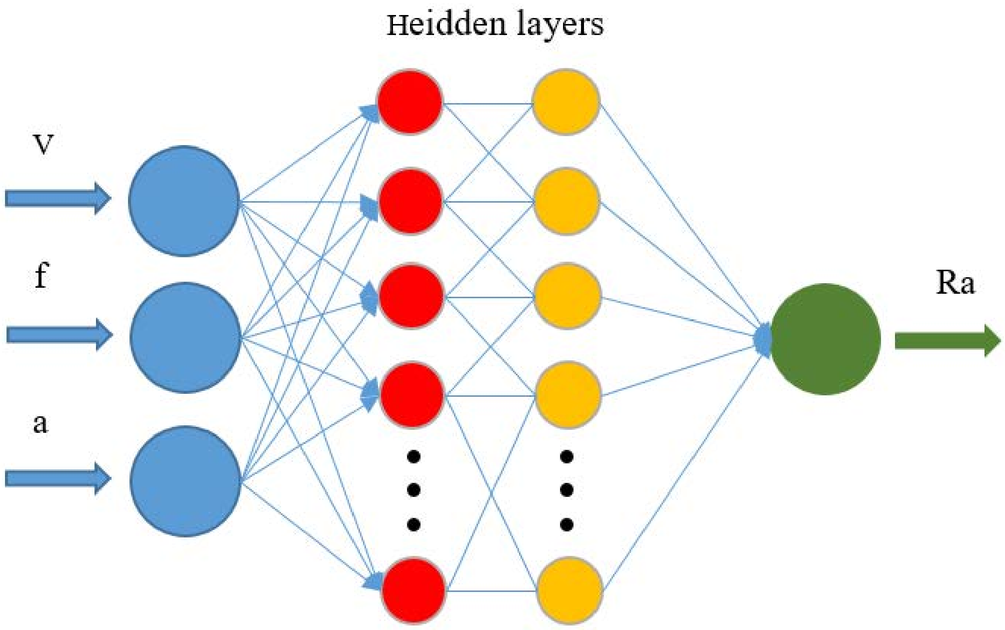

Figure 3: Diagram of surface roughness Ra, using AI.

Matrix plan - for the realization of the experimental part based on the main machining parameters, universal milling machine, metal cutting tool, etc. Table 3 are showed the matrix plan with main machining parameters and experimental plan. Also, are presented the measurement values of surface roughness after the cutting process regarding the experiment, and the measurement value is calculated to compare the practical part of the experiment with the theoretical part.

Table 3: The level of main machining parameters for realization of experiment.

Inputs	Cutting speed (V=X1)	Feed rate (f=X2)	Depth of cut (a=X3)
1	X_{1max} = 255	X_{2max} = 0.3	X_{3max} = 1.5
2	X_{1mid} = 160	X_{1mid} = 0.2	X_{1mid} = 1.0
3	X_{1min} =100	X_{1min} = 0.13	X_{1min} =0.5

Determining the surface roughness function and selecting the level of input sizes as well as determining the mathematical model for the surface roughness of the milling process as output function is given by the expressions as

$$Ra = B \cdot v^{\beta 1} \cdot f^{\beta 2} \cdot a^{\beta 3} \quad (1).$$

The expression can take the form as follow:

$$Ra = B \cdot X_1{}^{\wedge \beta 1} \cdot X_2{}^{\wedge \beta 2} \cdot X_3{}^{\wedge \beta 3} \quad (2).$$

In Table 4, V is showed the tensile strength for nominal thickness like our experiment with dimension 200x62x16mm, and measurement of hardness with mid-value HB=166, as showed in Table 4, as well as from a theoretical aspect it is read the value of tensile strength Rm as in Table 4, with value 550 Mpa.

Table 4: the tensile strength RM.

Nominal thickness [mm]	To 16	16 – 100	100 - 250	250 – 500
Rm [Mpa]	550	520	500	470

3 Results and Discussion

In the following steps are presented the results for testing material and surface roughness. Using the device HARTIP 3000, it makes nine measurements and after that is automatically calculated the middle value and is compared with Vickers hardness (HV), hardness Brinell (HB) and Rockwell hardness HRB. Measurement of hardness Brinell (HB), by a plate with a nominal thickness of 16 mm, after nine measurements have been achieved the average value of nine measurements HB = 166, based on Figure 1, when determining the type of steel as C35. Hardness measurements for the material selected for the surface roughness analysis, then the nominal D values of the hardness measurements are given below and also compared to HV, HB and HRB as in Table 4.

Table 4: Hardness measurement for nominal value D and HV, HB, HRB.

Test nr.	D	HV	HB	HRB
1	662	169	166	85.6
2	682	191	188	90.7
3	671	179	176	88.0
4	620	127	126	71.6
5	656	162	160	83.9
6	682	191	188	90.7
7	630	136	135	75.5
8	670	181	178	88.5
9	683	192	189	90.9
Mid value	662	169	166	85.6

This work measures surface roughness Ra, Rt and Rq, whereas we have the choice to present and analyze surface roughness Ra. As a device for measurement of surface roughness it utilizes the measuring tool from the company Mitutoyo type SurfTest SJ-301, also some input data are determined into the device as Standard ISO 1197, range AUTO, profile R, N = 5, Cut-off = 2.5, filter Gauss [10].

Scientists and engineers mainly collect the data in order to determine the nature of a relationship between theoretical and practical experiments. The experiment thus generates various data that could be denoted (x1, xn, . . . , xi+1), based on the machining parameters. The equation can be used for many purposes in the field of manufacturing such as surface roughness, measurement of temperature, cutting force, etc [15].

After some calculation of regression coefficient (B = 1.085; β_1 = 0.096; β_2 = 0.022; β_3 = 0.011) and combination of value for main machining parameters the expression is obtained,

$$Ra = 1.085 \cdot X_1{}^{\wedge 0.096} \cdot X_2{}^{\wedge 0.022} \cdot X_3{}^{\wedge 0.011} \qquad (3).$$

The investigation of the measured profile and R-Profile of surface roughness is presented with values Ra_{11} = 1.50 μm, Rz_{11} = 9.0 μm and Rq_{11} = 1.86 μm. Completely based on the input data of the Mitutoyo measuring device such as Profile R, cut-off 2.5 mm, filter gauss and range AUTO as seen in the output of measurements in Figure 4.

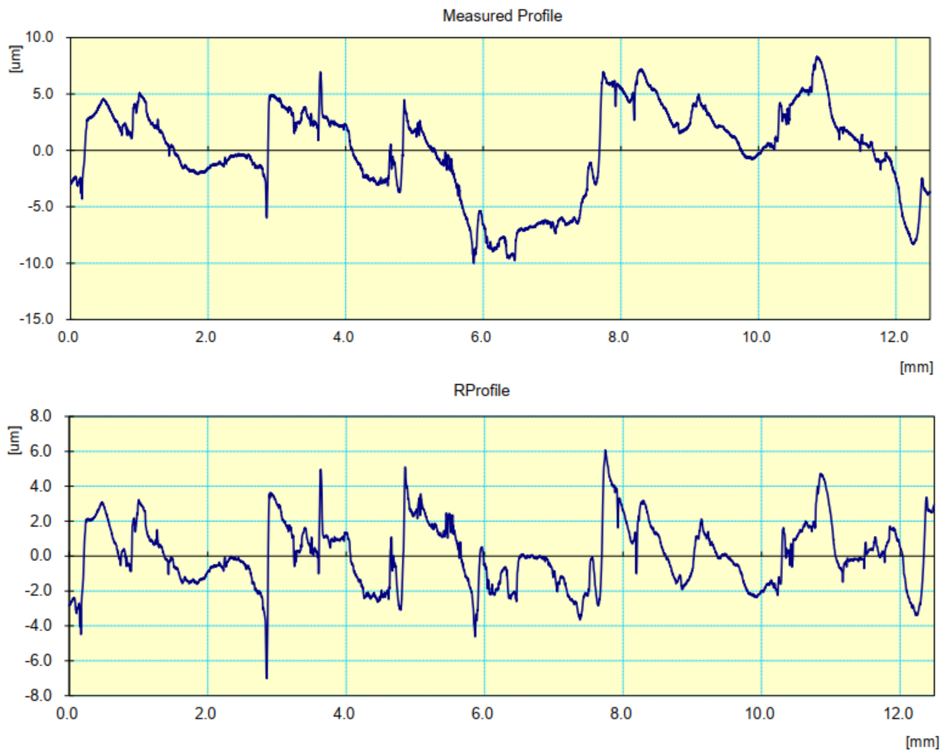

Figure 4: Measurement of surface roughness with Mitutoyo device.

Table 5 presents an experimental measurement of surface roughness Ra, Rq and Rt.

Table 5: Measurement of surface roughness Ra, Rq and Rt.

Nr. Exper.	Spindle speed n [rpm]	Feed rate f [mm/min]	Depth of cut [mm]	Ra [µm]	Rq [µm]	Rt [µm]
1	100	13	0.5	1.03	1.30	6.41
2	100	13	1	1.26	1.58	7.73
3	100	13	1.5	1.69	2.07	8.13
4	160	13	1.5	1.78	2.28	12.66
5	160	13	1	1.43	1.73	7.77
6	160	13	0.5	1.59	2.03	9.92
7	255	21	0.5	1.41	1.89	11.07
8	255	21	1	1.70	2.06	8.91
9	255	21	1.5	1.84	2.26	10.69
10	160	21	1.5	1.79	2.12	9.93
11	160	21	1	1.50	1.86	9.00
12	160	21	1	1.18	1.51	6.86
13	160	21	1	1.71	2.06	9.98
14	160	21	1	1.42	1.87	10.41
15	100	33	0.5	1.91	2.33	10.33
16	100	33	1	1.42	1.72	7.98
17	160	13	0.5	1.75	2.23	11.53
18	160	33	1	1.69	1.99	8.43
19	255	13	0.5	1.29	1.63	7.97
20	255	21	1.5	1.16	1.37	6.72
21	255	33	1.5	1.20	1.56	8.35

The model is significant when it fulfilled the conditions, and when the surface roughness prediction error is taken with five (5) percent as a value for orientation Ft = 10.01 and calculation of Fr, with value 2.406, as

$$F_r < F_t \quad (4).$$

After the calculation, the results are achieved as

$$2.406 < 10.01 \quad (5).$$

Table 6 showed the matrix plan and results of the natural logarithm of measurement surface roughness only for parameter Ra.

Table 5: Measurement of surface roughness Ra, Rq and Rt.

Nr. Exper.	X1	X2	X3	Measurement value Ra [µm]	Natural algorithm Y = lnRa	Theoretical value Ra [µm]
1	-1	-1	-1	1.03	0.03	1.401
2	-1	-1	0	1.26	0.231	1.41
3	-1	-1	1	1.69	0.525	1.419
4	0	-1	1	1.78	0.577	1.484
5	0	-1	0	1.43	0.358	1.475
6	0	-1	-1	1.59	0.464	1.466
7	1	0	-1	1.41	0.344	1.549
8	1	0	0	1.70	0.531	1.558
9	1	0	1	1.84	0.61	1.568
10	1	1	1	1.79	0.582	1.584
11	0	0	0	1.50	0.405	1.49
12	0	0	0	1.18	0.166	1.49
13	0	0	0	1.71	0.536	1.49
14	0	0	0	1.42	0.351	1.49
15	-1	1	-1	1.91	0.647	1.431
16	-1	1	0	1.42	0.351	1.44
17	0	-1	-1	1.75	0.56	1.466
18	0	1	0	1.69	0.525	1.506
19	1	-1	-1	1.29	0.255	1.533
20	1	0	1	1.16	0.148	1.568
21	1	1	1	1.20	0.182	1.584

Table 6 presents the analysis of relative errors, squares validation, mean squared and absolute errors using the Matlab software, such as the neural network.

Table 6: Analysis of relative errors.

Analysis of errors and squares	Values
Relative mean error (RME)	1.8093
R-squared validation	-28.24
Mean squared (MSE)	3.2737
Mean absolute errors (MAE)	0.47333

A new method of measurement of surface roughness is presented based on a color distribution statistical matrix, also as an optimal selection of machining parameters for the milling process is described [16, 17].

Figure 5 shows the 21 experiments of surface roughness that are generated in depend on measurement data, where blue points presented the practical measurement and yellow points are a predicted model in a theoretical way.

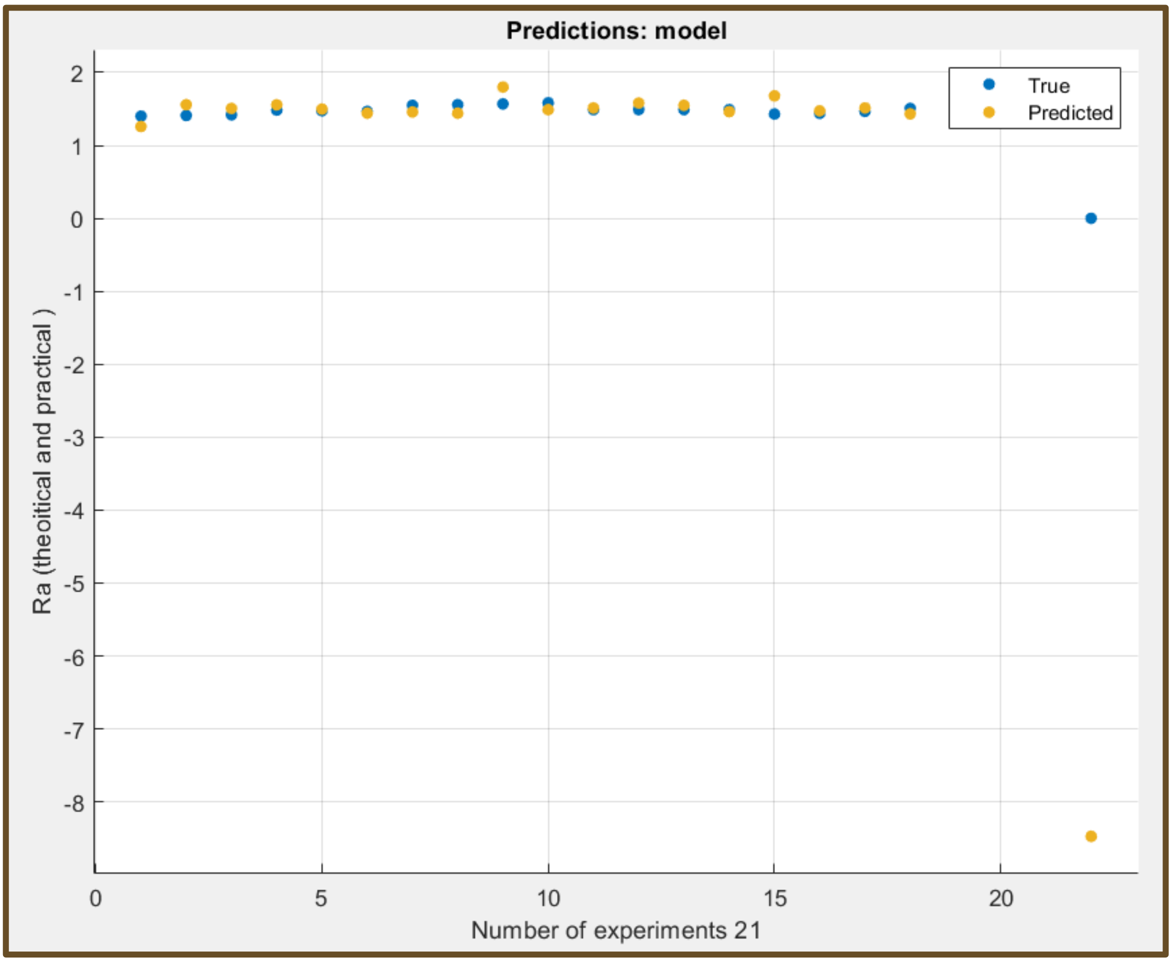

Figure 5: Comparison of the surface roughness value Ra for theoretical and practical.

Results are explained in Figure 6 for four measurements and their comparison from practical to theoretical way. Figure 6(a) shows the measurement of surface roughness R_{a1} which depended on the measurement of surface roughness in a practical way R_{a1p} =1.03 µm, regarding the theoretical value of surface roughness R_{a1t}=1.401 µm. Also, the diagram of Figure 6 is obtained depending on the main machining parameter as cutting speed (Vc m/min), depth of cut (mm), and feed rate (f mm/min) in this case is constant.

Figure 6(b) presents also surface roughness R_{a2}, in the function of cutting speed and depth of cut, where feed rate is taken as constant.

Figure 6(c) shows the measurement of surface roughness for experiment number Ra11, where the main machining parameter (cutting speed = 40 m/min, feed rate = 0.20 mm/min, and depth of cut = 1mm), are get for this case with a middle value. With these parameters are realized four experiment R_{a11}= 1.50 µm, R_{a12} = 1.18 µm, R_{a13} = 1.71 µm and R_{a14} = 1.42 µm. Whereas, the theoretical value for these experiments will be as follows R_{a11} =R_{a12}=R_{a13}=R_{a14}= 1.49 µm.

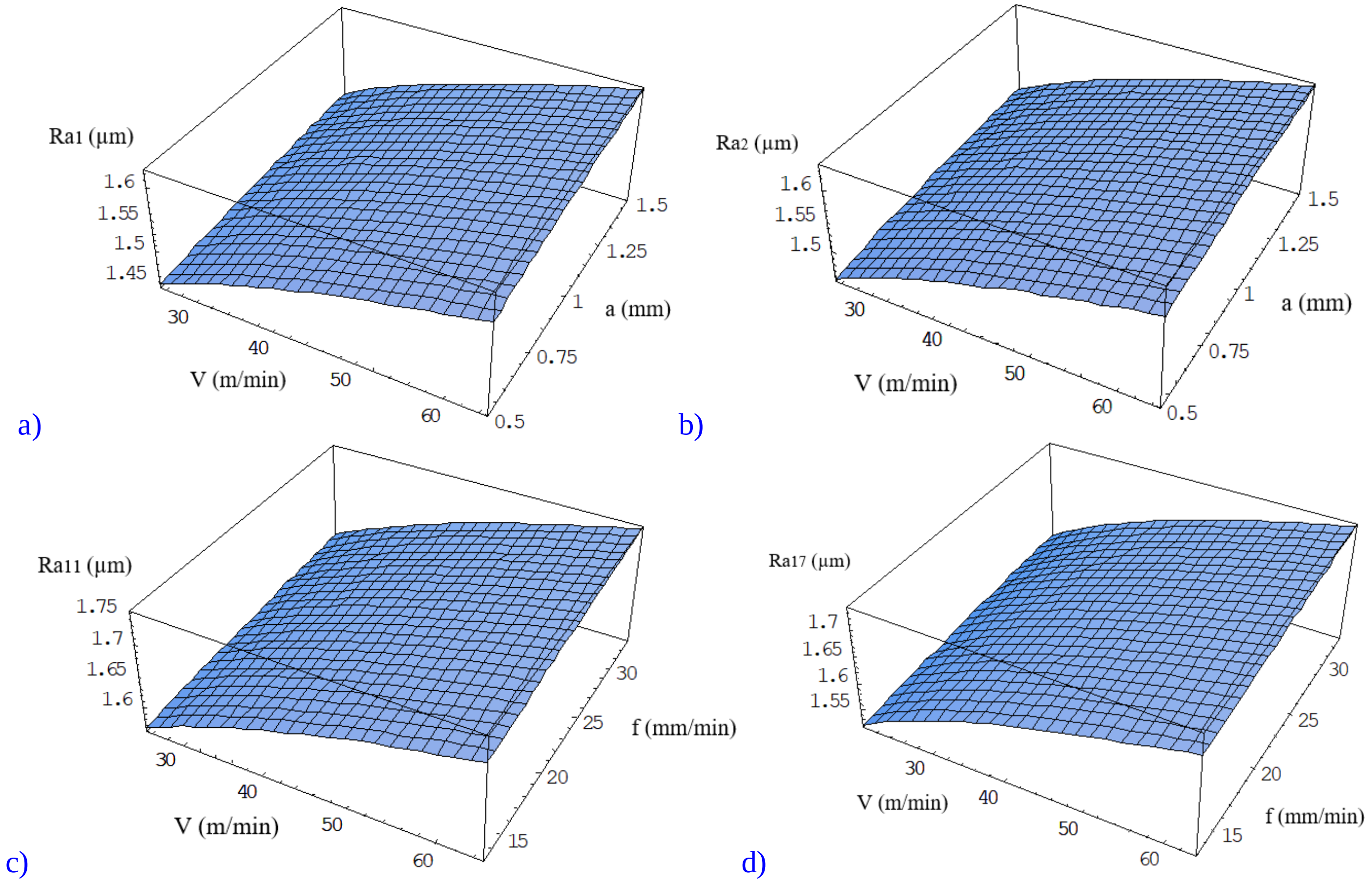

Figure 6: (a) Measurement of surface roughness R_{a1} = 1.401 μm (where cutting speed, feed rate, and depth of cut are taken by minimum level); (b) Surface roughness by experiment R_{a2} = 1.41 μm (where cutting speed and feed rate is taken as minimum level afterward depth of cut is taken at middle level); (c) Obtained results of surface roughness R_{a11} = 1.49 μm, where three levels of main machining parameters are taken as the middle level ; (d) Surface roughness by experiment R_{a17} = 1.466 μm (where cutting speed is taken as middle level, afterward feed rate and depth of cut are taken by minimum level).

However, practical values are almost never the same and their comparison with theoretical ones is variable. Figure 6(c) showed the diagram in the function of cutting speed Vc (m/min) and feed rate f (mm/min) as follows.

The measurement of surface roughness Ra_{17} is presented in the function of cutting speed (V) and feed rate (f) Figure 6(d).

Also the expression for calculation of surface roughness for the case of R_{a1}, R_{a2}, R_{a11} and R_{a17} is shown as follows, regarding Tables 4 and 5.

The calculation of R_{a1} with level code (X_1min, X_2min and X_3min),

$$R_{a1} = 1.085 \cdot X_{1min}{}^{\wedge 0.096} \cdot X_{2min}{}^{\wedge 0.022} \cdot X_{3min}{}^{\wedge 0.011} = 1.401\ [\mu m] \qquad (6).$$

The calculation of R_{a2}, based on the level code of the table (X_1mid, X_2min and X_3mid)

$$R_{a2} = 1.085 \cdot X_{1min}{}^{\wedge 0.096} \cdot X_{2min}{}^{\wedge 0.022} \cdot X_{3mid}{}^{\wedge 0.011} = 1.41\ [\mu m] \qquad (7).$$

The calculation of surface roughness with utilize of level code,

$$R_{a11} = 1.085 \cdot X_{1mid}{}^{\wedge 0.096} \cdot X_{2mid}{}^{\wedge 0.022} \cdot X_{3mid}{}^{\wedge 0.011} = 1.49\ [\mu m] \qquad (8).$$

Utilize of calculation for case of level code based on Table 5 (X1mid, X2min and X3min),

$$R_{a17} = 1.085 \cdot X_{1mid}{}^{\wedge 0.096} \cdot X_{2min}{}^{\wedge 0.022} \cdot X_{3min}{}^{\wedge 0.011} = 1.466\ [\mu m] \quad (9).$$

Mathematical modeling and multi-response optimization is used for improving machinability with using of artificial intelligence [18].

Figure 6 shows the 3D diagrams regarding the measurement and calculations based on the Equations above.

4 Conclusion

The paper mainly is focused on analyzing surface roughness also and another problem is measurements of the hardness of steel C35. Measurement of surface roughness with device Mitutoyo for the case of a milling operation is presented. This work performs twenty one measurements depending on the main machining parameters. Where are taken maximal, middle and minimal values for cutting speed, feed rate, and depth of cutting, also are combined and for experiments Ra_{11},..., Ra_{14} are taking the middle value for three machining of parameters. Measurement of hardness steel for material C45 is obtained through device Hard tip Tester 3000, with value HB = 166. The measurement of value for nominal hardness is compared from practical to the theoretical way such as Hardness Brinell (HB), Hardness Vickers (HV) and HRB.

The best value of surface roughness is for case one Ra_1 = 1.03 µm. Afterward are presented diagrams for four experiments Ra_1, Ra_2, Ra_{11}, Ra_{15} and Ra_{17}, which are depending on the main machining parameters.

5 Availability of Data And Material

Data can be made available by contacting the corresponding author.

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