International Journal of Advanced Engineering and Technology
ISSN: 2456-7655
Impact Factor: RJIF 5.54
www.newengineeringjournal.com
Volume 1; Issue 5; November 2017; Page No. 08-13

Investigating the surface roughness of AISI 1020 steel machined using TiN coated cemented carbide tool

[1] OO Awopetu, [2] PK Farayibi, [3] GE Olorunfemi
[1, 2, 3] Department of Industrial and Production Engineering, Federal University of Technology, Akure, Nigeria
[3] Engineering Materials Development Institute, Akure, Nigeria

Abstract
In machining, surface integrity of product is of major concern and crucial to some of the functional properties of the component in service. This work investigated the effect of cutting parameters on surface roughness of AISI 1020 mild steel on lathe turning in dry condition. An indexable titanium nitride (TiN) coated carbide tool insert mounted on a general multipurpose Widax tool holder was used for the turning. The parameters considered were cutting speed, feed rate and depth of cut while Taguchi method and analysis of variance were used to support the investigation. The result indicated that high cutting speed, low depth of cut and low feed rate are required for low surface roughness. A third order regression model was able to predict the surface roughness of AISI 1020 steel based on the parameter ranges employed with the presence of significant process parameter interactions and the coefficient of determination, R^2, of the model was obtained as 0.96.

Keywords: surface roughness, turning, ANOVA, coated carbide, mild steel, machining

1. Introduction

Surface roughness is a commonly encountered problem in machined surfaces, especially surface finish plays an important role on the product quality and it is a parameter of great importance in the evaluation of machining accuracy. It is defined as the finer irregularities of surface texture, which results from the inherent action of the production process (Subhajit and Mukherjee, 2014; Yadav *et al*., 2012) [8, 13, 15]. Surface finish influences functional properties of machined components such as fatigue strength, wear rate, coefficient of friction, creep life and corrosion resistance of the machined components. The most important parameter describing the surface integrity is surface roughness (Govindan and Vipindas, 2014) [3]. Surface roughness plays a significant role in machining industry for proper planning and control of machining parameters and optimization of cutting conditions (Shivam *et al*., 2016) [12]. Therefore, prediction or monitoring of the surface roughness of machined components is an important area of research. Previous researches have indicated that factors such as cutting speed, feed rate, depth of cut, tool geometry, work piece hardness, cutting edge angles, tool nose radius and tool setup strongly influence the surface roughness of machined product (Elssawi *et al*., 2015; Jithin and Ramesh, 2014) [2, 5].

Jha *et al*., (2015) [6] investigated the influence of process parameters on the machinability of AISI 1020 carbon steel using conventional turning operation and considered the spindle speed, feed rate, depth of cut, and rake angle as factors influencing machinability. It was reported that feed rate is the most significant factor influencing machinability and the cutting force increases as feed rate increases. Mukherjee *et al.*, (2014) [8, 13] investigated the influence of feed, depth of cut and speed on material removal rate of SAE 1020 material, and it was noted that depth of cut is the most significant followed by the feed. The material removal rate was maximised to increase productivity and efficiency of the machining process. Dhanenthiran (2016) [1] investigated the effect of process parameters in turning of cast iron using a titanium carbide insert and result indicated that high cutting speed and high feed rate are responsible for low surface roughness of the cast iron. Upletawala and Katratwar (2016) [14] reported on the various factors affecting lathe turning operation and it was noted that feed rate and depth of cut are most significant factor influencing surface roughness and these were followed by cutting speed. Also, nose radius of the tool is significant to obtaining a better surface finish of a work piece. Singh *et al.*, (2016) [11] studied the effect of cutting condition and nose radius on surface roughness of Aluminium 6061 turned using CNC lathe machine and it was noted that as nose radius increases, the surface roughness of the machined work piece decreases. Makadia and Nanavati (2013) [9] studied the effect of turning parameters on surface roughness of AISI 410 steel using response surface methodology and it was noted that surface roughness decreases with increasing tool nose radius and decreasing feed rate. Ince and Asilturk (2015) [4] studied the influence of cutting parameters on the surface roughness of Co-28Cr-6Mo medical alloy machined using CNC lathe machine. It was also reported that roughness decreases with increasing tool nose radius, increasing cutting speed, and decreasing feed rate. In another recent study, Kandure and Karwande (2017) [7] gave a review on optimisation of cutting parameters of different engineering materials for surface roughness in turning operation and noted that feed rate is the most significant parameter affecting roughness.

The previous studies have concentrated on the investigating the effect of the various process parameters independently on the machinability, surface roughness and material removal rate of lathe turned work piece, however, the interactions of the process parameters on the surface roughness achieved on work piece is yet to be verified. Hence, the aim of the study is to determine the effect of cutting speed, feed rate, depth of cut and their interactions on the surface roughness of machined surface of AISI 1020 steel to be subjected to turning using TiN coated carbide cutting tool on lathe machine.

2. Materials and Methods

2.1 Materials and Cutting tool

In this study, AISI 1020 steel bar of diameter 100 mm and 850mm long, obtained from iron and steel market, Agodi Gate, Ibadan, Nigeria, was used as the workpiece. The elemental composition of the AISI 1020 steel is presented in Table 1, as determined using BDL8001R-MCP model Spectrometer at FIIRO, Oshodi Lagos.

Table 1: Elemental composition of AISI 1020 steel

Element	Fe	Mn	S	C	P
wt.%	99.31	0.40	0.05	0.20	0.04

A non-regrindable, indexable titanium nitride (TiN) coated carbide insert (K-ISO grade) with a nose radius of 0.8 mm and clearance angle of 0^o, mounted on a general multipurpose PCLNR 2020K12 Widax tool holder, as shown in Figure 1, was employed as cutting tool for the turning operation. The cutting tool and the holder were obtained from Nnewi Industrial Tools Market in Anambra State, Nigeria.

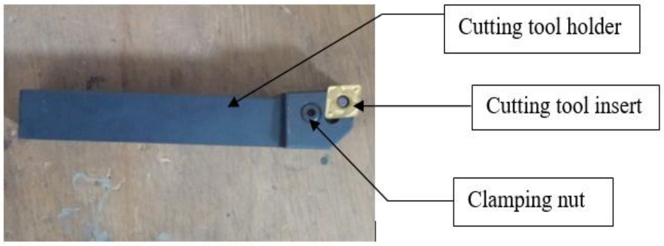


Fig 1: Coated Carbide Insert with Tool Holder

2.2 Machine Tool and Equipment

The experiment was conducted using the TiN coated cemented carbide tool mounted on the tool post of model GML-1440BGF lathe machine manufactured by GMC, Czechoslovakia shown in Figure 2. Data on surface roughness of the workpiece were obtained using a digital model SRT-6200 surface profilometer. The surface roughness measurement was taken by pressing start button on the tester as measuring probe transverse along the workpiece surface at cut-off length of 0.25 mm. The measured workpiece roughness value was then captured on its LCD display as well as PC connected to it at this cutting parameter.

Fig 2: Experimental setup on the lathe machine

2.3 Experimental Procedure

A dry turning operation was carried out on the AISI 1020 mild steel and orthogonal cutting tool approach against the workpiece was employed during the experiment. Three machining parameters were considered in this study which include: cutting speed, feed rate, and depth of cut and each parameter has four levels, as shown in Table 2 as the standard range of turning this workpiece material on lathe machine. The experiment was designed using Taguchi method which allows fewer experimental runs to yield a significant result. An L-16 orthogonal array was employed to obtain the sixteen experimental runs which were repeated three times. A new coated carbide insert edge was used for each experimental run. The surface profilometer was employed to measure the roughness of the machined surfaces of the workpiece at three different locations using a 0.8 mm cut-off length. The roughness of machined surfaces has been noted to be a significant factor influencing the functional properties of machined products in service. Thus, in this study, the surface roughness of the machined AISI 1020 mild steel was assessed to determine the effect of the various machining conditions employed during the experiment performed using L-16 orthogonal Taguchi design, as shown in Table 3.

Table 2: Major machining parameters and their levels

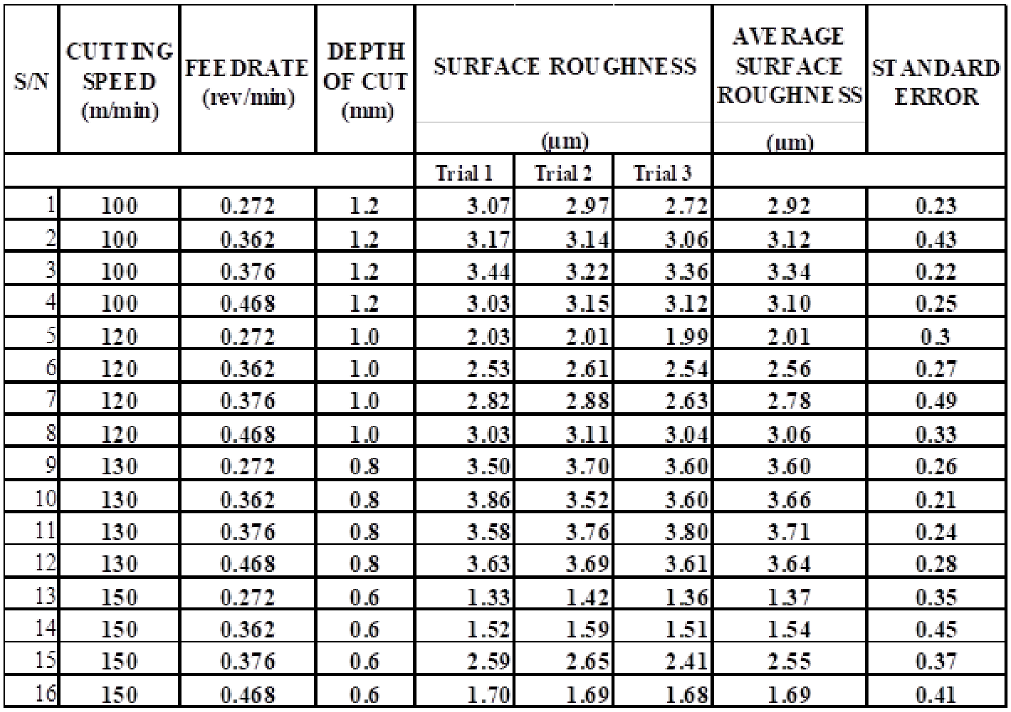
Cutting parameters	**Factor level**			
	1	**2**	**3**	**4**
Cutting speed (m/min)	100	120	130	150
Feedrate (rev/min)	0.272	0.362	0.376	0.468
Depth of cut (mm)	0.6	0.8	1	1.2

3. Results and Discussion

3.1 Effect of process conditions on machined surface roughness

Table 3 presents the average surface roughness values obtained from the experiment. The significance of each parameter on the surface roughness was evaluated using analysis of variance (ANOVA) and relevant regression equations to predict the roughness was developed are shown below:

Table 3: Experimental data of cutting conditions and response variable



S/N	CUTTING SPEED (m/min)	FEEDRATE (rev/min)	DEPTH OF CUT (mm)	SURFACE ROUGHNESS (µm)			AVERAGE SURFACE ROUGHNESS (µm)	STANDARD ERROR
				Trial 1	Trial 2	Trial 3		
1	100	0.272	1.2	3.07	2.97	2.72	2.92	0.23
2	100	0.362	1.2	3.17	3.14	3.06	3.12	0.43
3	100	0.376	1.2	3.44	3.22	3.36	3.34	0.22
4	100	0.468	1.2	3.03	3.15	3.12	3.10	0.25
5	120	0.272	1.0	2.03	2.01	1.99	2.01	0.3
6	120	0.362	1.0	2.53	2.61	2.54	2.56	0.27
7	120	0.376	1.0	2.82	2.88	2.63	2.78	0.49
8	120	0.468	1.0	3.03	3.11	3.04	3.06	0.33
9	130	0.272	0.8	3.50	3.70	3.60	3.60	0.26
10	130	0.362	0.8	3.86	3.52	3.60	3.66	0.21
11	130	0.376	0.8	3.58	3.76	3.80	3.71	0.24
12	130	0.468	0.8	3.63	3.69	3.61	3.64	0.28
13	150	0.272	0.6	1.33	1.42	1.36	1.37	0.35
14	150	0.362	0.6	1.52	1.59	1.51	1.54	0.45
15	150	0.376	0.6	2.59	2.65	2.41	2.55	0.37
16	150	0.468	0.6	1.70	1.69	1.68	1.69	0.41

The data obtained were used to plot the relationship between the machining parameters (cutting speed, feed rate and depth of cut) and the roughness of the machined surfaces. Figure 3 shows that a decreasing trend exists between the cutting speed and measured surface roughness. It was also noted that employing a lower feed rate and high cutting speed resulted in a lower value of surface roughness. This was indicated by the lowest surface roughness of 1.37±0.35 µm observed when a feed rate of 0.272 mm/rev and cutting speed of 150 m/min were employed during the turning operation. Figure 4 shows that a positive trend exists between the measured roughness and depth of cut, as the depth of cut increases so also the surface roughness value increases. Since, the lower the surface roughness the better, then lower depth of cut is necessary to achieve a desirably low surface roughness. This is supported by the lowest depth of cut of 0.6 mm employed in this study to achieve the lowest surface roughness of 1.37±0.35 µm. Furthermore, Figure 5 corroborates the trend observed in Figure 3, indicating that a low surface roughness is obtained when a low feed rate is applied during machining. The influence of the process conditions observed on the surface roughness here agrees with previous research done by Nithyanandam, *et al.*, (2015) and Yanda, *et al.*, (2010). It is worthy to note that higher cutting force is generated on the tool when a higher feed rate is applied which will result in higher power consumption. This higher cutting force results in high heat energy generated at the cutting tool-work piece interface, which leads to increased tool wear, decreased tool life and high surface roughness of machined work piece.

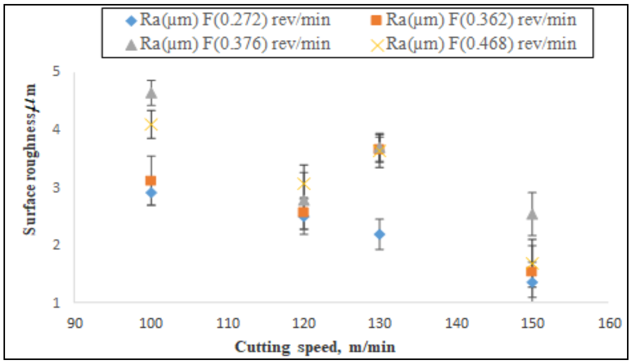


Fig 3: Inverse dependence of surface roughness on cutting speed

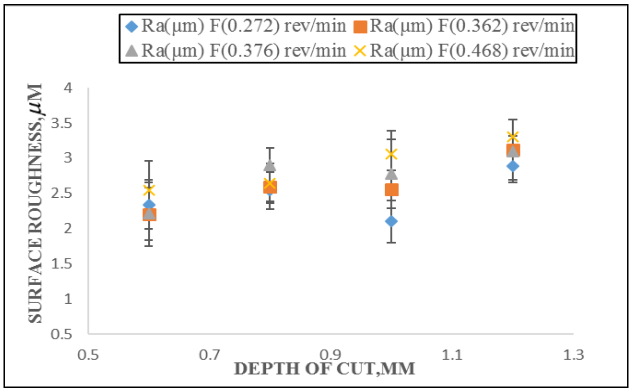


Fig 4: Direct dependence of surface roughness on depth of cut

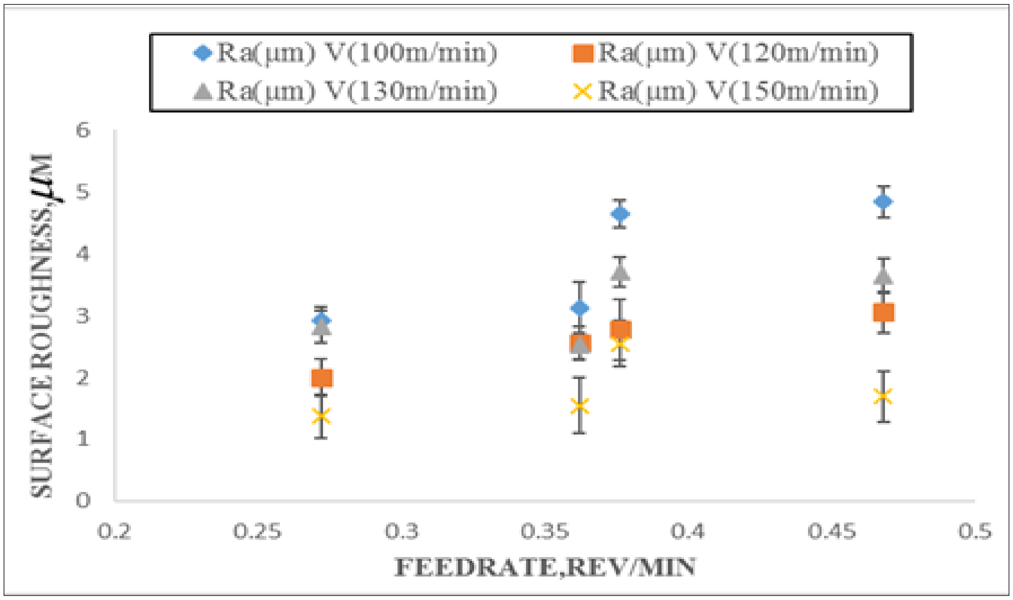


Fig 5: Positive dependence of surface roughness on feed rate

3.2 Analysis of variance and Regression modelling

In order to establish the significance of each process condition employed in this study on the measured surface roughness, analysis of variance (ANOVA) was adopted. The significance of parameter interactions was also checked to know if their second order and interactions have an influence on the work piece surface roughness. Table 4 presents the ANOVA for the surface roughness. The result indicated a strong significance for the cutting speed and feed rate, while depth of cut has slight or no significance on the roughness at 95% confidence level. The significance of these independent process factors agrees with the trends observed in Figures 3 – 5.

Table 4: ANOVA for surface roughness of AISI 1020 mild steel

Source	DF	ADJ SS	ADJ MS	F-Value	P-Value	Remarks
Regression	11	8.73799	0.794362	9.10	≤ 0.023	Relevant
V	1	0.05948	0.059475	0.68	≤ 0.004	Relevant
F	1	0.15373	0.153731	1.76	≤ 0.002	Relevant
D	1	0.06460	0.064596	0.74	0.004	Relevant
V^2	1	0.00441	0.004408	0.05	≤ 0.003	Relevant
F^2	1	0.20023	0.200235	2.29	≤ 0.002	Relevant
V*F	1	0.03730	0.037302	0.43	≤ 0.005	Relevant
F*d	1	0.01987	0.019872	0.23	0.658	Non-significant
F^3	1	0.23810	0.238100	2.73	≤ 0.001	Relevant
V2*f	1	0.03452	0.034523	0.40	≤ 0.005	Relevant
V*f^2	1	0.01368	0.013682	0.16	≤ 0.004	Relevant
F^2*d	1	0.00873	0.008730	0.10	0.768	Non-significant
Error	4	0.34911	0.087277			
Total	15	9.08709				

(DF = Degrees of freedom, ADJ SS= Adjusted sums squares, ADJ MS= Adjusted mean squares)

Furthermore, the second order, third order and interactions of these parameters were also analysed using ANOVA. It is noteworthy that some of these interactions are statistically significant at influencing the surface roughness, thus indicating that a first order or second order models may not be adequate to predict the surface roughness based on these process parameters.

A third order model was generated to predict the influence of the process parameters and their interactions on the surface roughness of the work piece as shown in equation (1). The model was able to accurately predict the surface roughness within the range of parameters specified in Table 2, with a coefficient of determination R^2 of 0.96.

Ra (μm) = $285 - 0.817V - 1584F - 64.6D - 0.00030V^2 + 3344F^2 + 3.41VF + 198\,FD - 2586F^3 - 0.00223VFD - 2.74\,VF^2 - 176\,F^2D$ where, Ra is the surface roughness, V is the cutting speed, F is the feed rate and D is the depth of cut.

Figure 6 shows the normal probability plot of the residues based on the predictive model generated for the surface roughness of the work piece. It can be inferred that the deviation between the experimental results and the predicted results are distributed normally and the regression model is well fitted with the observed surface roughness. This further supports the validity of the third order model generated as sufficient to predict the surface roughness.

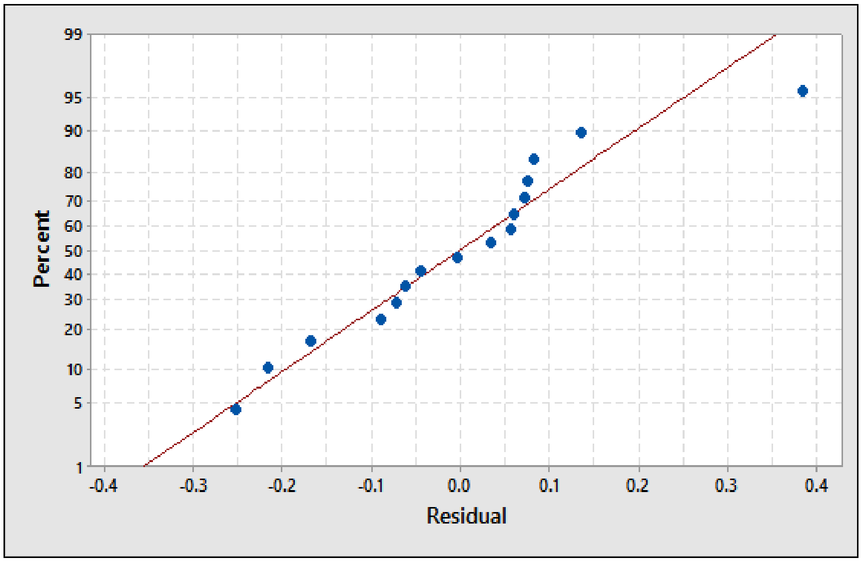


Fig 6: The normal probability residual plot for the surface roughness data

Figure 7 compares the experimental data to predict data of surface roughness of AISI 1020 mild steel. The predicted values of the surface roughness are close to the recorded experimental results obtained during the actual turning operation, thus the model seems adequate.

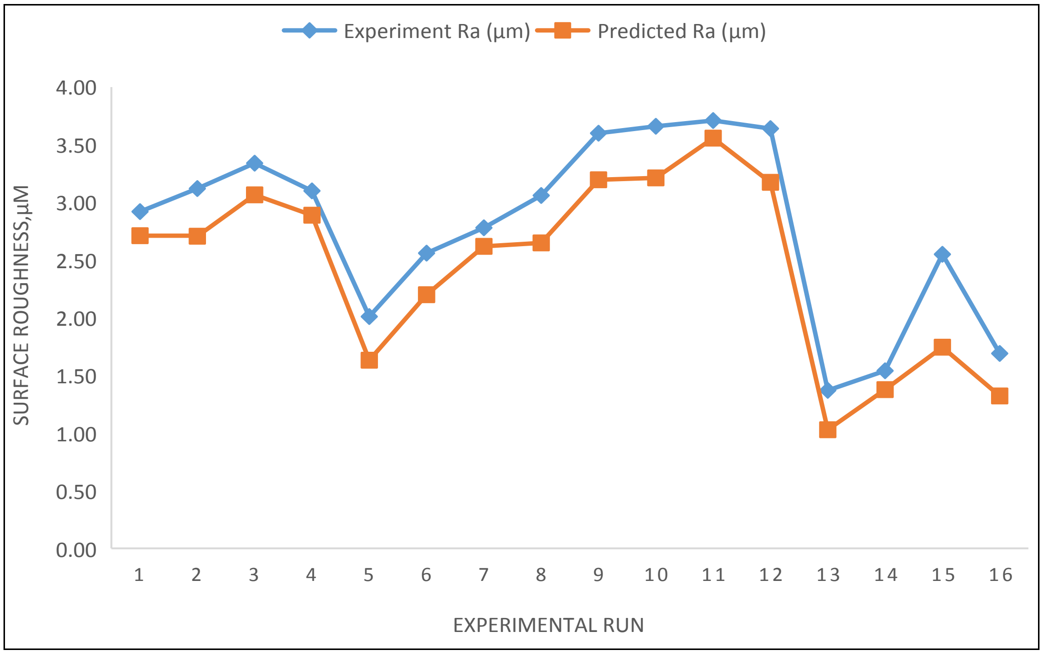


Fig 7: Comparison of experimental and predicted surface roughness

4. Conclusion

The turning of AISI 1020 mild steel was successfully carried out using a TiN coated carbide cutting tool. A low surface roughness of machined work piece is supported by high cutting speed, low depth of cut and low feed rate. The best surface roughness obtained was 1.37±0.35 µm, which was obtained using a cutting speed of 150 m/min, feed rate of 0.272 mm/rev and depth of cut of 0.6mm. ANOVA showed that the processing parameters and some of their interactions are statistically significant at influencing surface roughness. A third order model was established which predicts the roughness with a coefficient of determination of 0.96.

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