CORRELATION BETWEEN SURFACE ROUGHNESS AND CUTTING PARAMETERS IN DIFFERENT MACHINING PROCESSES

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Abstract: *This empirical study was examined to determine between surface roughness and cutting parameters for turning and milling. The 3D measurements of surface roughness were obtained with Nano-Focus confocal microscope. The variables were utilized* R_z *as dependent variable and cutting parameters as control factors; respectively, cutting speed, cutting depth, cutter radius and feeding. Multi-linear regression model was used for determination of relation between variable of roughness and cutting parameters. In terms of detection the magnitude and direction of relations, partial correlation was conducted on MATLAB 2021. Mathematical regression models were constituted for turning and milling processes separately. For both machining processes,* R^2 *values were found as 99.9% with considering* R_z *and all cutting parameters all together. Several* R^2 *values were also acquired to* R_z *variable and different cutting parameters. According to these* R^2 *values of different cutting parameters, partial correlation model was established for both processes.*

Key words: *Cutting parameters machining process, milling process, multi-linear regression analysis, surface roughness, turning process.*

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1. Introduction

Machining process is to provide the removal of unwanted portion on a metal workpiece by means of various manufacturing techniques in the scope of shape or design. The two main types of machining process are confronted as traditional machining and conventional machining (Yusup et. al, 2012; Adnan et. al.,2015). Turning and milling are the most common machining cutting method among traditional machining process. Therefore, the specimens, operated via turning and milling operations, were used to analysis in consideration of 3D surface roughness measurement.

There are some technical dissimilarities between turning and milling machining process, even though both have attended to shape workpieces through cutting tool. Milling operation has been more complex in contacting tool and workpiece than turning operation. Fundamentally, milling process has carried out a rotary motion of cutting tool and a rectilinear motion of workpieces, whereas turning process has carried out a rotary motion of workpiece and a linear motion of cutting tool (El-Hofy, 2014).

Surface roughness and cutting parameters are the most common characteristics during evaluating quality of manufactured workpieces. Especially in traditional machining techniques, evaluating the relation between them provides the well improvable field to academic researchers to develop the workpiece quality based on manufacturing conditions.

In this study, surface roughness parameter was selected as R_z. R_z is roughness parameter that is usually called ten-point average heights or the average maximum peak to valley of five consecutive sampling lengths within the measuring length. Significant number researchers consider roughness parameter Rz more relevant in comparison with the roughness parameter R_a which is one of the most used roughness parameter of the surface roughness topography characterization. This is due to the fact that R_z describes in more accurate manner the depth of the valleys, which is very significant property in terms of the exploitation when it comes to the surfaces that need constant and consistent lubrication as the action to minimize friction and allow smooth movement of interacting components (Ostergllava et.al., 2021).

2. Literature Review

In this study, to calibrate the topographical characterization and measurement of materials, to improve their surface, to minimize deviations from quality and target, geometry and cutting parameters were investigated. Rising spindle speed, which has no effect on size, affects roughness. has a negative effect. Therefore, it is recommended to use lower spindle speeds for further testing in the study (Klauer et al., 2020).

In this experimental study, the surface roughness of the workpieces is estimated using a hybrid algorithm based on time series. By choosing the appropriate length of the captured images, the accuracy in estimating the surface roughness has been increased. It shows that the estimated surface roughness is very close to the surface roughness value obtained by the contact measurement method (Pour, 2018).

It is the aim of this experimental study to investigate the measurement uncertainty in surface roughness. Surface roughness measuring device is highly preferred in the sector. Measurements were made on the milling and turning surfaces where the measurements could be repeated several times (Farkas & Dregelyi-Kiss, 2018).

The aim of this study is to take advantage of the signal properties in vibration measurements. Correlation analysis was performed to estimate the surface roughness of S45C steel and the input layer parameters of the artificial neural network (ANN) were collected. Experimental results show that the surface roughness is affected not only by the cutting parameters, but also by the vibration behaviour during milling (Wu and Lei, 2019).

Many researchers compare Rz, one of the most used roughness parameters in surface roughness topography characterization, with the roughness parameter Ra. It is because Rz gives more accurate results when it comes to surfaces that require constant lubrication as the act of minimizing friction and allowing smooth movement of interacting components. In this experimental study, during hard turning of steel C 55 (DIN) using mixed ceramics MC 2 (Al2O3 + TiC), the roughness parameter Rz was predicted (Ostergllava et al., 2021).

This experimental study presents an analysis of the relationships between instant cutting tool displacements and surface roughness. Milling tests were conducted on hard-to-cut low-carbon hardened alloy steel. During the experiment, the machined surface roughness was measured with stylus application and optical profile gauges. Studies show that tool overhang significantly affects surface properties. The surface roughness formation was affected by the dynamic deflections of the workpiece of the cutting tool due to milling (Wojciechowski et al., 2018).

This study proposes the use of convolutional neural network to evaluate surface roughness directly from digital image of surface topography. The models are selected and analyzed based on their five loss functions and their accuracy. The predicted values are compared with the actual surface roughness values measured using a stylus profilometer. The performance of the proposed model is evaluated for the estimation of the surface roughness (Rifai et al., 2020).

3. Material and Method

The material of specimens was selected as C45 grade steel, which proposes wide range for dimension, manufacturing, supplying and mechanical properties. The chemical and mechanical properties of C45 are presented in Table 1 and Table 2.

Table 1. Chemical Composition of C45 Steel (Matweb, 2022).

Material	**C%**	**Fe%**	**Mn%**	**S%**	**P%**
C45	0.42-0.50	98.51-98.98	0.60-0.90	≤0.050	≤0.040

Table 2. Mechanical Properties of C45 Steel (Matweb, 2022).

Hardness, Brinell	165-220
Tensile Strength, Ultimate	590-740 MPa
Tensile Strength, Yield	280-320 MPa
Elongation at Break	14.0 %
Modulus of Elasticity (Typical for steel)	210 GPa
Poisson Ratio (Typical For Steel)	0.30
Shear Modulus (Typical for steel)	80 GPa

The specimens of C45 grade steel were treated by turning and milling machining processes. The cutting parameters were designated as cutting speed (m/min), cutter radius (mm), cutting depth (mm), feeding (mm/rev). These parameters according to related machining process are presented in Table 3. Each set point value about surface roughness was assigned to each cutting parameters correspondingly machining process. Additionally, dimensions of specimens are 345x125x40mm as plate shape.

Table 3. Process parameters for specimens.

Machining Process	**Set Point Value (R_z)**	**Cutting Speed (m/min)**	**Cutting Depth (mm)**	**Cutter Radius (mm)**	**Feeding (mm/rev)**
Values for Turning Process	6.3 µm	250	0,06	0,30	0,10
	10 µm	160	0,06	0,50	0,16
	20 µm	160	0,10	0,20	0,20
	40 µm	130	0,20	0,50	0,32
	80 µm	130	0,20	0,30	0,48
Values for Milling Process	6.3 µm	180	0,15	170	0,11
	10 µm	180	0,15	170	0,17
	20 µm	75	0,15	70	0,31
	40 µm	75	0,20	70	0,46
	80 µm	100	0,20	70	0,78

An empirical study was performed to reveal correlation between surface roughness and cutting parameters in turning and milling processes. Cutting parameters of the milling process were utilized for analysing the relationship between surface roughness and milling process parameters, and likewise parameters of turning process.

Surface roughness values were obtained from the specimens by measurement of Nipkow disc confocal microscope (NanoFocus - µsurf). NanoFocus-surf microscope has been fulfilled with the specifications of 1.6 µm spatial resolution, 0.04 nm Z resolution and 3.1 mm Z range.

The surface roughness measurements of specimens were duplicated 5 times for each specimen related to turning and milling process separately. The surface roughness measurements were obtained 3 separate points on specimens. In the surface roughness measurement, the amplitude roughness parameters were acquired symbolled and named as R_a - arithmetic average profile roughness, and R_z - ten-point average height. However, R_z was selected for analysing the correlation between cutting parameters; accordingly, the set point values were taken as R_z.

The specimens were classified regarding to repetition number of surface roughness measurement and measurement point on specimen. Surface roughness measurement results are presented in Table 4.

Table 4. Surface roughness measurement results for turning and milling machining process

Specimen Numbers	Turning Specimens Measured by 3D Roughness Tester					Milling Specimens Measured by 3D Roughness Tester				
	Rz (µm)					Rz (µm)				
	6,3	**10,0**	**20,0**	**40,0**	**80,0**	**6,3**	**10,0**	**20,0**	**40,0**	**80,0**
SP1A	6,410	9,910	20,110	40,970	78,120	6,430	10,990	19,900	40,700	77,960
SP1B	6,710	9,880	20,240	40,550	78,950	6,440	10,798	18,800	40,900	77,790
SP1C	6,840	9,880	20,210	41,150	78,750	6,480	11,080	19,890	40,400	77,990
SP2A	6,520	10,120	20,010	41,200	78,870	6,490	11,001	19,100	40,500	78,090
SP2B	6,510	10,180	20,180	40,870	78,110	6,400	10,980	20,000	40,800	78,110
SP2C	6,390	10,900	19,870	40,150	79,875	6,249	9,997	21,357	40,283	81,549
SP3A	6,350	9,800	18,990	40,010	80,010	6,197	9,750	21,590	40,013	80,916
SP3B	6,300	9,750	20,975	39,920	79,650	6,330	11,210	22,050	40,001	80,617
SP3C	6,290	10,150	20,649	39,864	80,890	6,299	10,554	18,779	39,999	80,720
SP4A	6,290	10,200	20,110	39,990	81,943	6,320	10,314	19,361	39,819	81,050
SP4B	6,310	10,150	20,020	39,760	80,849	6,431	10,422	21,345	40,519	81,550
SP4C	6,250	10,750	19,560	39,870	80,033	6,411	9,896	20,564	40,032	80,946
SP5A	6,220	9,200	19,220	39,880	79,980	6,289	9,548	20,281	39,748	81,750
SP5B	6,300	9,850	19,820	40,013	80,596	6,275	9,442	20,098	39,869	81,250
SP5C	6,220	9,610	20,080	39,785	80,346	6,310	10,050	19,743	40,138	79,999
Mean	6,388	10,021	20,003	40,249	79,811	6,353	10,377	20,179	40,233	80,018
Std Deviation	0,171	0,391	0,462	0,497	1,012	0,085	0,565	0,952	0,351	1,446

Statistical analyses were conducted by using surface roughness measurements and cutting parameters. The main aim was to reveal any relation between surface roughness and cutting parameters for turning and milling machining processes separately. For each process, mathematical model was constituted as multi-linear regression model and, in the formula (1), R_z is dependent variable, and the others are independent variables.

$$R_z = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \varepsilon \quad (1)$$

where,

$R_z = Ten - point\ surface\ roughness\ height$

$x_1 = Cutting\ speed\ (m/min)$
$x_2 = Cutting\ depth\ (mm)$
$x_3 = Cutting\ radius\ (mm)$
$x_4 = Feeding\ (mm/rev)$

Before analysing the multi-linear regression model, they were examined whether the measurement results were in accordance with normalization. Normally distributed measurement results were utilized for determining the coefficient of control factors in multi-linear regression model. In general, the model in Figure 1 was used for detection of relation in the study.

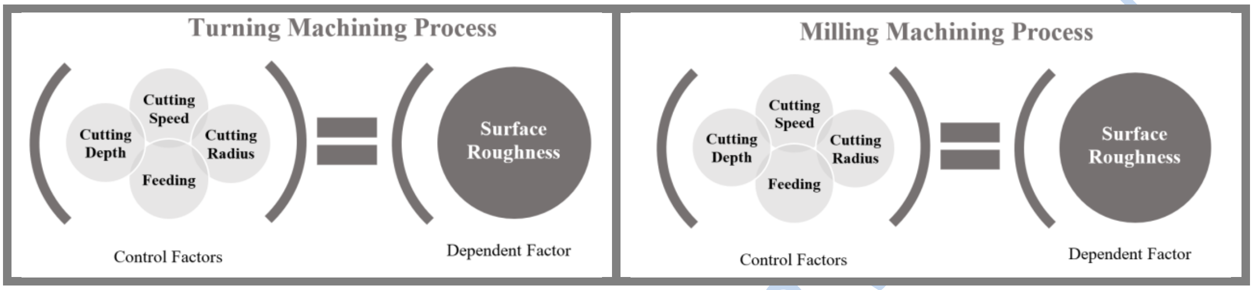


Figure 1. Factors for analysis of relation between surface roughness and cutting parameters

After determination the relations between surface roughness and cutting parameters, magnitude and direction of relation were examined by using correlation analysis. The correlation analysis is significantly related with regression analysis; thus, the correlation coefficients of search parameters are able to account for magnitude and direction of each relation according to detected multi-linear regression model. Correlation and partial correlation formula are shown in formula (2) and (3) (Holmes, 2001).

$$r_{xy} = \frac{\sum_i (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_i (x_i - \bar{x})^2 (y_i - \bar{y})^2}} \qquad (2)$$

where

$r_{xy} = Correlation\ coeficient\ of\ the\ linear\ relationship\ between\ x\ and\ y$
$x_i = Values\ of\ the\ x\ variable\ in\ a\ sample$
$\bar{x} = Mean\ of\ total\ x\ variables\ in\ a\ sample$
$y_i = Values\ of\ the\ y\ variable\ in\ a\ sample$
$\bar{y} = Mean\ of\ total\ y\ variables\ in\ a\ sample$

$$r_{xyz} = \frac{r_{xy} - r_{xz} r_{yz}}{\sqrt{(1 - r_{xz}^2)(1 - r_{yz}^2)}} \qquad (3)$$

where

$r_{xyz}\ Partial\ correlation\ coeficient\ of\ the\ linear\ relationship\ between\ x, y\ and\ z$
$r_{xy} = Correlation\ coeficient\ of\ the\ linear\ relationship\ between\ x\ and\ y$
$r_{xz} = Correlation\ coeficient\ of\ the\ linear\ relationship\ between\ x\ and\ z$
$r_{yz} = Correlation\ coeficient\ of\ the\ linear\ relationship\ between\ y\ and\ z$

4. Result and Discussion

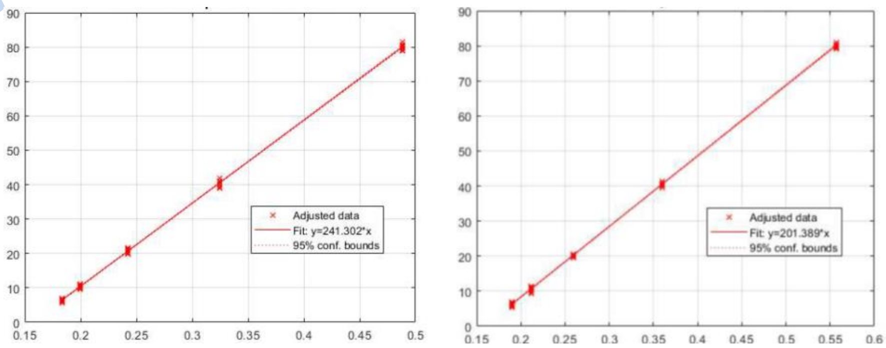
The experiments were conducted for determining, comparing, and analysing significantly existing relation, magnitude and direction of these relation between surface roughness as ten-point surface roughness height and cutting parameters as cutting speed, cutting depth, cutter radius and feeding on turning and milling machining process. Multi-linear regression analysis was carried out for both machining process, separately. MATLAB 2021 software were utilized for all statistical analyses.

Regression model was constituted correspondingly dependent variable as R_z (ten-point surface roughness height-µm) and control factors as cutting speed (m/min), cutting depth(mm), cutter(mm) radius and feeding(mm/rev) for both processes. Ten-point surface roughness height parameters are symbolized as R_{zt} for turning process and R_{zm} for milling process and the mathematical models are presented in formula (4) and (5). The regression results obtained from multi-linear regression analysis are shown in Table 5.

$$R_{zt} = -37.776 + 0.0985\, x_1 - 36.452\, x_2 - 7.0611\, x_3 + 238.43 x_4 \quad (4)$$
$$R_{zm} = -31.943 + 0.658 x_1 - 187.76 x_2 - 0.685\, x_3 + 72.813 x_4 \quad (5)$$

Table 5. Parameters of multi-linear regression model for turning machining process

Parameters	TURNING PROCESS			MILLING PROCESS		
	Coefficients	**Standard Deviations**	***p*-Value**	**Coefficients**	**Standard Deviations**	***p*-Value**
Intercept	-37.776	0.9103	4.9984e-51	-31.943	0.832	9.6114e-49
Cutter Speed	0.0985	0.0032	2.6662e-42	0.658	0.045	7.6696e-23
Cutter Depth	-36.452	3.385	1.6804e-16	187.76	11.23	3.8053e-26
Cutter Radius	-7.0611	0.797	4.9734e-13	-0.685	0.053	4.5156e-20
Feeding	238.43	1.765	2.2921e-86	72.813	3.475	7.1674e-32



(a) Turning Process *(b) Milling Process*

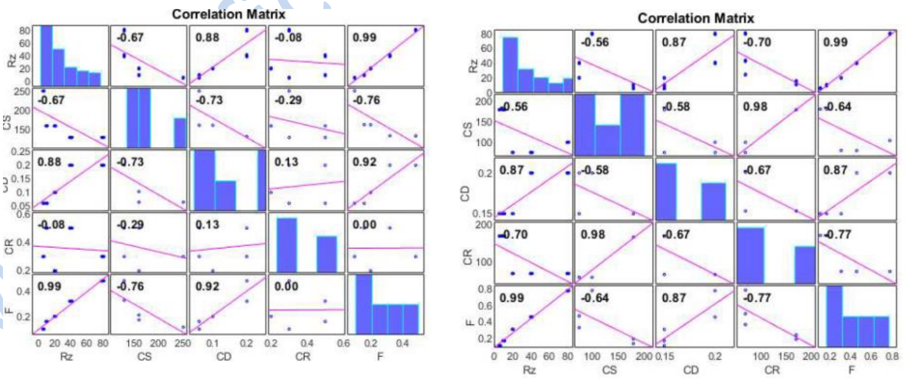
Figure 2. Variable plot of multi-linear regression model for cutting parameters and surface roughness

In terms of specifically application differences, the R^2 values were propounded and, in both processes, R^2 values are 99.9% and this means that surface roughness and cutting parameter values of both processes have relations with each other and the values can explain the regression model in proportion to 99.9%.

The main issue is to reveal which of magnitude and direction correlations are possessed by these relations. Therefore, in both processes Pearson corelation analysis was utilized for determining the magnitude and direction of existed relations. With the boost of the regression model, which was constituted that R_z as dependent value and cutting parameters as control factors, correlation coefficients of relations were obtained. The results of correlation coefficient are presented in Table 6 and correlation matrix are illustrated in Figure 3.

Table 6. Correlation coefficients of multi-linear regression model for turning machining process

	TURNING PROCESS					MILLING PROCESS				
	R_z	**Cutter Speed**	**Cutter Depth**	**Cutter Radius**	**Feeding**	**R_z**	**Cutter Speed**	**Cutter Depth**	**Cutter Radius**	**Feeding**
R_z	1.000	-0.671	0.883	-0.083	**0.990**	1.000	-0.558	0.869	-0.698	**0.993**
Cutter Speed	-0.671	1.000	-0.734	-0.295	-0.759	-0.558	1.000	-0.584	0.981	-0.642
Cutter Depth	0.883	-0.734	1.000	0.125	0.915	0.869	-0.584	1.000	-0.666	0.865
Cutter Radius	-0.083	-0.295	0.125	1.000	0.005	-0.698	0.981	-0.666	1.000	-0.769
Feeding	0.990	-0.759	0.915	0.005	1.000	0.993	-0.642	0.865	-0.769	1.000



(a) Turning Process *(b) Milling Process*

Figure 3. Correlation matrix for cutting parameters and surface roughness

In turning machining process, R^2 values of regression models are significant correspondingly *p* values, except the regression model for R_z and cutter radius value. In milling machining process, all R^2 values are significant correspondingly *p* values as considering statistically 99% significance level, as well. Several regression models were constituted based upon specific dependent and independent parameters.

Table 7. R^2 values of regression models for turning and milling process

	TURNING PROCESS			**MILLING PROCESS**		
	R^2	**Adjusted** R^2	**Significance p-Value**	R^2	**Adjusted** R^2	**Significance p-Value**
Model_01 ***Dependent:*** R_z ***Control Factors:*** Cutter Speed, Cutter Depth, Cutter Radius, Feeding	0.999	0.999	0.000	0.999	0.999	0.000
Model_02 ***Dependent:*** R_z ***Control Factors:*** Cutter Speed, Cutter Depth, Feeding	0.999	0.999	0.000	0.999	0.999	0.000
Model_03 ***Dependent:*** R_z ***Control Factors:*** Cutter Speed, Feeding	0.997	0.997	0.000	0.998	0.998	0.000
Model_04 ***Dependent:*** R_z ***Control Factor:*** Cutter Speed	0.450	0.443	0.000	0.311	0.302	0.000
Model_05 ***Dependent:*** R_z ***Control Factor:*** Cutter Depth	0.780	0.777	0.000	0.756	0.753	0.000
Model_06 ***Dependent:*** R_z ***Control Factor:*** Cutter Radius	**0.007**	**0.006**	**0.474***	0.487	0.480	0.000
Model_07 ***Dependent:*** R_z ***Control Factor:*** Feeding	0.981	0.981	0.000	0.987	0.987	0.000

Table 8. Partial correlation analysis results for turning machining process

	R_z	**Cutter Speed**	**Feeding**
R_z	1.000	-0.671	0.990
Cutter Speed	-0.671	1.000	-0.759
Feeding	0.990	-0.759	1.000

Partial correlation for dependent value as R_z, control factors as cutter speed and feeding is -0.9328.

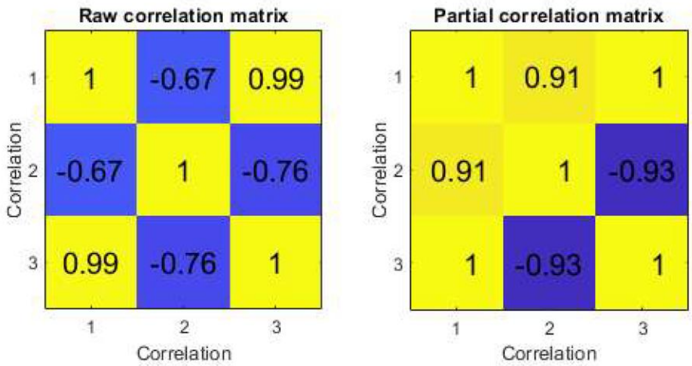


Figure 4. Raw correlation matrix and partial correlation matrix on dependent value as R_z control factors as cutter speed and feeding for turning machining process

Table 9. Partial correlation analysis results for milling machining process

	R_z	Cutter Speed	Cutting Depth	Feeding
R_z	1.000	-0.558	0.869	0.993
Cutter Speed	-0.558	1.000	-0.584	-0.642
Cutting Depth	0.869	-0.584	1.000	0.865
Feeding	0.993	-0.642	0.8651	1.000

Partial correlation for dependent value as R_z, control factors as cutter speed and feeding is -0.9971.

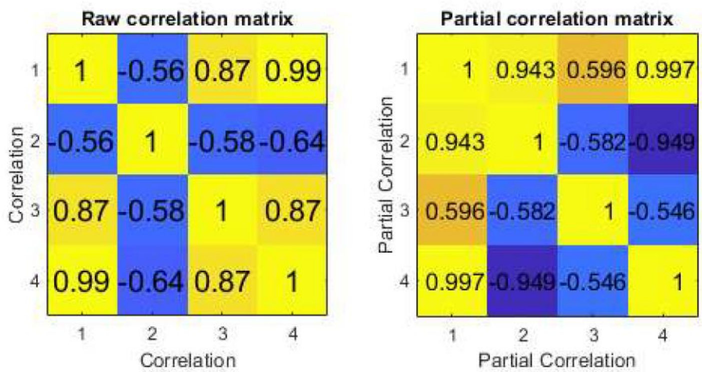


Figure 5. Raw correlation matrix and partial correlation matrix on dependent value as R_z control factors as cutter speed and feeding for milling machining process

5. Conclusion

This empirical study was investigated to determine between surface roughness and cutting parameters for turning and milling. The specimens were operated with the techniques of turning and milling. The 3D measurements of surface roughness were obtained with Nano-Focus confocal microscope. The variables were utilized Rz as dependent variable and cutting parameters as control factors; respectively, cutting speed, cutting depth, cutter radius and feeding. Multi-linear regression model was used for determination of relation between variable of roughness and cutting parameters. In terms of detection the magnitude and direction of relations, partial correlation was conducted on MATLAB 2021. Mathematical regression models were constituted for turning and milling processes separately. For both machining processes, R^2 values were found as 99.9% with considering Rz and all cutting parameters all together. Several R2 values were also acquired in deference to Rz variable and different cutting parameters. According to these R^2 values of different cutting parameters, partial correlation model was established for turning and milling processes.

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