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INVESTIGATION OF SURFACE ROUGHNESS IN HIGH SPEED MILLING OF AISI 1015 LOW CARBON STEEL USING RESPONSE SURFACE METHODOLOGY

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Abstract

In the present study, an attempt is made by using response surface methodology to investigate the effect of cutting parameters on surface roughness during face milling of AISI 1015 low carbon steel with uncoated carbide insert at: cutting speeds of 300 – 500 rpm, feed rates of 30 – 100 mm/min and axial depth of cut of 0.25 – 1.0 mm. Average surface roughness values were measured and analysed as the response parameter. It was observed that feed rate had the most significant effect on surface roughness. Optimum cutting parameters were observed at 300 rpm cutting speed, 50 mm/min feed rate and axial depth of cut of 0.5 mm.

Keywords: ***Milling, uncoated carbide insert, response surface methodology, surface roughness***

1. Introduction

Good machinability connotes optimal combination of factors such as low: cutting force, high material removal rate, good surface integrity, accurate and consistent workpiece geometrical characteristics, low tool wear rate and an effective chip removal operation. The machinability of material is greatly influenced by the kind and shape of cutting tool used [1]. Obtaining optimal machining parameters is crucial to effective competition in manufacturing world. In material removal processes like milling, drilling and turning, improper selection of cutting conditions leads to poor surface integrity and dimensional inaccuracy. In view of the significant role of milling operations in today's manufacturing world, it is very necessary to optimize machining parameters for the operation of different workpiece materials. Surface roughness has been identified as one of the most essential factors in tribology. It helps in determining the quality of a machine operation [2]. It is an important measure of product quality since it greatly influences the performance of mechanical parts as well as production cost. Surface roughness has an impact on the mechanical properties like fatigue behaviour, corrosion resistance, and creep life. It also affects other functional attributes of parts like friction, wear, light reflection, heat transmission, lubrication, and electrical conductivity. Sometimes, various catastrophic failures causing high costs have been attributed to the surface finish of the components [3]. Surface integrity is also an important factor for hygienic integrity of parts produced because a smooth surface finish decreases the risk of system contamination and increases the speed of cleaning and sterilization. The importance of surface integrity of machined components has generated a lot of research interest in this area. Pratyusha *et al.* [4] reported that during milling of AISI 304 austenitic stainless steel with carbide inserts the depth of cut had the most significant influence on surface roughness, cutting speed and feed rate. Radhika and Talupula [5] also noted that during milling of low carbon steel reported the surface roughness decreases with increase in cutting speed but decreases with a decrease in feed rate and depth of cut. Patel and Patel [6] investigated CNC end milling operation of AISI 1018 low carbon steel on a vertical machining centre using physical vapour deposition (PVD) coated carbide end mill tools at spindle speeds of 800, 1000 and 1200 rpm; feed rates of 0.122, 0.184 and 0.239 mm/rev; depths of cut 0.5, 0.75 and 1.0 mm; and different tool of 2,3 and 4 number of tool flute, using three different types water miscible cutting oils. Sulaiman *et al.* [7] used RSM with a small central composite design to predict and optimize machining parameters during end milling of titanium alloy Ti-6Al-4V on a vertical machining centre under the influence of magnetic field from permanent magnets with uncoated tungsten carbide–cobalt (WC-Co) milling insert at cutting speeds of 19.55, 40, 70, 100, 120.45 m/min; feed rates of 0.02, 0.05, 0.1, 0.15, 0.18 mm/tooth; depths of cut of 0.24, 0.5, 0.88, 1.25, 1.51 mm, measuring surface roughness as response parameter. They observed that feed rate had the most significant effect on surface roughness, followed by cutting speed and depth of cut and that a combination of high cutting speed, low feed rates and low depth of cut was needed to produce optimum surface roughness. They reported a minimum surface roughness value of 0.12 µm at an optimum cutting speed of 86 m/min, optimum depth of cut of 0.52 mm and optimum feed rate of 0.08 mm/tooth.

Kadirgama *et al.* [8] applied a combination of RSM and Radian Basis Function Network (RBFN) optimization models during milling of mould aluminium alloys (AA6061-T6) on a six axis machining centre with coated carbide inserts at cutting speeds of 100, 140, 180 m/min; feed rates of 0.1, 0.15, 0.2 mm/rev; axial depths of cut of 0.1, 0.15, 0.2 mm; radial depths of cut of 2.0, 3.5, 5.0 mm in wet cutting environment using water soluble coolant, measuring surface roughness as the response parameter. They reported that both RSM and RBFN revealed that feed rate has the most significant influence on surface roughness followed by the axial depth, cutting speed, and radial depth. Philip et al. [9] used Box-Behnken design of RSM during dry end milling of ASTM A995 grade 4A cast duplex stainless steels on a semi automatic milling machine with titanium carbonitride (TiCN) coated tungsten carbide inserts at spindle speeds of 500, 1000 rpm; feed rates of 40, 100 mm/min; axial depths of cut 0.4, 1.2 mm measuring surface roughness as response parameter. It was reported that feed rate had the most significant influence on surface roughness followed by axial depth of cut and spindle speed. Philip *et al* [9] reported that optimal surface roughness of 0.52 µm was obtained at high spindle speed of 1000 rpm, low feed rate of 40 mm/min and low axial depth of cut of 0.4 mm. Patwari *et al.* [10] coupled RSM and genetic algorithm (GA) models for the prediction and optimization of surface roughness during end milling of S45C medium carbon steel on a vertical machining centre under dry cutting conditions with titanium nitride (TiN) coated carbide inserts at high cutting speeds of 100, 114.3, 158, 218.5, 250 m/min; axial depths of cut of 1.005, 1.15, 1.59, 2.2, 2.516 mm; feed rates of 0.039, 0.05, 0.089, 0.16, 0.204 mm/tooth. They also reported that feed rate had the most significant effect on surface roughness, followed by axial depth of cut and cutting speed and that the interaction of cutting speed and feed rate had a significant effect on surface roughness values. Furthermore, it was reported that an increase in either the feed or the axial depth of cut increases the surface roughness, whilst an increase in the cutting speed decreases the surface roughness. Jain [11] reported that a smoother surface finish can be obtained in face milling than in peripheral milling. However, in the present study, an attempt is made to investigate the effects of machining parameters on surface roughness during face milling of low carbon steel using response surface methodology (RSM).

2. Materials and Methods

2.1 Materials

The workpiece material used for this study was low carbon steel block of 122 x 40 x 87 mm dimension. In order to confirm their chemical composition, a test sample of the workpiece material was subjected to spectrometry analysis using Arun Technologies MetalScan PolySpek Junior Spectrometer. The chemical composition of the low carbon steel workpiece material is presented in Table 1. Uncoated carbide inserts grade P30 was used to perform the face milling operation.

Table 1. Chemical composition of low carbon steel workpiece material

% C	% Si	% Mn	% Ni	% Cr	% Mo	% N	% P	% S	% Fe
0.153	0.171	0.517	0.022	0.050	0.008	0	0.006	0.012	98.86

2.2 Cutting Tool

. Carbide cutting tool is widely used in metal cutting industry for the cutting of different hard materials. In this work, uncoated carbide inserts with the grade P 30 was used to perform the cutting action while machining the workpiece material.

2.3 Method

The design of experiment based on Response Surface Method (RSM) was used. The experimental plan consists of three controllable variables namely: cutting speed, feed rate and depth of cut. A central composite design (uniform precision) with six central replicates was selected.

with three different levels for each variable. The ranges of variable were selected based on the cutting tool catalogue and the experimental trial tests. The upper and lower limits of the process variables were identified. The upper limit of a factor was coded +1 and lower limit as -1. The selected process parameters with their limit values are given in the Table 2. Minitab-17 software was used to obtain the central composite design. The selected design matrix is a two-level, three factor (2^3) central composite factorial design (CCD) yielding a total number of 20 experimental runs as shown in Table 3. It comprises of 8 factorial design plus six centre points and six star points. The surface roughness (R_a) is considered as the output responses.

Table 2: Cutting parameters and their levels

Parameters	Levels		
	L1	L2	L3
Cutting speed (rev/min)	300	400	500
Feed rate (mm/min)	50	75	100
Depth of cut (mm)	0.25	0.5	0.75

Table 3: Experimentation layout using central composite design

Runs	Coded Value			Actual Value		
	Cutting Speed (v) rev/min	Feed rate (f) mm/min	Depth of cut (d) mm	Cutting Speed (v) rev/min	Feed rate (f) mm/min	Depth of cut (d) mm
1	-1	-1	-1	300	50	0.25
2	+1	-1	-1	500	50	0.25
3	-1	+1	-1	300	100	0.25
4	+1	+1	-1	500	100	0.25
5	-1	-1	+1	300	50	0.75
6	+1	-1	+1	500	50	0.75
7	-1	+1	+1	300	100	0.75
8	+1	+1	+1	500	100	0.75
9	$-\alpha$	0	0	231.821	75	0.5
10	$+\alpha$	0	0	568.179	75	0.5
11	0	$-\alpha$	0	400	33	0.5
12	0	$+\alpha$	0	400	117	0.5
13	0	0	$-\alpha$	400	75	0.08
14	0	0	$+\alpha$	400	75	0.92
15	0	0	0	400	75	0.5
16	0	0	0	400	75	0.5
17	0	0	0	400	75	0.5
18	0	0	0	400	75	0.5
19	0	0	0	400	75	0.5
20	0	0	0	400	75	0.5

The values of these cutting parameters were selected based on the configuration of the FCQV 63 CNC milling machine used for the milling operation. The experimental set up for the milling operation is as shown in Fig. 1. The milling machine has a maximum spindle speed of 3500 rpm, maximum feed rate of 5000 mm/min and a spindle drive motor power of 27.4kW. The low carbon steel workpiece material of dimension 122 x 40 x 87 mm was held firmly on the table-vice installed on the milling machine. Uncoated carbide inserts grade P30 were mounted on to the 100 mm diameter tool holder. For each experimental run, the set of cutting parameter were set on the CNC programme for the milling operation. For each experimental run, the workpiece was face milled to a length of 122 mm under wet cutting environment using commercially available soluble oil coolant. Fresh face milling inserts were used for each experimental run. After each face milling operation, the surface roughness of the machined surface was measured using the SRT-6200 surface roughness tester having a diamond stylus tip of radius 10 µm. The experimental set up for surface roughness measurement is presented in Fig. 2.

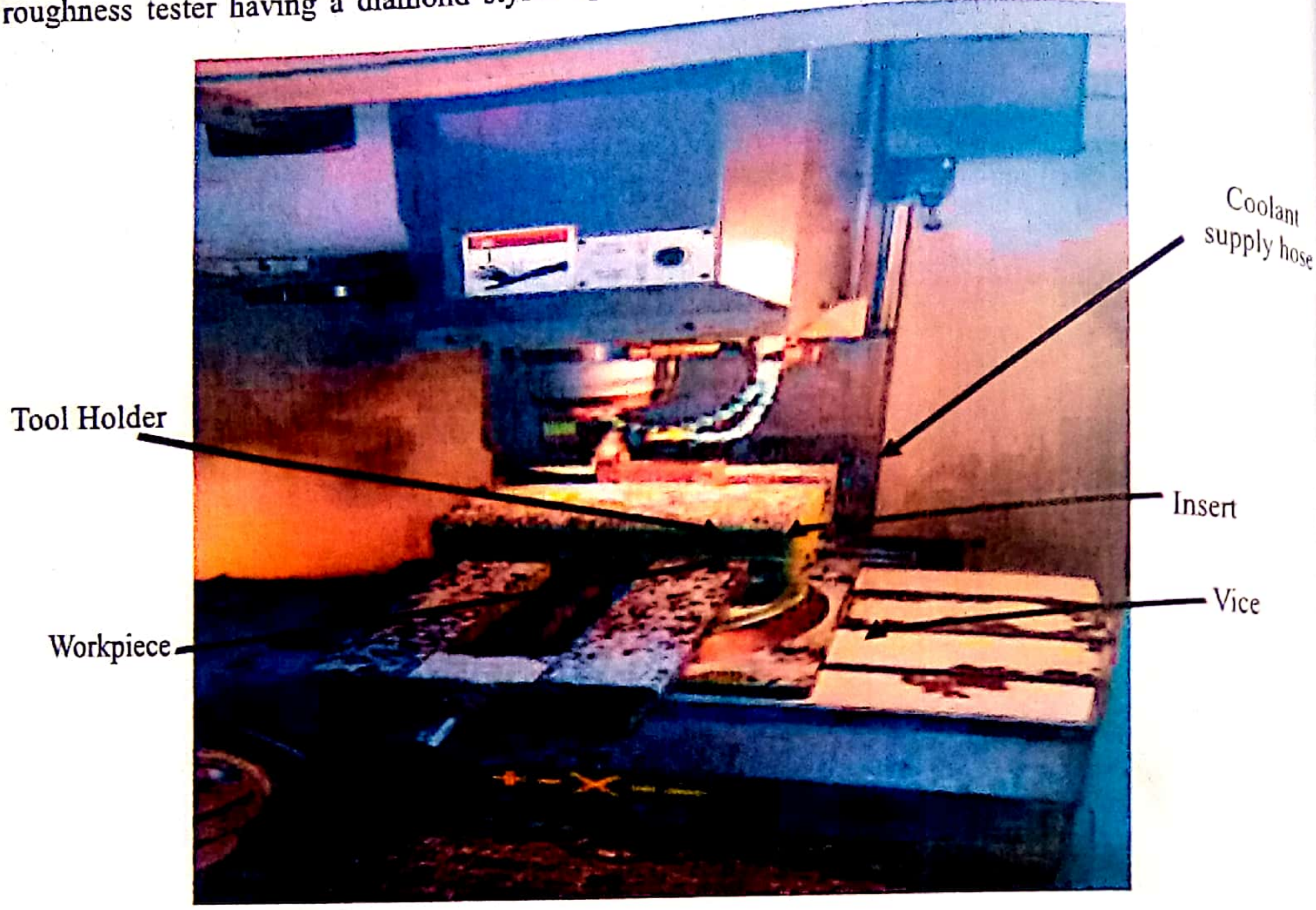

Figure 1: Experimental set up for the milling operation

Figure 2: Experimental set up for surface roughness measurement

3. Results and Discussion

The analysis of variance (ANOVA) for the surface roughness data is presented in Table 4. Feed rate has the most significant effect on surface roughness with a percentage contribution of 38.15%; followed by axial depth of cut of 33.18% and lastly by cutting speed of 23.97%. This is in agreement with the observations of Kareem *et al.* [12] and Rajesh [13] who reported that the feed rate was the most significant factor affecting surface roughness.

Table 4. Analysis of variance (ANOVA) for surface roughness

S/N	Factor	DOF	SS	MS	F	P
1	Cutting speed	2	35.92	17.96	33.17325	23.96773
2	Feed rate	2	57.18	28.59	52.80754	38.15352
3	Depth of cut	2	49.73	24.865	45.92723	33.18249
4	Error	13	7.0382	0.5414		4.69626
5	Total	19	149.8682	7.8878		100

For the purpose of optimising the response of the process parameters the signal-to-noise (S/N) ratio "the smaller the better" characteristic was selected as shown in equation 1.

$$S/N = -10\log\frac{1}{n}\left(\sum_{i=1}^{n} y_i^2\right) \qquad (1)$$

Where, S/N is signal to noise ratio, n is the number of repetition in a trial and y is the measure quality characteristic for the ith repetition.

From Fig. 3, the main effect plot for surface roughness shows that the optimal cutting parameters were observed at 300 rpm cutting speed (level 1), 50 mm/min feed rate (level 1) and 0.5 mm axial depth of cut (level 2).

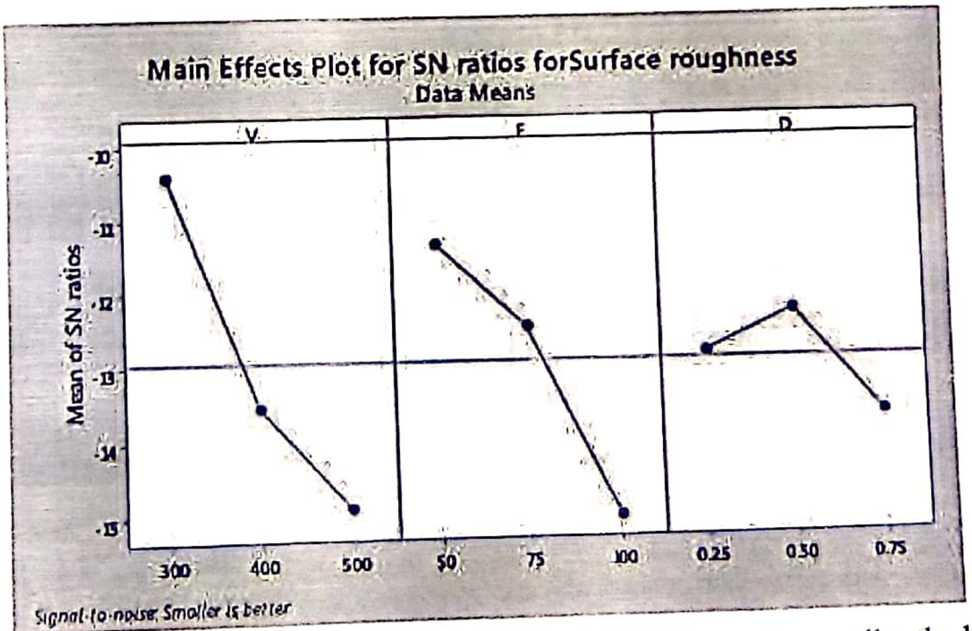

Figure 3: Main effect of process parameters using S/N ratio the smaller the better

These optimal values when substituted in the regression equation shown in equation (1) gave the optimum value for surface roughness. . The model equation for surface roughness (*Ra*) is given as:

Surface roughness (R_a) =

$$-0.41 + 0.00111\,V_c + 0.0344\,fr + 3.06\,d_c \qquad (2)$$

R^2 = 29.9 % and R^2 (adj) = 16.7 %

The following notations were used in the mathematical models V_c: cutting speed, *fr*: feed rate, d_c: axial depth of cut and *Ra*: surface roughness. The low values of R^2 and R^2 (adj) may be due to experimental uncertainty.

Fig. 4 shows the contour plot for the surface roughness. It was observed that the minimum surface roughness was obtained at depth of cut is 0.3 mm when feed rate was 50 mm/ rev when the a constant cutting speed. Surface roughness rises for axial depth of cut from 0.7 mm at feed rate of 8 mm/rev and above.

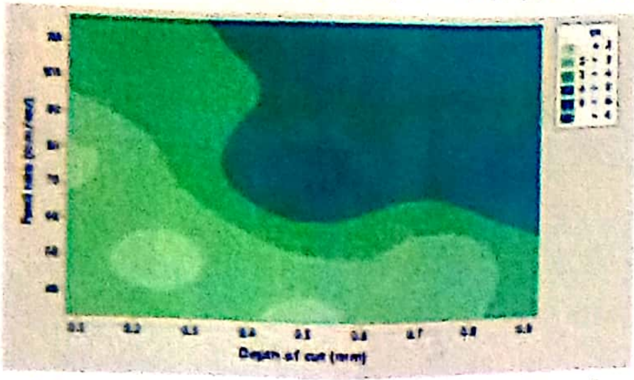

Figure 4: Contour plot of feed rate and depth of cut on surface roughness.

Fig. 5 shows the contour plot of surface roughness when the values of feed rate are plotted against the values of cutting speed when axial depth of cut is kept constant. It was observed that surface roughness increases as feed rate increased with increase in cutting speed with the range of 80 mm/rev and above for virtually all the cutting speed except between feed rate of between 95 mm/rev and 110 mm/rev and cutting speed of between 250 rpm and 330 rpm.

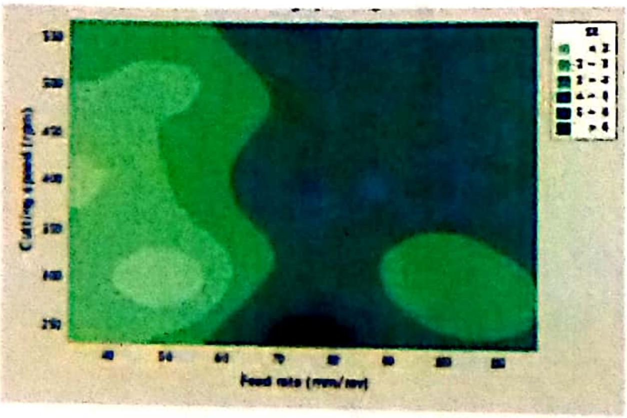

Figure 5: Contour plot of cutting speed and feed rate on surface roughness.

Fig. 6 shows the contour plot of surface roughness when the values of depth of cut are plotted against the values of cutting speed and feed rate kept constant. It was observed that best surface finish can be obtained at 0.1mm axial depth of cut and 400 rpm. Similarly best surface finish can be obtained at the region of 0.75 mm axial depth of cut and cutting speed of 280 rpm and 300 rpm cutting speed.

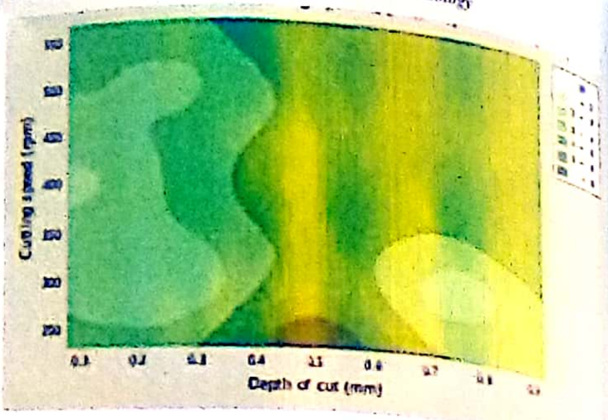

Figure 6: Contour plot of cutting speed and depth of cut on surface roughness

4. Conclusion

The following conclusion can be drawn from this study, feed rate had the most significant effect on surface roughness with a percentage contribution of 38.15%; followed by depth of cut of 33.18% and cutting speed of 23.97%. The optimum values for the cutting parameters for the surface roughness were observed at 300 rpm cutting speed, 50 mm/min feed rate and 0.5 mm depth of cut.

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