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Full Length Research Paper

The Effect of Parameters and Optimization of Surface Roughness and Cutting Temperature in Turning of AISI 1020 Carbon Steel using Taguchi Technique and ANOVA

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ABSTRACT: Quality and productivity play significant role in today's manufacturing market. In this research work, turning operation is performed on mild steel aimed at evaluating the best process environment which could simultaneously satisfy requirements of both quality and as well as productivity. Here we conducted experiments by taking Cutting Speed, Feed Rate & Depth of cut as process parameters and got the optimized value of Surface Roughness and Cutting temperature. An L9 orthogonal array, the signal-to-noise (S/N) ratio and the analysis of variance (ANOVA) are employed to the study the performance characteristics in the turning on CNC using tungsten coated carbide cutting tool insert with a nose radius of 0.8mm. The analysis of results shows that the combination of process parameters for minimum surface roughness is obtained at 75m/min cutting speed, 0.2 mm/rev feed and 1.0 mm depth of cut for minimum surface roughness. It is observed that feed rate and the speed plays important role in minimizing surface roughness. For maximum material removal rate, the optimum values are cutting speed of 75m/min, feed rate of 0.2 mm/ rev and depth of cut of 0.6 mm. It is also observed that depth of cut and the speed plays important role in minimizing cutting temperature. Finally, the relationship between cutting parameters and responses were developed by using the Minitab 18.1 software and regression equations were developed. For surface roughness and cutting temperature, the values of 2.313μm and 65.39^{0}C were determined using their respectively objective functions with their optimum parameters (values).

Keywords: Taguchi, ANOVA, signal to noise ratio, Minitab, insert, cutting temperature and surface roughness

INTRODUCTION

In manufacturing, machining is a vital part of production process and its main objective today is to produce low cost, high quality products in short time. With the advancing technology, chip cutting based machining (turning, milling, drilling etc.) methods still retain their importance. Manufacturers competitiveness in the market rely on their manufacturing engineers and production personnel to quickly and effectively set up manufacturing processes of their products. There is a wide variety of applications of Mild Steel in the areas of electrical devices, construction of pipelines, products, construction as structural steel, automobile manufacturing industry, railway parts and many others.

AISI (American Iron and Steel Institute) 1020 (0.18% - 0.23% carbon) is one of the most commonly used mild steel for simple structural applications for its excellent weld-ability and machinability. Functional properties of machined components such as corrosion resistance, wear rate, coefficient of friction, and fatigue strength of the machined components, these properties are always influenced by the surface finish or quality of the product. Surface roughness, surface texture and dimensional deviations of a product are a result of cutting parameters (Sonowal *et al*., 2017). In enhancing the quality of machined products and in reducing machining costs, the selection of optimal cutting parameters is a very important

issue for every machining process. Today, increasing the productivity and the quality of the machined parts in terms of work piece dimensional accuracy, good surface finish, ensuring minimum cutting temperature, less tool wear on the cutting tools, high metal removal rate and economy of machining in terms of time per component, cost per component and the performance of the product are the main challenges of metal cutting industry during machining process (Das *et al*., 2012).

Taguchi Parameter Design is a powerful and efficient method for optimizing quality and performance output of manufacturing processes, thus a powerful tool for meeting this challenge. This work focuses on the influence of cutting speed, feed and the depth of cut on the surface roughness and the cutting temperature of mild steel material during orthogonal turning. A single characteristics optimization model based on Taguchi method will be employed to determine the best combination of the machining parameters such as cutting speed, feed and depth of cut to attain the minimum surface roughness and cutting temperature simultaneously. In order to obtain optimal cutting parameters to achieve the best possible surface finish, manufacturing industries have resorted to the use of handbook based information and operators' experience. This traditional practice is not sustainable and leads to deficiencies in surface finish and decrease in the productivity due to sub-optimal use of machining capability. Manufacturing industries in developing countries suffer from this major drawback of not running the machine at their optimal operating conditions. The disadvantage of this unscientific practice is the decrease in productivity due to sub optimal use of machining capability.

Turning in its basic form, can be defined as the machining of an external surface, with the cylindrical work piece rotating, with a single-point cutting tool, and with the cutting tool feeding parallel to the axis of the work piece and at a distance that will remove the outer surface of the work. Turning is used to reduce the diameter of the work piece and to produce a smooth finish on the metal. Turning operation is very important material removal process in modern industry. At least one fifth of all applications in metal cutting are turning operations (Saraswat *et al.* 2014). An optimum combination input parameters for ensuring minimum cutting temperature and surface finish are desirable for sustainability performance of the machining process. There is a close relationship among productivity, quality and the above response parameters in machining operations. The surface roughness is a widely used index of product quality in terms of various parameters such as aesthetics, corrosion resistance, subsequent processing advantages, fatigue life improvement and precision fit of critical mating surfaces. Most researches on machining show that the most widely considered machining performances by researchers are surface roughness, optimal tool life by ensuring good cutting temperature followed by machining/production cost and material removal rate (Yusup *et al.*, 2012).

The focus of this study is to develop a statistical model for using the main cutting parameters of cutting speed, feed rate and depth of cut on AISI 1020 Mild Steel work piece. Machining tests will be carried out with coated carbide tipped cutting tool. The experimental investigation will be carried out on a CNC machine. Samples of round bars of AISI 1020 Mild Steel will be used. The values obtained for the surface roughness and cutting temperatures during the machining will be evaluated to determine the effects of each machining parameter, using Minitab 18 software. Design of Experiment via Taguchi technique will be employed, and Analysis of variance (ANOVA) will also be used to determine the significant effect of each machining parameter on the response parameters.

There is need to meet the increasing demand of manufacturing complicated components of high accuracy in large quantities. The turning operation is a basic metal cutting operation widely used in the manufacturing industry. The important task in accomplishing high performance is based on optimum selection of machining parameters for a turning operation and this is the main challenge of metal cutting industry today.

Literature review

The development of materials which allowed new improved tools, new lathes and automatic machines, automatic control, ultra-precision machining, computer integrated machines, milling and turning centres were introduced in the 20th century. Therefore, Automation in any manufacturing centre can help eliminates wastes, reduces costs, production cycle times, reduces drastically the amount of manual tasks and increases process robustness and product quality, (Ehibor and Aliemeke, 2021).

Kpina and Nwosu, (2018) investigated the roughness characteristics of surface profile generated in turning of AISI 1040 Mild Steel using NAG=MATI175 lathe machine. The study aimed at modeling of machining parameters in turning operation to enhance surface quality. Machining was done using high speed steel under dry cutting condition. The machining parameters were the spindle speed, the feed rate; the L27 orthogonal array was selected. A multiple regression model was developed to study the effect of cutting parameters on surface quality/roughness. The prediction ability of the model was tested and analysis of variance (ANOVA) was carried out. From the experimental test, the results reveals that the combination that gives the optimum condition of better surface finish are the feed rate of level 1 (0.10mm/rev, spindle speed of level 3 (900rpm), depth of cut at level 1 (0.5mm) and nose radius at level 1 (0.6mm). in addition, the author recommends that further study could be possible considering other factors such as the use of

cutting fluid, the effects of coolant systems on turning operation maybe considered for better quality of machined surface.

Mgbemena *et al*. (2016) embarked on an investigation on the study of AISI 1018 carbon steel during turning operation to reduce tooling costs as a result of tool wear and achieve optimum metal removal rate. Taguchi technique was employed using the L9 orthogonal array and the analysis of variance (ANOVA) to investigate the effect of the turning parameters on Metal Removal Rate (MRR) and Tool Wear Rate (TWR).

The results revealed that depth of cut is the most significant process parameter for MRR with a percentage contribution of 86.84%; for the metal removal rate, the optimal machining condition was obtained at a cutting speed of 140 rpm, a feed of 0.30mm/rev and a depth of 0.75mm.

The cutting speed and the feed rate are the most significant process parameters for TWR with percentage contributions of 60.86% and 30.03% respectively. For the tool wear rate, the optimal machining condition was obtained at a cutting speed of 140 rpm, a feed of 0.30 mm/rev and a depth of 0.75mm. The study concludes that AISI 1018 low carbon steel has a maximum MRR of 35.29mm3⁄s and a minimum TWR of 0.21mm⁄s.

Neeraj *et al.* (2014) carried out the determination of the optimal cutting parameters for EN9 steel in turning operation. The analysis of variance (ANOVA) and signal to noise ratio (S/N ratio) were used to study the performance characteristics in turning operation. The cutting speed, feed rate and depth of cut were selected as an input parameter to optimize the surface roughness.

Romesh *et al*. (2017) investigated the effect of Process Parameters and Optimization of MRR in Turning ofEN8 Steel on CNC Lathe using Response Surface Methodology. From the experimental tests carried out, the cutting speed, depth of cut and feed rate, all found to have contributed in obtaining maximum MRR but depth of cut is the most significant factor. Using regression analysis, the evaluation of the mathematical model shows that the predicted values are much closer to experimental values and the percentage error for the optimum MRR is minimum.

RSM has been applied to optimize the results. The optimum set of parameters are cutting speed 1200rpm, depth of cut– 0.3& feed rate – 0.25mm/rev, and the optimum value of MRR is 5476.16mm^3/min. their contribution factor depth of cut (72.64 %), cutting speed is (32.84%) while feed rate has insignificant effect on MRR. The aim of this research work is to determine the effect of process parameters and optimization of surface roughness and cutting temperature in orthogonal turning of mild steel using Taguchi technique and ANOVA. This aim will be achieved through the following objectives.

To carry out machining of Mild Steel using Design of Experiment (DOE) via Taguchi technique.

To develop empirical models for prediction of machining quality characteristics — Minimum Surface Roughness and Cutting Temperature.

To find out which process parameters is more or less significant in influencing the response parameters using the Analysis of Variance (ANOVA). Generation of Regression equations used to find the optimum surface roughness and the cutting temperature.

MATERIALS AND METHODS

AISI 1020 carbon steel is a commonly used carbon steel with good combination of strength and ductility which can be hardened or carburized with a density of 7.87g/cm^3. With good form-ability and weld-ability, and by heating between 815- 871°C (1500 - 1600°F), this steel can be hardened and then followed by water quenching. Forging processes can be carried out on AISI 1020 carbon steel at 1260°C (2300°F) down to 982°C (1800°F). AISI 1020 carbon steel can be tempered and hardened by cold working and by heat treatment, then quenching. It has wide range of applications which includes in the field of manufacturing and aerospace, for simple structural applications such as cold headed bolts. Other applications of this steel includes for pins, shafts, chains, lightly stressed gears, hard wearing surfaces and for case hardened components where core strength is not mandatory. The work piece material is shown in (Figure 1 and Table 3), in the form of round bars each 50mm diameter and 600mm length. The chemical composition and mechanical properties are shown in the (Tables 1 and 2).

The selected machining parameters for the analysis and their effect on surface roughness and cutting temperature are cutting speed, feed rate and the depth of cut. The choice of machining parameters was made by taking into account the capacity/limiting cutting conditions of the CNC turning machine, tool manufacturer's catalogue and the values taken by researchers in the literature. Cutting speed (v), feed rate (f) and depth of cut (*d*) were chosen as the input parameters for this experimental work. A total of 9 experiments based on Taguchi's L 9 (3^3) orthogonal array were carried out with different combinations of the levels of the input parameters. The following three cutting speeds 75, 125 and 175 m/min, feed rate of 0.2, 0.4 and 0.6 mm/rev with depth of cut 0.6, 0.8 and 1.0 mm were taken.

Cutting tool inserts and holder

In the experimental tests, coated carbide cutting tools will be used. This cutting tool to be use is proper for machining of AISI 1020 carbon steel. Inserts of ISO CNMG 120408 designation having 0.4mm nose radius was mounted on the tool holder. For this reason, the selection of the right

Table 1: Chemical composition of AISI 1020 Mild Steel in percentage weight.

Material	Carbon (%)	Manganese (%)	Phosphorus (%)	Sulphur (%)	Iron (%)
AISI 1020 Mild Steel	0.18	0.4	0.04	0.05	Balanced

Table 2: Mechanical properties of AISI 1020 Mild Steel.

Material	Density (g/m3)	Elastic Modulus (GPa)	Yield Strength (MPa)	Tensile Strength (MPa)	Hardness (HB)	Elongation (%)	Poison Ratio
AISI 1020 Mild Steel	7.87	205	350	420	121	15	0.29

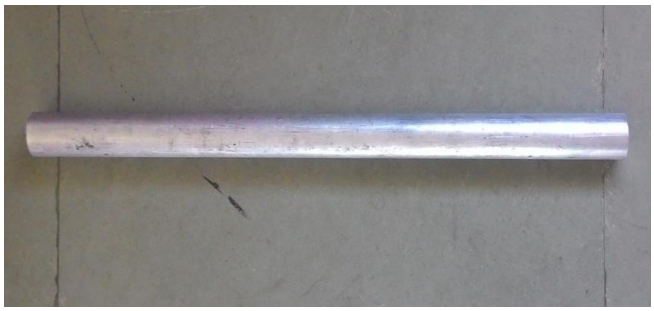

Figure 1: AISI 1020 Mild Steel

Figure 2: Insert mounted on the tool holder.

Table 3: Experimental conditions

Work piece material	AISI 1020 Mild Steel
Length of work piece	600mm (Machined Length = 500mm)
Diameter of work piece	50mm (49.5mm after pre-cut)
Lathe used	CNC Lathe
Surface Tester	Mitutoyo (SJ-210 ISAO 1997) portable surface tester
Cutting Tool Used	Coated Cemented Carbide Cutting Tool
Cutting Temperature Reader	Digital Infra-Red Thermometer (Up to 1100^{o}c)

cutting tool geometry is important in metal cutting (Harinath *et al.,* 2014). An insert mounted on the tool holder is shown below in (Figure 2).

Experimental setup

With the use of DOE via Taguchi, experimental tests are

Table 4: Coded value of process factor

Factors	Units	Level 1	Level 2	Level 3
Cutting Speed	m/min	-1	0	+1
Feed	mm/rev	-1	0	+1
Depth of Cut	Mm	-1	0	+1

Table 5: Process parameters with their values at 3 levels.

Factors	Symbols	Level 1	Level 2	Level 3
Spindle Speed (m/min)	V	75	125	175
Feed Rate (mm/rev)	F	0.2	0.4	0.6
Depth of Cut (mm)	D	0.6	0.8	1.0

Table 6: Experimental data.

Spindle Speed (m/min)	Feed Rate (mm/rev)	Depth of cut (mm)	Surface R. (Ra) μm			Average (Ra) μm	Temp. (^{O}C)
			RUN 1	RUN2	RUN3		
75	0.2	0.6	2.401	2.452	2.436	2.430	65.3
75	0.4	0.8	2.617	2.805	2.723	2.715	68.2
75	0.6	1.0	3.309	3.167	3.268	3.248	70.4
125	0.2	0.8	2.861	2.972	3.121	2.984	67.5
125	0.4	1.0	3.182	3.461	3.176	3.273	79.8
125	0.6	0.6	3.524	3.787	3.684	3.665	70.4
175	0.2	1.0	2.724	2.931	2.811	2.822	95.2
175	0.4	0.6	3.532	3.571	3.823	3.642	83.1
175	0.6	0.8	4.027	4.202	4.146	4.125	80.7

designed in which planned changes are made to the input parameters of a process or system. The assessment of the effects of these changes on a pre-defined output are then determined. A number of levels are defined that represent the range for which the effect of that parameter is desired to be known for each input variable. Taguchi proposed the experimental design which involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varies. Taguchi method tests pairs of combinations unlike the factorial design which involves the testing of all possible combinations (Basil *et al.,* 2014). This allows for the collection of the necessary data to determine which factors most affect the response quality with a minimum amount of experimentation, thus saving time and resources.

Taguchi's Design of Experiment

An experimental strategy in which effects of multiple factors are studied simultaneously by running tests at various levels of the factors is known as Design of Experiment (DOE). Taguchi DOE is a powerful and efficient method over other traditional methods. A series of structured tests are designed in which planned changes are made to the input variables of a process or system and the effects of these changes on a pre-defined output are then assessed. The response is then measured for each run. These differences are then attributed to the input variables acting alone (called a single effect). Minitab 18 software was used for generating the Taguchi's orthogonal array.

Determining the degree of influence of the process parameters during turning of AISI 1020 Mild Steel, three factors, each at three levels are taken as shown below. In this research, nine experiments were conducted at different parameter levels and the L9 orthogonal array was used, which has nine rows corresponding to the number of experimental tests.

Determinations of surface roughness and cutting temperature

Surface finish is an essential requirement in determining the surface quality of a product and also is often a good predictor of the quality for cracks or corrosion. Roughness is a measure of the texture of a surface and it was measured using a tester (Model – Mitutoyo SJ-210 ISO 1997) portable surface roughness tester at three different points of the machined work piece. Digital Infra-Red thermometer was used in taking the cutting temperature during the machining process (Tables 4-9).

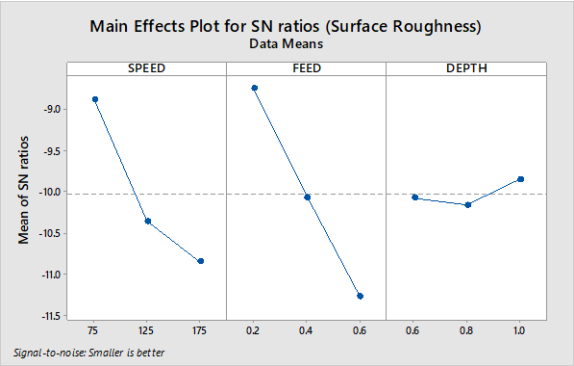

Figure 3: Main effect plot for surface roughness.

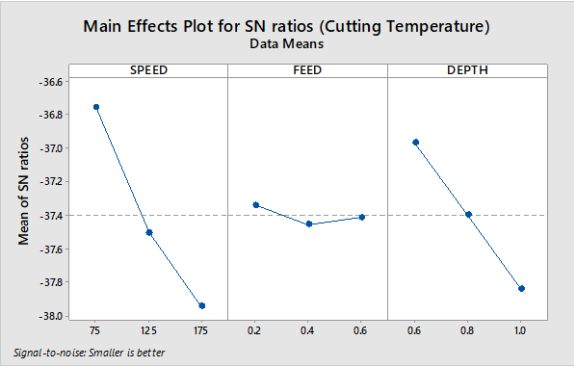

Figure 4: Main effect plot for cutting temperature.

RESULT AND DISCUSSION

Main effect plots

The main effect plots of signal to noise ratio (S/N Ratio) shown in figure for surface roughness are used to determine the optimum value for each input parameters during the turning process for all optimum responses listed above. The lower the better characteristics were chosen for surface roughness. Here the optimal turning parameters for the surface roughness as shown in (Figures 3 and 4) are 75 rpm for spindle speed (level 1), 0.2 mm/rev for feed rate (level 1) and 1.0 mm for the depth of cut (level 3). For cutting temperature. The lower the better characteristics were also chosen for cutting temperature. Here the optimal turning parameters for cutting temperature as shown in (Figure 4) are 75 rpm for spindle speed (level 1), 0.2 mm/rev for feed rate (level 1) and 0.6 mm for the depth of cut (level 1).

Signal to noise ratio

Parameters that have an effect on the output in Taguchi design are into 2 parts: the controllable factors and the uncontrollable (or noise) factors. The term 'signal' represents the desirable value (mean) for the output characteristic and the term 'noise' represents the undesirable value for the output characteristic. Quality characteristic deviating from the desired value are measured using the S/N Ratio. Smaller-the-Better is employed for surface roughness. As a result, we tend to minimize the surface roughness.

ANOVA analysis for surface roughness

ANOVA statistics as shown was used to study the significance of the input parameters on the Surface Roughness. From the nine experiments performed of Taguchi, the results for surface roughness were obtained. The experimental results analyzed as shown using MINITAB 18.1 software. The importance of the factors on the required characteristics was shown in the ANOVA table. As shown in (Table 10), the significant effects of cutting speed, feed rate and depth of cut on the surface roughness are as follows: Cutting Speed (36.88%), Feed Rate (57.11%), Depth of Cut (1.91%) while the residual error is (4.10%). This result shows that feed rate has more significant impact followed by the cutting speed. As shown in (Table 11), the significant effects of cutting speed, feed rate and depth of cut on the cutting temperature are as follows: Cutting Speed (63.66%), Feed Rate (0.46%), Depth of Cut (33,77%) while the residual error is (2.11%). This result shows that the spindle speed has more significant impact followed by the depth of cut. This indicated for surface roughness that the feed rate, distantly followed by the cutting speed is more significant than the depth of cut on the surface roughness during this machining operation. While for cutting temperature, the spindle speed followed by the depth of cut is more significant than the feed rate on the cutting temperature during this machining operation.

Regression equation for surface roughness

Regression analysis has been performed to find out the relationship between input factors and Surface Roughness. During regression analysis it was assumed that the factors and the response are linearly related to each other. Regression equation is used to find the optimum (minimum) surface roughness at any cutting parameters.

Surface R. = 1.625 + 0.00732 Speed + 2.335 Feed - 0.328 Depth.
Surface R. = 1.625 + 0.00732 (75) + 2.335 (0.2) - 0.328 (1.0)
Ra = 2.313μm
R – sq = 93.32%, R – sq (adj) = 89.30%.
Regression equation is used to find the optimum (minimum) cutting temperature at any cutting parameters.
Cutting Temp. = 46.52 + 0.1007, Speed + 1.08 Feed +

Table 7: Surface roughness characteristics.

Experimental Number	Spindle Speed (rpm)	Feed Rate (mm/rev)	Depth of Cut (mm)	SRFACE roughness, (Ra) μm	S/N ratio	TEMP. (^{O}C)	S/N ratio
1	150	0.3	0.6	2.430	-7.7121	65.3	-36.2983
2	150	0.2	0.8	2.715	-8.6754	68.2	-36.6757
3.	150	0.4	1.0	3.248	-10.2323	73.2	-37.2902
4.	330	0.2	0.8	2.984	-9.4960	75.2	-37.5244
5.	330	0.3	1.0	3.273	-10.2989	79.8	-38.0401
6.	330	0.4	0.6	3.665	-11.2815	70.4	-36.9515
7.	630	0.2	1.0	2.822	-9.0111	81.2	-38.1911
8.	630	0.3	0.6	3.642	-11.2268	76.3	-37.6505
9.	630	0.4	0.8	4.125	-12.3085	79.4	-37.9964

Table 8: Response for signal to noise ratios (surface roughness).

Level	Cutting speed	Feed rate	Depth of cut
1	-8.873	-8.740	-10.073
2	-10.359	-10.067	-10.160
3	-10.849	-11.274	-9847
Delta	1.976	2.534	0.312
Rank	2	1	3

Table 9: Response for signal to noise ratios (cutting temperature).

Level	Cutting Speed	Feed Rate	Depth of Cut
1	-36.75	-37.34	-36.97
2	-37.57	-37.46	-37.40
3	-37.95	-37.41	-37.84
Delta	1.19	0.12	0.87
Rank	1	3	2

Table 10: Analysis of variance for means (surface roughness).

Source	DF	Seq SS	Adj SS	Adj MS	F	P (%Cont.)
Speed	2	0.84502	0.84502	0.42251	8.99	36.88%
Feed	2	1.30854	1.30854	0.65427	13.93	57.11%
Depth	2	0.04380	0.04380	0.02190	0.47	1.91%
Residual Error	2	0.09395	0.09395	0.04698		4.10%
Total	8	2.29131	2.29131			

Table 11: Analysis of variance for means (cutting temperature).

Source	DF	Seq SS	Adj SS	Adj MS	F	P (% Con.)
Speed	2	154.887	154.887	77.4433	30.21	63.66
Feed	2	1.127	1.127	0.5633	0.22	0.46
Depth	2	82.160	82.160	41.0800	16.03	33.77
Residual Error	2	5.127	5.127	2.5633		2.11

18.50 Depth.

Cutting Temp. = 46.52 + 0.1007 (75) + 1.08 (0.2) + 18.50 (0.6)

Cutting Temp.= 65.39^{0}C.

R – sq = 96.35%, R – sq (adj) = 94.17%.

Contour plots

The Contour Plot shows the effect of the most two influential parameters on the surface roughness. This shows the relationship between the speed and the feed in

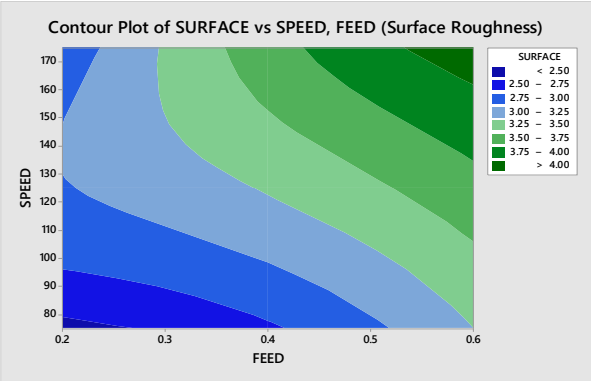

Figure 5: Contour Plots for Surface Roughness.

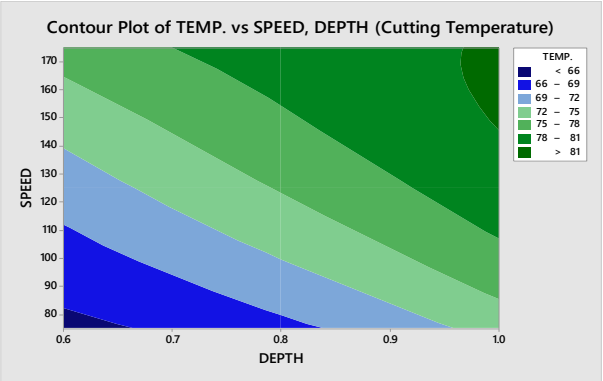

Figure 6: Contour Plots for Cutting Temperature.

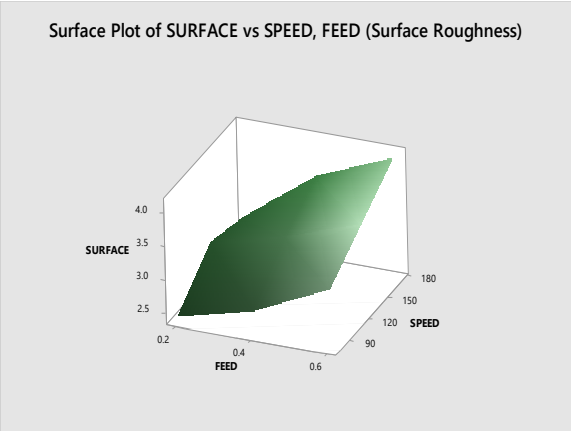

Figure 7: 3D Surface Graph for Surface Roughness.

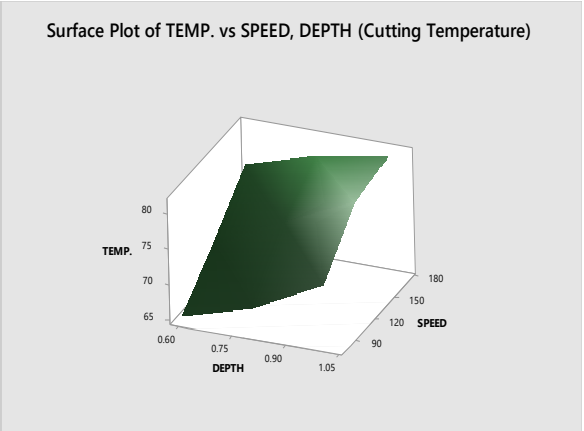

Figure 8: 3D Surface Graph for Cutting Temperature.

(Figure 5) indicates that the best surface roughness quality is at the lower left region. Therefore, as the speed and feed reduces, the surface quality increases. Figure 6 also indicates that the best (minimum) cutting temperature is at the lower left region. Therefore, as the speed and depth of cut reduces, the cutting temperature decreases.

3D surface plots

The 3D Surface Plot shows the effect of the two most influential parameters on the surface roughness. From the 3D surface plot for surface roughness in Fig. 7, the surface roughness decreases with decrease in both speed and the feed rate which is in agreement with the contour plot. For the cutting temperature, the 3D surface plot in Fig. 8 shows that the cutting temperature decreases with decrease in both speed and the depth of cut which is in agreement with the contour plot.

Conclusion

Predictive and optimization models for the prediction and optimization of machining parameters leading to minimum surface roughness and cutting temperature during turning of mild steel using coated tungsten carbide insert (CNMG 120408) were presented in this study under dry cutting environment. The Surface roughness is principally plagued by feed rate, spindle speed and then depth of cut. With the rise in feed rate the surface roughness increases. The parameters taken within the experiments area unit optimized to get the minimum surface roughness potential. The optimum setting of cutting parameters for high quality turned work piece is as:

1. Spindle Speed = 75 m/min (Level 1)
2. Feed Rate = 0.2 mm/ rev (Level 1)
3. Depth of Cut = 1.0 mm (Level 3)

For the surface roughness, the value of 2.313μm was determined using the objective function with the above optimum parameters. The Cutting Temperature is principally influenced by spindle speed, and depth of cut. With the rise in spindle speed and depth of cut, the cutting temperature increases. The parameters taken within the experiments area unit optimized to get the minimum surface roughness potential. The optimum setting of cutting parameters for minimum cutting temperature is as:

1. Spindle Speed = 75 rpm (Level 1)
2. Feed Rate = 0.2 mm/ rev (Level 1)
3. Depth of Cut = 0.6 mm (Level 1)

For the cutting temperature, the value of 65.39^0C was determined using the objective function with the above optimum parameters.

Recommendations

In this research work, solely three input (operating) parameters which are the spindle speed, the feed rate and the depth of cut are studied in accordance with their effects. Other areas that should also be explored include types of Inserts, cutting conditions (dry or wet) and cutting tool geometry. Also, other output parameters like material removal rate, cutting forces, cutting tool wear and tool life. The parameters could also be optimized for the overall best economy of machining.

Conflict of interest

The authors of this article have not declared any conflict of interest.

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