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Analysis of Surface Roughness during Turning of AISI D2 Steel

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Abstract – Main goal of Industry at present is to manufacture products with high quality at low cost. The industry has to meet the challenges of quality and productivity of machined parts during turning that too economically. This paper presents the experimental study related to the optimization of cutting parameters in turning of AISI D2 steel by coated carbide inserts using Response Surface Methodology (RSM). The RSM based Central Composite Design (CCD) is employed as an experimental design. The relationship between cutting parameters (cutting speed (m/min), feed (mm/rev) and depth of cut (mm)) and the response parameter (surface roughness (µm)) is analysed using the contour plots. The influence of each cutting parameter is studied through Analysis Of Variance (ANOVA). Cutting speed and depth of cut are found to be significant parameters for surface roughness. The interaction of cutting speed and feed is significant factor for surface roughness.

Keywords – Turning, RSM, AISI D2 Steel, Surface Roughness.

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INTRODUCTION

Machining is an important manufacturing process that is used in a wide range of applications. From aerospace applications to the manufacturing of energy systems and medical robots, there is major reliance on machining. Turning is a machining process used to obtain the desired dimension of round metal. The main objective of present industrial era is to produce low cost quality product with required dimensions in an optimum time *[2]*. Turning process involves of removal of material from the outer diameter of a rotating cylindrical workpiece. It reduces the diameter of the workpiece, usually to a specified dimension, and to produce a smooth finish on the workpiece. Generally, the work piece will be turned so that adjacent sections have different diameters. In its basic form, it can be defined as the machining of an external surface: with the work piece rotating, 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 as shown in Figure 1. The selection of machining parameters for a turning operation is a very important task in order to accomplish high performance. By high performance, means good machinability, better surface finish, lesser rate of tool wear, higher material removal rate; faster rate of production etc. Present day metal cutting industry has to meet the challenges of quality and productivity of the machined parts during turning economically.

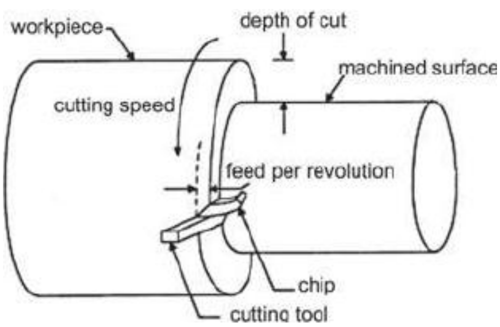


Fig.1 Basic turning process *[2]*

LITERATURE REVIEW

Studies on Surface Roughness

Sharma et al. *[1]* developed a model to predict the surface roughness on EN -31 alloy steel by optimizing the input parameters (spindle speed, feed rate and depth of cut) by using coated carbide tool. A second order mathematical model was developed using regression technique and optimization carried out using Box-Behnken of response surface methodology. They concluded that the surface roughness does not vary much with experimental depth of cut in the range of 0.1 to 0.3 mm. Also a minimum surface roughness (0.595µm) can obtained at medium feed (0.115mm/rev), higher depth of cut (0.3mm) and low speed (90m/min). Agrawal et al. *[3]* performed 39 experiments to study the effect of cutting parameters (speed, feed, depth of cut) influencing the machined surface roughness. AISI 4340 steel work piece (hardened up to 69 HRC) was machined with a commercially available CBN insert under dry conditions. They used the machining outcome as an input to develop various regression models to predict the average machined surface roughness. Three regression models– Multiple regression, Random forest, and Quantile regression were applied to the experimental outcomes. They found out that random forest regression model is a superior choice over multiple regression models for prediction of surface roughness. Salunke and Rathi *[4]* carried out an experimental study to optimize the effects of cutting parameters (cutting speed, feed and depth of cut) on surface roughness for turning of AISI D2 steel with ceramic tool. They used the Taguchi's L9 orthogonal array and analysis of variance (ANOVA) to investigate characteristics, also developed a regression model to predict the surface roughness. They concluded that the cutting speed is the most influencing parameter to surface roughness followed by feed rate and prediction of surface roughness can be done effectively with this model. The main effects plot is shown in Figure 2 which indicates that the surface roughness parameter reduces with gradually increase of cutting speed. When the speed increases from 115 to 195 m/min the surface roughness decreased. Khidhir et al. *[5]* have developed a predictive model for surface roughness and temperature in turning operation of AISI 1020 mild steel The factors taken into consideration were speed, feed and depth of cut. By using ANOVA they found that cutting speed and depth of cut are significant parameters which affect surface roughness. Using cemented carbide in a dry condition using the RSM Box-Behnken design.

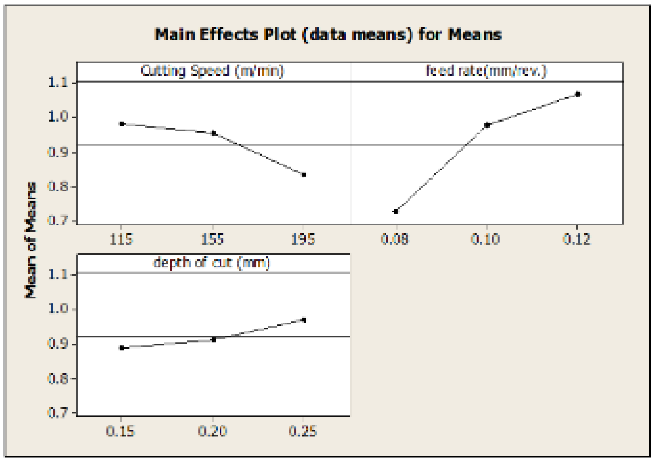
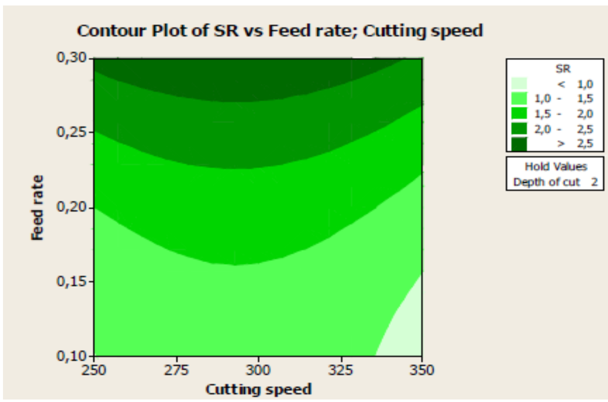
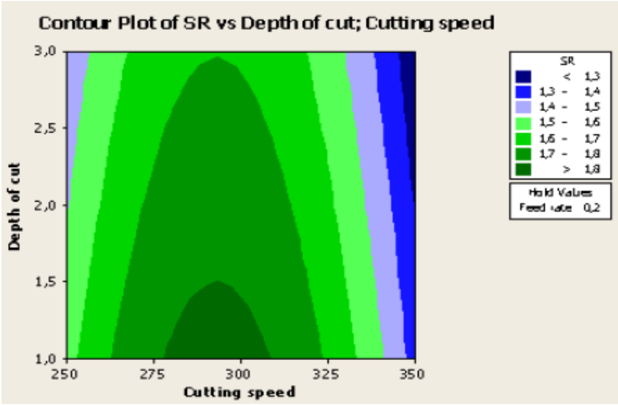


Fig. 2 Main effects plot of surface roughness Ra (μm) *[4]*

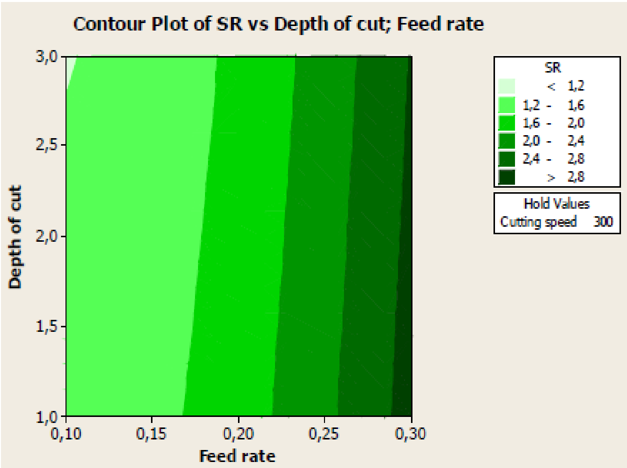
They compared results of the developed predicted model with those of the real experiments. The percentage of error obtained from the CNC turning machine was from 0% to 2% for both predicted models. It is clear that increasing cutting speed with decreasing feed rate will decrease the surface roughness as shown in Figure 3(a) and surface roughness reaches its highest value when cutting speed is medium with low depth of cut as shown in Figure 3(b) whereas surface roughness is minimized at low feed rate and depth of cut as shown in Figure 3(c). Borse *[6]* carried out an experimental investigation of turning process parameters on EN-31 material, for optimization of surface roughness. He used carbide inserts for machining to study effects of process parameters, viz, cutting speed, feed and depth of cut. The design of experiment and optimization of surface roughness was carried out by using Taguchi L9 orthogonal array and Grey Relational analysis. Based on the average grey relational analysis he concluded the optimum values of speed, feed and depth of cut for surface roughness. Valera and Bhavsar *[7]* carried out an experimental study of power consumption and surface roughness characteristics in turning operation of EN-31 alloy steel with TiN+Al_2O_3+TiCN coated tungsten carbide tool under different cutting parameters. Cutting parameters selected were speed, feed, and depth of cut. The experimental setup included five different spindle speeds keeping feed rate and depth of cut constant and so on. The machining experiments were carried out on the lathe machine in dry condition. They concluded that spindle speed, feed and depth of cut significantly affect the surface roughness and power consumption but needs a detailed DoE to optimize the process and to find out the most significant parameter. Beatrice et al. *[8]* developed a model based on Artificial Neural Network (ANN) to simulate hard turning of AISI H13 steel with minimal cutting fluid application. This model was used to predict the surface roughness in terms of cutting parameters (speed, feed, and depth of cut). Taguchi technique was used for experimentation and ANN for prediction of the surface roughness. The fluid application parameters like pressure at the injector, rate of application of cutting fluid, composition of cutting fluid and frequency of pulsing were maintained in the optimized condition. They found that predictions made by the ANN model matched well with the experimental results.



a) cutting speed vs feed rate



b) cutting speed vs depth of cut

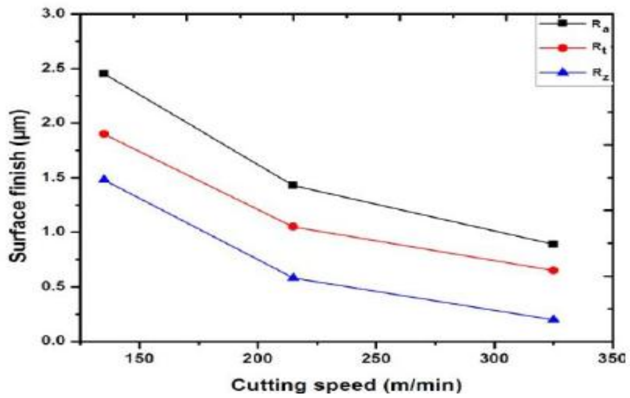


c) feed rate vs depth of cut

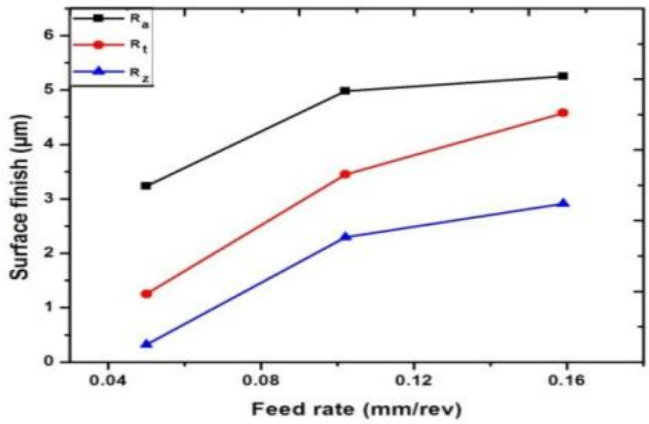
Fig. 3 Contour plots of surface roughness *[5]*

Davis et al. *[9]* obtained the optimal levels of the parameters (speed, feed, depth of cut) for getting minimum surface roughness by performing the turning operations on EN24 steel by carbide cutting tool in wet condition. Taguchi method was used for the design of experiments to study the effect of three different parameters on the Surface Roughness. They concluded that feed rate followed by depth of cut and spindle speed was the combination of the optimal levels of factors and by ANOVA they found that none of the factors were significant. Srithar et al. *[10]* performed experiments to investigate and analyse the surface roughness for turning of AISI D2 steel using the coated carbide insert. They discussed the importance of hard turning of AISI D2 steel by selecting parameters like speed, feed, and depth of cut. Investigations were carried out on conventional lathe using the prefixed cutting conditions. They concluded that with increase in cutting speed the surface roughness decreases, refer Figure 4(a),

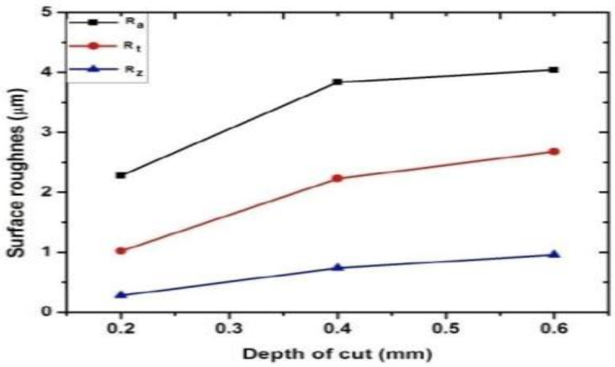
Gradual increase of feed rate and depth of cut increases the surface roughness as shown in Figure 4(b), (c) respectively. Muley et al. *[11]* made an attempt to optimize the material removal rate (MRR) and surface roughness for a given range of cutting parameters in turning operation. The material used was AISI D2 steel and the tool insert used was mixed ceramic (Al_2O_3 + TiCN) coated with TiN. The experimentation was done by varying the cutting speed for five values, by keeping feed and depth of cut constant. They concluded that increase in cutting speed decreases the surface roughness as shown in Figure 5. Camposeco *[12]* carried out an experimental study for optimization of cutting parameters in rough turning of AISI 6061 T6 Aluminium. Parameters selected were speed, feed, and depth of cut and carbide insert as a cutting tool. Energy consumption and surface roughness were minimized, while the material removal rate of the process was maximized.



(a)



(b)



(c)

Fig. 4 Surface roughness parameters with respect to (a) cutting speed (b) feed rate (c) depth of cut *[10]*

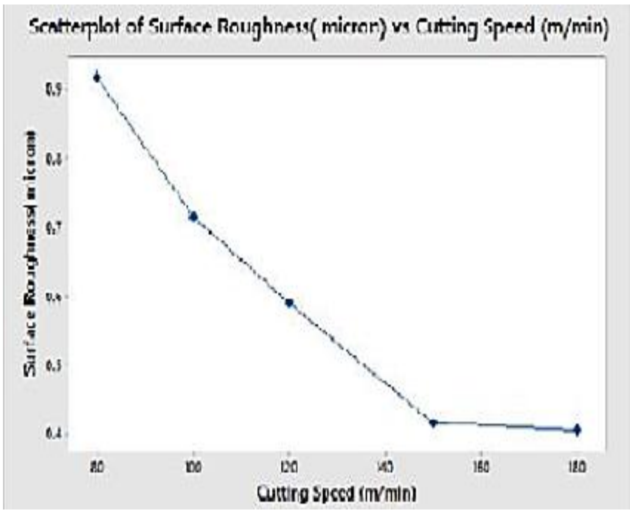


Fig. 5 Scatterplot of Surface Roughness vs cutting speed *[11]*

Central Composite Design (CCD) was used for the experimental runs. Response Surface Method was employed to obtain the regression model for the energy consumed during machining, specific energy, surface roughness and material removal rate. The adequacy of the model was proved by Analysis of Variance and counter plots were used to analyse the relationship between cutting parameters and the response variables. She concluded that the values of depth of cut and cutting speed had little influence and feed rate has the highest influence on surface roughness. Bartarya and Choudhury *[13]* performed turning of hardened EN31 bearing steel (60 ± 2 HRC) which is equivalent to AISI52100 using CBN insert. They examined the effect of cutting parameters (speed, feed, and depth of cut) on the cutting forces and surface roughness produced. A full factorial DoE procedure was used to develop the force and surface roughness regression models, within the range of parameters selected. They concluded that most energy efficient cut can be achieved for relatively lower and moderate cutting speeds with moderate depth of cut in the range of parameters selected for nearly all feed values selected in the range. By ANOVA they concluded that depth of cut, feed rate and their interaction was found to be the most influential parameter affecting surface roughness. Panda et al. *[14]* investigated the surface roughness under dry turning of EN 31 steel using multilayer coated carbide inserts through Taguchi's L_{16} orthogonal array design. The cutting parameters selected were cutting speed, feed, and depth of cut at four levels. They also developed the mathematical model for the better prediction of surface roughness using RSM and correlated for its significance. Taguchi's technique was used for the parametric optimisation of surface roughness. Through ANOVA they found that feed was the most dominating parameter for affecting surface roughness. Figure 6 shows that the surface quality was better by increasing cutting speed up to 110 m/min and then surface roughness increased with the increase in cutting speed. Increase in the feed increased the surface roughness and the surface roughness decreased as depth of cut increased from 0.2 - 0.4 mm.

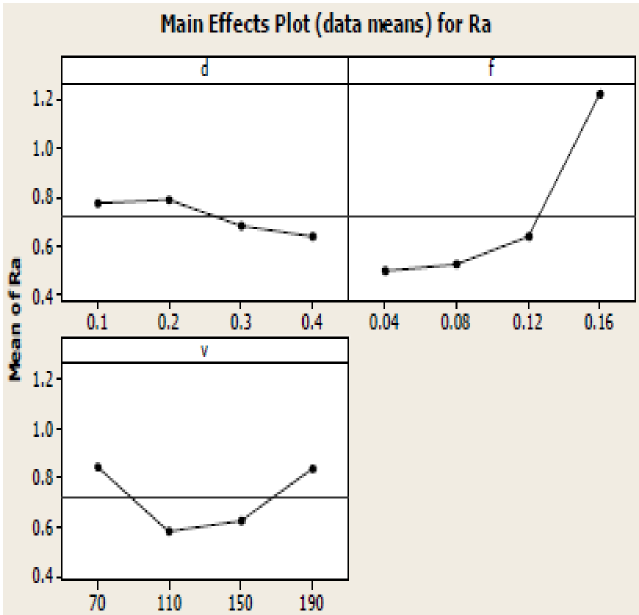


Fig.6 Main effects plot of surface roughness Ra (µm) *[14]*

Verma et al. *[15]* carried out an analysis of optimum conditions to get minimum surface roughness in turning of ASTM A424 type alloy steel. Cutting parameters selected were cutting speed, feed and depth of cut and Taguchi method was used for experimental design. A total of 9 experiments were performed with different combinations of the levels of the input parameters. Using ANOVA they concluded that cutting speed has significant role in producing lower surface roughness followed by feed rate. Kumar et al. *[16]* carried out an experimental study to investigate the effects of cutting parameters viz. spindle speed, feed and depth of cut on surface finish in face turning of EN-8. A total of 27 experiments were conducted using ceramic carbide inserts. Multiple regression modelling was performed to predict the surface roughness by using machining parameters. A multiple regression analysis (RA) was used to determine the performance of experimental measurements and to show the effect of cutting parameters on the surface roughness. They concluded that the effect of feed is greater than the spindle speed. Rao et al. *[17]* performed the experiments on turning of Al6061 alloy and its composites containing fly ash 0 - 15% in step of 5% with the use of K10 grade tungsten carbide and Poly Crystalline Diamond (PCD) inserts. The parameters chosen were cutting speed, feed at four levels keeping depth of cut constant. They prepared the specimens and carried out 20 experiments on CNC lathe machine. They concluded that PCD inserts exhibits the lower surface roughness while turning composite containing 10% fly ash when compared with that of K10 tungsten carbide inserts. The surface roughness was high for the Al containing 15% fly ash due to the presence of micro pores. Motorcu *[18]* investigated the surface roughness in turning of AISI 8660 hardened alloy steel in terms of cutting parameters such as cutting speed, feed, depth of cut and tool nose radius using Taguchi method. Machining was carried out using PVD coated ceramic tool under different conditions. Using second order regression model the surface roughness was predicted which were very close to the experimental values. By using ANOVA he concluded that the feed was dominating factor followed by depth of cut and tool nose radius. Also the interaction of feed rate and depth of cut was found to be significant on the surface roughness.

EXPERIMENTAL PROCEDURE

Workpiece Material and Cutting Tool

The workpiece material selected is AISI D2 tool steel of 32 mm diameter and 125 mm length. Tool steel refers to a variety of carbon and alloy steels that are particularly well suited to be made into tools. Their suitability comes from their distinctive hardness, resistance to abrasion and deformation and their ability to hold a cutting edge at elevated temperatures. It is high carbon, high chromium with extremely high wear resisting properties. The CNMG 120408 MT TT5100 Taegu Tec make inserts coated with TiCN-Al_2O_3-TiN were used for turning of AISI D2 steel.

Experimental Work

The dry turning experiments were performed using MTAB MAXTURN plus CNC Lathe, ideally suitable for machining high precision components on mass production. The values of the selected machining parameters, three parameters, each at three levels of are shown in Table 1 and the experimental setup is shown in Figure 7. RSM is used for experimental design and process optimization in this experimentation. The RSM based central composite design or CCD is used for experimental design. The CCD consists of 20 runs which include eight factorial runs, six axial or star runs, and six center runs. The machined surface roughness was measured by a surface tester (Taylor Hobson, Surtronic 25, UK) available at Advanced Manufacturing Lab, WCE, Sangli. The surface roughness values were measured at cut off length of 0.8 mm as shown in Figure 8.

Table 1: Process Parameters and Their Levels

Process parameters	Level 1	Level 2	Level 3
Cutting speed (m/min)	50	100	150
Feed rate (mm/rev)	0.05	0.1	0.15
Depth of cut (mm)	0.2	0.4	0.6

RESULTS AND ANALYSIS

After performing all the experiments with predetermined values of parameters, the values of surface roughness are measured. Results of the experiments are shown in Table 2. The results of experiments are studied using contour plots. Analysis is carried out using Minitab-17 software.

Fig.7 Experimental setup

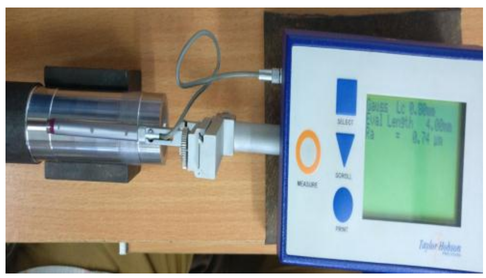


Fig.8 Surface roughness measurement using surface tester

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Analysis of Variance (ANOVA)

The analysis of variance (ANOVA) is used to identify the most significant variables. This analysis is carried out at 90% confidence level. The ANOVA for surface roughness is shown in Table 3. It is observed that cutting speed and depth of cut are significant for surface roughness. The quadratic terms cutting speed*cutting speed (V_c^2) and feed rate*feed rate (f^2) as well as the interaction term cutting speed*feed rate (V_c*f) are significant factors for surface roughness.

Table 2: Results of the Experiments

Std. order	Cutting Speed, (V_c) (m/min)	Feedrate, (*f*) (mm/min)	Depth of cut, (d)(mm)	SR (Ra) (µm)
1	50	25.196	0.2	0.975
2	150	75.587	0.2	1.865
3	50	75.587	0.2	1.225
4	150	226.760	0.2	1.09
5	50	25.196	0.6	1.995
6	150	75.587	0.6	3.705
7	50	75.587	0.6	1.905
8	150	226.760	0.6	1.39
9	15.91	16.035	0.4	4.83
10	184.09	185.530	0.4	1.44
11	100	16.035	0.4	1.575
12	100	185.530	0.4	1.58
13	100	100.782	0.064	0.645
14	100	100.782	0.736	2.575
15	100	100.782	0.4	0.84
16	100	100.782	0.4	0.895
17	100	100.782	0.4	1.17
18	100	100.782	0.4	1.07
19	100	100.782	0.4	1.145
20	100	100.782	0.4	1.19

Table 3: Anova for Surface Roughness

Source	Degree of freedom	Adj SS	Adj MS	P-Value
V_c	1	1.4453	1.44530	0.108
f	1	0.1401	0.14014	0.595
d	1	1.9366	1.93662	0.068
V_c* V_c	1	6.0516	6.05163	0.005
f * *f*	1	1.4727	1.47269	0.105
d*d*	1	0.1975	0.19754	0.529
V_c* *f*	1	2.4327	2.43273	0.045
V_c* *d*	1	0.4080	0.40804	0.370
f * *d*	1	0.6150	0.61504	0.276
S=0.680894 R-Sq =76.54% R-Sq(pred) =55.43% R-Sq(adj) = 0.00%				

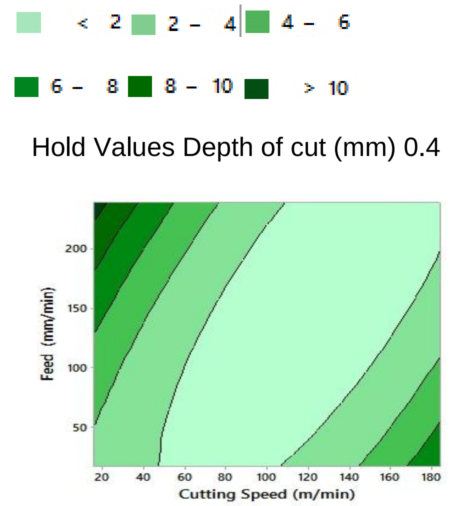
ANALYSIS AND DISCUSSIONS

The surface contour plot for the surface roughness is obtained as shown in the Figure 9. It can be seen in Figure 9(a) that at lower values of cutting speed and at higher values of feed rate the surface roughness is maximum.

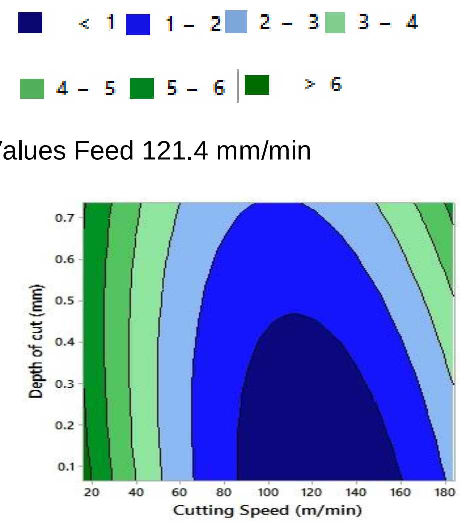
Surface roughness is minimum in region of cutting speed at 90 – 160 m/min and at lower depth of cut as seen in Figure 9(b).

The surface roughness is minimum in the region of medium feed rate and lower depth of cut, but it increases as the feed rate and depth of cut increases as shown in Figure 9(b).

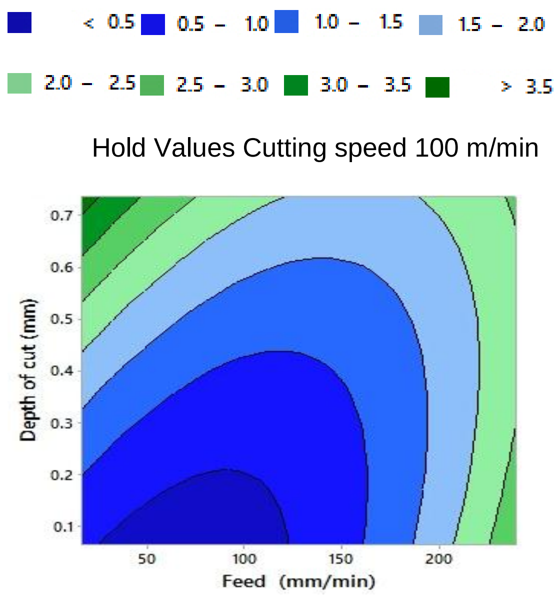
It is observed that the surface roughness is minimized at the region of medium values of cutting speed, feed rate and lower values of depth of cut.



a) Surface roughness vs feed (mm/min), cutting speed (m/min)



b) Surface roughness vs depth of cut (mm), cutting speed (m/min)



c) Surface roughness vs depth of cut (mm), feed (mm/min)

Fig. 9 Contour plots for surface roughness

CONCLUSIONS

By carrying out the literature review, performing the experiments and analysis on AISI D2 steel by turning process, the following conclusions are drawn: The surface roughness decreases when the speed goes on increasing whereas feed and depth of cut go on decreasing. From literature it is found that feed rate is the most significant factor affecting surface roughness followed by depth of cut and cutting speed. From analysis it is found that the cutting speed and depth of cut are significant parameters for surface roughness.

The interaction of cutting speed and feed rate and quadratic term cutting speed as well as feed rate are the significant factors for surface roughness. The surface roughness is minimized at the medium values of cutting speed (120 m/min), feed rate (100 mm/min) and lower value of depth of cut (0.0636 mm).

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