EFFECT OF PROCESS PARAMETERS ON SURFACE ROUGHNESS AND MATERIAL REMOVAL RATE IN CNC END MILLING PROCESS

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Abstract: **Quality and productivity play important role in today's manufacturing market. Now a day's due to very stiff and cut throat competitive market condition in manufacturing industries. The main objective of industries reveal with producing better quality product at minimum cost and increase productivity. CNC end milling is most vital and common operation use for produce machine part with desire surface quality and higher productivity with less time and cost constrain. To obtain main objective of company regards quality and productivity. In the present research project an attempt is made to understand the effect of machining parameters such as cuttin g speed (m/min), feed rate (mm/min),depth of cut (mm), no of cutting flute that are influences on responsive output parameters such as Surface Roughness and Material Removal Rate by using optimization philosophy. The effort to investigate optimal machining parameters and their contribution on producing better Surface quality and higher Productivity.**

Keywords: **CNC end milling, Surface roughness, MRR, SS 316.**

1. INTRODUCTION

Milling is the process of machining flat,curved, or irregular surfaces by feeding the work piece against a rotating cutter containing a number of cutting edges. The milling machine consists basically of a motor driven spindle, which mounts and revolves the milling cutter, and a reciprocating adjustable worktable, which mounts and feeds the work piece. Among several CNC industrial machining processes, milling is a fundamental machining operation. End milling and face milling is the most common metal removal operation encountered. It is broadly used in a variety of manufacturing industries including the aerospace, automotive sectors, where quality is vital factor in the production of slots, pockets, precision molds and dies.

To understand full automation in machining, computer numerically controlled (CNC) machine tools have been implemented during the past decades. CNC machine tools require less operator input; provide greater improvements in productivity, and increase the quality of the machined part.

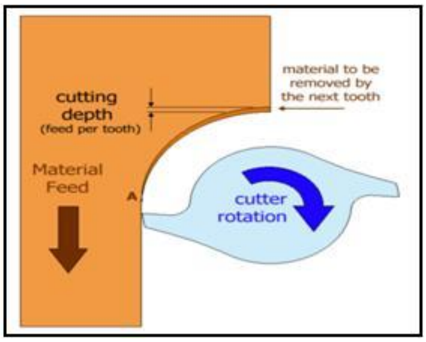


Fig.1.1 Introduction of Milling

Surface roughness is an important measure of the technological quality of a product and a factor that greatly influences manufacturing cost. The quality of the surface plays a very important role in the performance of milling as a good-quality milled surface significantly improves fatigue strength, corrosion resistance, or creep life. In addition, surface roughness also affects surface friction, light reflection, ability of holding a lubricant, electrical and thermal contact resistance. Consequently, the desired surface roughness value is frequently specified for an individual part, and specific processes are selected in order to achieve the specified finish.

METHOD OF MILLING

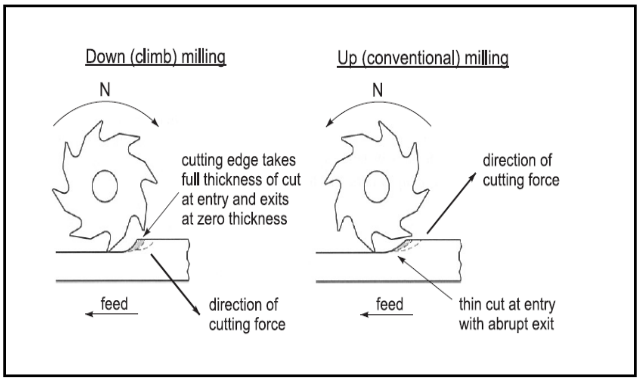


Fig.1.2 Method of Milling

Down (climb) milling: when the cutter rotation is in the same direction as the movement of the workpiece being fed. In down milling, the cutting force is directed into the work table, which allows thinner work parts to be machined. Better surface finish is obtained but the stress load on the teeth is abrupt, which may damage the cutter.

Up (conventional) milling: in which the work piece is moving towards the cutter, opposing the cutter direction of rotation. In up milling, the cutting force tends to lift the workpiece. The work conditions for the cutter are more favorable. Because the cutter does not initiate to cut when it makes contact (cutting at zero cut is impracticable), the surface has a natural waviness.

END MILLING OPERATION

The cutter, called end mill, has a diameter less than the workpiece width. The end mill has helical cutting edges carried over onto the cylindrical cutter surface. End mills with flat ends (so called squire-end mills) are used to generate pockets, closed or end key slots, etc. End milling is the most common metal removal operation encountered. It is widely used to mate with other part in die, aerospace, automotive, and machinery design as well as in manufacturing industries. Automatic tool changer, which is used to exchange cutting tools between the tool magazine and machining center spindle when required. The tool changer is controlled by the CNC program.

 Automatic work part positioning. Many of machining centers are equipped with a rotary worktable, which precisely position the part at some angle relative to the spindle. It permits the cutter to perform machining on four sides of the part.

Fig.1.3 CNC Machining Center (VMC 850) CHARACTERISTICS OF CNC MACHINE

- Flexibility in automation
- Change-over (product) time, effort and cost are much less.
- Less or no jigs and fixtures are needed
- Complex geometry can be easily machined
- High product quality and its consistency
- Optimum working condition is possible
- Lesser breakdown and maintenance requirement.
- Faster deliver a product.
- Reduce WIP inventory.

MATERIAL REMOVAL RATE (MRR)

Material removal rate in milling operation is

the volume of metal removed in unit time.

MRR (mm^3/min) = w*d*f

Where,

w = width of cut, mm d = depth of cut, mm

f = feed rate, mm/min

CNC MACHINING CENTER

The machining centre, developed in the late

50's is a machine tool able to perform multiple machining operations on a work part in one setup under NC program control

A machining center is a highly automated machine tool able to performing multiple machining operations under CNC control. The features that make a machining center unique include the following:

- Tool storage unit called tool magazine that can hold 80 - 120 different cutting tools.

SURFACE ROUGHNESS

Roughness is a measure of the texture of a

surface. It is quantified by the vertical deviations of a real surface from its ideal form. If these deviations are large, the surface is rough; if they are small the surface is smooth. Roughness is typically considered to be the high frequency, short wavelength component of a measured surface. Surface roughness 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 behavior, corrosion resistance, creep life, etc.

CUTTING PARAMETER

- Cutting velocity (Vc): It is the peripheral speed of the cutter is defined by,

$$V = \pi DN$$

Where, D is the cutter outer diameter, and N is the rotational speed of the cutter.

- Feed per tooth fz: The basic parameter in milling equivalent to the feed in turning. Feed per tooth is selected with regard to the surface finish and dimensional accuracy required.

- Feed per revolution fr: It determines the amount of material cut per one full revolution of the milling cutter. Feed per revolution is calculated as

$$fr = fz*z$$

z being the number of the cutter's teeth.

• Feed per minute fm: Feed per minute is calculated taking into account the rotational speed N and number of the cutter's teeth z,

$$fm = fz*z*N = fr*N$$

II. LITRETURE REVIEW

Many investigators have suggested various methods to explain the effect of machining parameter on surface roughness and MRR in CNC end milling process.

B. C. Routara, et al, [1] were carried out "Roughness modeling and optimization in CNC end milling using response surface method: effect of workpiece material variation". They describe use and steps of Full factorial design of experiments to find a specific range and combinations of machining parameters like spindle speed, feed rate and depth of cut to achieve optimal values of response variables like Roughness parameters (Ra, Rq, Rsk, Rku and Rsm) in machining of three different materials like 6061-T4 aluminum, AISI 1040 steel and medium leaded brass UNS C34000. The second-order model was postulated in obtaining the relationship between the surface roughness parameters and the machining variables. The analysis of variance (ANOVA) was used to check the adequacy of the second-order model roughness modeling in milling is specific to the roughness parameter of particular Concern as well as to the work piece-tool material combination employed in the process.

John D. Kechagias, et al, [2] were carried out "Parameter Optimization during Finish End Milling of Al Alloy 5083 using Robust Design". They describe use and steps of Taguchi design of experiments and orthogonal array L18 to find a specific range and combinations of machining parameters like Core diameter (50%), Flute angle (38^{o}), Rake angle (22^{o}), Relief angle 1^{st} (22^{o}), Relief angle 2^{nd} (30^{o}), Cutting depth (1.5mm), Cutting speed (5000 rpm), Feed (0.08mm/flute). The influence of cutter geometry and cutting parameters during end milling on the surface texture of aluminium (Al) alloy 5083 was experimentally investigated. Surface texture parameters (Ra, Ry, and Rz) were measured on three different passes on side surface of pockets and analyzed using statistical techniques. The results reveal that the cutting speed, the peripheral 2^{nd} relief angle, and the core diameter have significant effect in surface texture parameters. Once the relief angle 2^{nd} takes its optimum value (30^{o}) the surface roughness decreases while the cutting speed increases. This is accordance with the cutting theory.

Amit Joshi & PradeepKothiyal, [3] were carried out "Investigating Effect of Machining Parameters of CNC Milling on Surface Finish by Taguchi Method". The effects of various parameters of end milling process like spindle speed, depth of cut, feed rate have been investigated to reveal their Impact on surface finish using Taguchi Methodology. Experimental plan is performed by a Standard L9

Orthogonal Array on five blocks of aluminum cast heat-treatable alloy (100 X 34 X20 mm) with using HSS End mill tool. The results of analysis of variance (ANOVA) indicate that the feed Rate is most influencing factor for modeling surface finish. The graph of S-N Ratio indicates the optimal setting of the machining parameter which gives the optimum value of surface finish. The optimal set of process parameters has also been predicted to maximize the surface finish is 3.0723 μm.

M.F.F. Ab. Rashid and M.R. Abdul Lani, [4] were carried out "Surface Roughness Prediction for CNC Milling Process using Artificial Neural Network". The purpose for this research is to develop mathematical model using multiple regression and artificial neural network model for artificial intelligent method. Spindle speed, feed rate, and depth of cut have been chosen as predictors in order to predict surface roughness. 27 samples of 400mmx100mmx50mm 6061 Aluminum were run with using HSS End mill tool (No of flute = 4, Dia. D=10mm) carried out on FANUC CNC Milling α- T14E. The experiment is executed by using full factorial design. Analysis of variances shows that the most significant parameter is feed rate followed by spindle speed and lastly depth of cut. After the predicted surface roughness has been obtained by using both methods, average percentage error is calculated. The mathematical model developed by using multiple regression method shows the accuracy of 86.7% which is reliable to be used in surface roughness prediction. On the other hand, artificial neural network technique shows the accuracy of 93.58% which is feasible and applicable in prediction of surface roughness. The result from this research is useful to be implemented in industry to reduce time and cost in surface roughness prediction.

Bharat Chandra Routara, et al, [5] were carried out “Optimization in CNC end milling of UNS C34000 medium leaded brass with multiple surface roughnesses characteristics”. The present study ighlights a multi-objective optimization problem by applying utility concept coupled with Taguchi method through a case study in CNC end milling of UNS C34000 medium leaded brass as a workpiece material and Coated with TiAlN End mill Cutter (diameter, 8 mm; Overall length, 108 mm; Fluted length, 38 mm; Helix angle, 30°). The study aimed at evaluating the best process environment which could simultaneously satisfy multiple requirements of surface quality. In view of the fact, the traditional Taguchi method cannot solve a multi-objective optimization problem; to overcome this limitation, utility theory has been coupled with Taguchi method. Depending on Taguchi’s Lower-the- Better (LB) response criteria; individual surface quality characteristics has been transformed into corresponding utility values. Individual utility values have been aggregated finally to compute overall utility degree which serves as representative objective function for optimizing using Taguchi method. Utility theory has been adopted to convert a multi-response optimization problem into a single response optimization problem; in which overall utility degree serves as the representative single objective function for optimization. The study of combined utility theory and Taguchi method for predicting optimal setting. Based on Taguchi’s Signal-to-Noise ratio (S/N), analysis has been made on the overall utility degree and optimal process environment has been selected finally which corresponds to highest S/N Ratio. Optimal result has been verified through confirmatory test. The case study indicates application feasibility of the aforesaid methodology proposed for multi response optimization and off-line control of multiple surface quality characteristics in CNC end milling.

Anish Nair & Dr. P Govindan, et al, [6] were carried out “Multiple Surface Roughness Characteristics Optimization in CNC End Milling of Aluminium using PCA”. The present study highlights a multi objective optimization problem by applying the Principal components analysis method coupled with the Taguchi method .Total 27 experimental run conducting on 6061-T4 Aluminium with CVD coated carbide tool . The study is aimed at evaluating the best process parameters which could simultaneously provide multiple requirements of surface quality. In the present work individual response correlations have been eliminated first by means of Principal components Analysis (PCA). Principal components are found out which are independent quality indices. The principal component having the highest accountability proportion is considered as the objective function. Finally the taguchi method has been used to solve this objective function. In the current paper two surface roughness parameters (Ra and Rz) have been taken into consideration.

Reddy B. Sidda, et al, [7] were carried out “Optimization of surface roughness in CNC end milling using response surface methodology and genetic algorithm”. In this study, minimization of surface roughness has been investigated by integrating design of experiment method, Response surface methodology (RSM) and genetic algorithm. The experiments were conducted on AISI P20 mould steel (100x100x10 mm) with CVD coated carbide tool inserts (TN 450) and CNC Vertical milling machine 600 II, KENAMETAL tool holder BT40ER40080M 20 ATC by using Taguchi’s L50 orthogonal array in the design of experiments (DOE)

.Considering the machining parameters such as Nose radius (R), Cutting speed (V), feed (f), axial depth of cut (d) and radial depth of cut (rd). A predictive response surface model for surface roughness is developed using RSM. The response surface (RS) model is interfaced with the genetic algorithm (GA) to find the optimum machining parameter values. To achieve the minimum surface roughness, the appropriate process parameters are determined. Nose radius, cutting speed, feed rate, axial depth of cut and radial depth of cut are considered as process parameters GA has reduced the surface roughness of the initial model significantly. Surface roughness is improved by about 44.22%.

III. MATERIAL SELECTION

Stainless steel AISI 316 or SS316 solid round bar. Dimension of material is Ø50 X 15 mm.

CHEMICAL COMPOSITION

Table 3.1 Chemical composition

Grade	C	Mn	Si	P	S	Cr	Mo	Ni	N
316	-	-	-	0	-	16.0	2.00	10.0	-
	0.08	2.0	0.75	0.045	0.03	18.0	3.00	14.0	0.10

MECHANICAL PROPERTIES

Table 3.2 Mechanical properties

Grad e	Tensile Strengt h (MPa) min	Yield Strengt h 0.2% Proof (MPa) min	Elongati on (% in 50mm) min	Hardness	
				Rockwe ll B (HR C) max	Brinell (HB) max
316	515	205	40	95	217

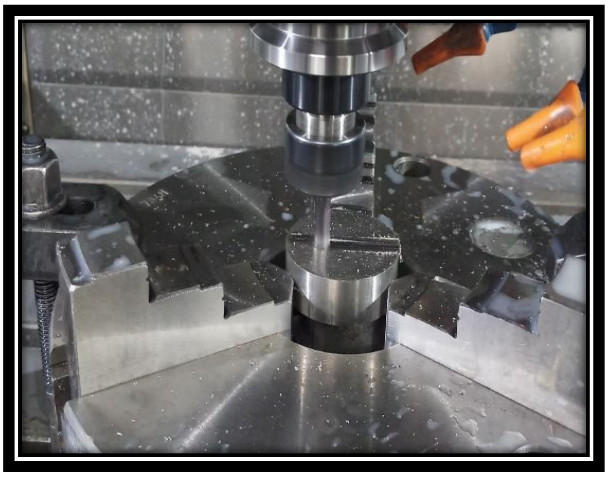
KEY PROPERTIES

- Higher strength
- Better creep resistance
- Excellent mechanical properties
- Excellent corrosion properties
- Superior oxidation resistance
- Good fabricability

APPLICATION

- Gasket, flanges, spring & exhaust manifolds
- Valve & pump trim
- Food preparation equipment in chloride environments.
- Laboratory benches & equipment.
- Coastal architectural panelling, railings & trim.
- Boat fittings, Furnace parts.
- Chemical containers, including for transport.
- Heat Exchangers

EXPERIMENTAL SET UP



Experiment perform on CNC milling machine

Plan of experimental runs as per Box-Behnken design

Std Order	Run Order	Vc (m/min)	fm (mm/min)	d (mm)	z	Ra (µm)	MRR (mm^3/min)
20	1	350	80	0.3	4	1.67	27289
24	2	300	95	0.2	6	1.545	14607
4	3	350	95	0.2	4	1.46	12365
6	4	300	80	0.3	3	2.21	52821
14	5	300	95	0.1	4	0.985	6785
5	6	300	80	0.1	3	1.05	16085
22	7	300	95	0.2	3	1.485	37500
23	8	300	65	0.2	6	0.68	14844
9	9	250	80	0.2	3	1.92	51313
25	10	300	80	0.2	4	1.31	15750
19	11	250	80	0.3	4	1.87	41464
2	12	350	65	0.2	4	1.38	25305
11	13	250	80	0.2	6	1.28	11367
21	14	300	65	0.2	3	1.71	36298
10	15	350	80	0.2	3	1.63	25982
15	16	300	65	0.3	4	1.75	28534
26	17	300	80	0.2	4	1.26	14682
3	18	250	95	0.2	4	1.367	45357
27	19	300	80	0.2	4	1.386	19338
13	20	300	65	0.1	4	1.04	5551
16	21	300	95	0.3	4	1.9	30669
1	22	250	65	0.2	4	1.489	15779
7	23	300	80	0.1	6	1.054	6428
12	24	350	80	0.2	6	1.295	20146
18	25	350	80	0.1	4	1.25	10204
8	26	300	80	0.3	6	1.035	21571
17	27	250	80	0.1	4	1.18	10607

ANALYSIS OF VARIANCE (ANOVA)

Response Surface Regression: Ra (µm) Vs. Vc (m/min), fm (mm/min), d (mm), z

The analysis was done using uncoded units.

Table 5.3 Estimated Regression Coefficients for Means of Ra (µm)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	14	2.98150	0.212965	22.07	0.000
Linear	4	0.38263	0.095657	9.91	0.001
Vc(m/min)	1	0.10623	0.106230	11.01	0.006
fm(mm/min)	1	0.04951	0.049506	5.13	0.043
d(mm)	1	0.05753	0.057531	5.96	0.031

z	1	0.21869	0.218685	22.67	0.000
Square	4	0.14314	0.035785	3.71	0.035
Vc(m/min)*Vc(m/min)	1	0.10169	0.101691	10.54	0.007
fm(mm/min)*fm(mm/min)	1	0.00091	0.000913	0.09	0.764
d(mm)*d(mm)	1	0.00789	0.007888	0.82	0.384
z*z	1	0.06434	0.064339	6.67	0.024
2-Way Interaction	6	0.75648	0.126081	13.07	0.000
Vc(m/min)*fm(mm/min)	1	0.01020	0.010201	1.06	0.324
Vc(m/min)*d(mm)	1	0.01822	0.018225	1.89	0.194
Vc(m/min)*z	1	0.01575	0.015748	1.63	0.226
fm(mm/min)*d(mm)	1	0.01051	0.010506	1.09	0.317
fm(mm/min)*z	1	0.35004	0.350044	36.28	0.000
d(mm)*z	1	0.35176	0.351759	36.46	0.000
Error	12	0.11578	0.009648		
Lack-of-Fit	10	0.10773	0.010773	2.68	0.303
Pure Error	2	0.00805	0.004025		
Total	26	3.09728			

The second order quadratic equation for Predicted Ra (µm)

The mathematical relationship for correlating the surface roughness and the considered process variables has been obtained as follows:

Regression Equation in Uncoded Units

Ra(µm) = 12.24 - 0.1268 Vc(m/min) - 0.0842 fm(mm/min) + 10.73 d(mm) - 1.542 z
+ 0.000614 Vc(m/min)*Vc(m/min) + 0.000058 fm(mm/min)*fm(mm/min)
+ 3.85 d(mm)*d(mm) + 0.0563 z*z + 0.000224 Vc(m/min)*fm(mm/min) -
0.0450 Vc(m/min)*d(mm)+ 0.00269 Vc(m/min)*z + 0.0342 fm(mm/min)*d(mm)
+ 0.01269 fm(mm/min)*z - 1.908 d(mm)*z

From above Table 5.3 that indicated the second-order quadratic models were developed for surface roughness. The fit summary indicates that the quadratic model is statistically significant for analysis of Tool life. The R-Sq value of surface roughness is 96.26% and adjusted square value of surface roughness is 91.90%, which indicates that the developed regression model is adequately significant at a 95% confidence level.

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0982264	96.26%	91.90%	77.06%

Coded Coefficients

Table 5.4 Analysis of Variance for Means of Ra (µm)

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	12.24	3.08	3.98	0.002	
Vc(m/min)	-0.1268	0.0382	-3.32	0.006	408.89
fm(mm/min)	-0.0842	0.0372	-2.27	0.043	386.89
d(mm)	10.73	4.39	2.44	0.031	240.22
z	-1.542	0.324	-4.76	0.000	311.50

Vc(m/min)*Vc(m/min)	0.000614	0.000189	3.25	0.007	290.25
fm(mm/min)*fm(mm/min)	0.000058	0.000189	0.31	0.764	257.25
d(mm)*d(mm)	3.85	4.25	0.90	0.384	37.25
z*z	0.0563	0.0218	2.58	0.024	121.43
Vc(m/min)*fm(mm/min)	0.000224	0.000218	1.03	0.324	182.67
Vc(m/min)*d(mm)	-0.0450	0.0327	-1.37	0.194	109.33
Vc(m/min)*z	0.00269	0.00211	1.28	0.226	117.78
fm(mm/min)*d(mm)	0.0342	0.0327	1.04	0.317	98.33
fm(mm/min)*z	0.01269	0.00211	6.02	0.000	106.90
d(mm)*z	-1.908	0.316	-6.04	0.000	34.41

Analysis of variance (ANOVA) in Table 5.4, at 95% confidence level, no of flutes and cutting were most significant parameters while other followed by depth of cut and feed were significant (at p-value < 0.05). Similarly, of all the interactions, only the interaction of feed*no of flutes and depth of cut*no of flutes were found statistically most significant. Other interactions were insignificant effect to the surface roughness.

Response Surface Regression: MRR (mm3/min) Vs. Vc (m/min), fm (mm/min),z

The analysis was done using uncoded units.

Table 5.5 Estimated Regression Coefficients for Means of MRR (mm^3/min)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	14	25709190167	1836370726	37.29	0.000
Linear	4	4560926845	1140231711	23.16	0.000
Vc(m/min)	1	75537685	75537685	1.53	0.239
fm(mm/min)	1	273972812	273972812	5.56	0.036
d(mm)	1	499136205	499136205	10.14	0.008
z	1	2795135907	2795135907	56.77	0.000
Square	4	3477404420	869351105	17.66	0.000
Vc(m/min)*Vc(m/min)	1	769958580	769958580	15.64	0.002
fm(mm/min)*fm(mm/min)	1	140701291	140701291	2.86	0.117
d(mm)*d(mm)	1	1861519	1861519	0.04	0.849
z*z	1	2914111008	2914111008	59.18	0.000
2-Way Interaction	6	4794836582	799139430	16.23	0.000
Vc(m/min)*fm(mm/min)	1	2460507212	2460507212	49.97	0.000
Vc(m/min)*d(mm)	1	258164556	258164556	5.24	0.041
Vc(m/min)*z	1	1522277360	1522277360	30.92	0.000
fm(mm/min)*d(mm)	1	1103550	1103550	0.02	0.883
fm(mm/min)*z	1	15059616	15059616	0.31	0.590
d(mm)*z	1	537724287	537724287	10.92	0.006
Error	12	590871119	49239260		
Lack-of-Fit	10	526082647	52608265	1.62	0.440
Pure Error	2	64788473	32394236		
Total	26	26300061287			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
7017.07	97.75%	95.13%	87.54%

The second order quadratic equation for Predicted MRR

The mathematical relationship for correlating the MRR and the considered process variables has been obtained as follows:

Regression Equation in Uncoded Units

MRR (mm^3/min) = 233153 - 3382 Vc(m/min) + 6266 fm(mm/min) + 999590 d(mm) - 174277 z + 53.4 Vc(m/min)*Vc(m/min) + 22.8 fm(mm/min)*fm(mm/min) + 59079 d(mm)*d(mm) + 11973 z*z - 110.2 Vc(m/min)*fm(mm/min) - 5356 Vc(m/min)*d(mm)+ 837 Vc(m/min)*z + 350 fm(mm/min)*d(mm) - 83 fm(mm/min)*z - 74583 d(mm)*z…………………………..*eq.*(5.4)

From above Table 5.5 that indicated the second-order quadratic models were developed for surface roughness. The fit summary indicates that the quadratic model is statistically significant for analysis of Tool life. The R-Sq value of surface roughness is 97.75% and adjusted square value of surface roughness is 95.13%, which indicates that the developed regression model is adequately significant at a 95% confidence level.

Table 5.6 Analysis of Variance for Means of MRR (mm^3/min)

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	233153	219740	1.06	0.310	
Vc(m/min)	-3382	2731	-1.24	0.239	408.89
fm(mm/min)	6266	2656	2.36	0.036	386.89
d(mm)	999590	313956	3.18	0.008	240.22
z	-174277	23131	-7.53	0.000	311.50
Vc(m/min)*Vc(m/min)	53.4	13.5	3.95	0.002	290.25
fm(mm/min)*fm(mm/min)	22.8	13.5	1.69	0.117	257.25
d(mm)*d(mm)	59079	303848	0.19	0.849	37.25
z*z	11973	1556	7.69	0.000	121.43
Vc(m/min)*fm(mm/min)	-110.2	15.6	-7.07	0.000	182.67
Vc(m/min)*d(mm)	-5356	2339	-2.29	0.041	109.33
Vc(m/min)*z	837	150	5.56	0.000	117.78
fm(mm/min)*d(mm)	350	2339	0.15	0.883	98.33
fm(mm/min)*z	-83	150	-0.55	0.590	106.90
d(mm)*z	-74583	22569	-3.30	0.006	34.41

Analysis of variance (ANOVA) in Table 5.6, at 95% confidence level, no of flutes and depth of cut were most significant parameters while other followed by feed rate are significant, but cutting speed insignificant effect on MRR (at p-value < 0.05). Similarly, of all the interactions, only the interaction of cutting speed*feed, depth of cut*no of flutes and cutting speed*no of flutes were found statistically most significant. Other interactions were insignificant to the MRR.

5.7 EXPERIMENTAL VALIDATION

he purpose of the validation experiments is to validate accuracy of the predictive model. To predict and verify the improvement in the surface roughness and MRR for machining of SS 316 steel by end milling process with respect to the chosen initial parameters setting, verification test are used.

The model was experimentally validated by conducting experiments with new set of parameters in Table 5.7 shows the verifications of the model predictions for surface roughness and MRR. A good agreement is observed among the predicted and actual results. To assess the accuracy of the model, percentage errors and average percentageerror were calculated. The maximum prediction error in surface roughness of 4.0% and MRR of 4.3% .The average percentage of error in surface roughness of 3.7% and MRR of 3.24% so, Validation an underlining the satisfactory performance of the prediction model.

Table 5.7 Accuracy Test of Prediction Model

Speed	Feed rate	Depth of cut	Flute	Predictive		Experimental		% of error	
Vc	fm	d	z	Ra (μm)	MRR (mm^3/min)	Ra (μm)	MRR (mm^3/min)	Ra (μm)	MRR (mm^3/min)
85	65	0.1	6	0.76	17738	0.79	18536	2.8	4.3
100	95	0.2	6	1.76	35365.6	1.87	33985	5.7	4.0
70	95	0.1	3	1.15	108507	1.12	110942	2.6	2.1
85	65	0.3	3	2.26	115815	2.18	112740	4.0	2.7
100	80	0.2	4	1.36	37227.8	1.41	38453	3.5	3.1
							Average % of error	3.7	3.24

Deviation of the predicted values from the experimental values has been worked out to get the % error for the validation data. The same has been plotted and shown in Fig. 5.1 and Fig. 5.2.

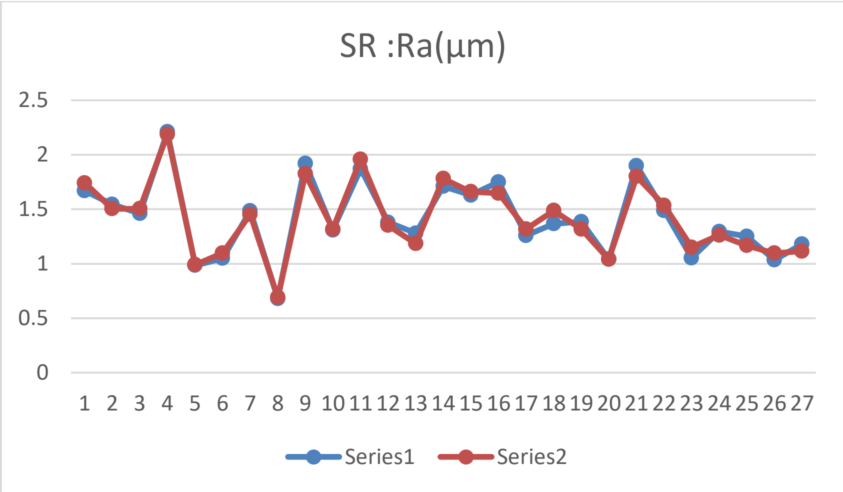


Fig. 5.1 Surface roughness vs. Experiment number for train data

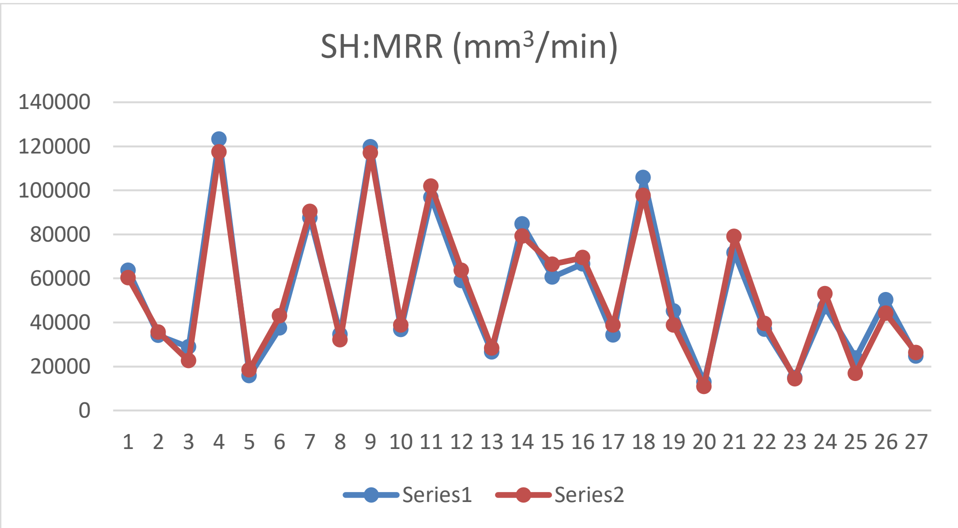


Fig. 5.2 MRR vs. Experiment number for train data

Fig.5.1 and Fig.5.2 indicated that measured values of each response are plotted and their closeness to the predicted value depicts the accuracy (fitness) of the model. In most of the cases, predicted and the experimental values follow close match and the extent of deviation is marginal.

5.8 MULTI RESPONSE OPTIMIZATION

Derringer and Suich (1980) describe a multiple response method called desirability. It is an attractive method for industry for optimization of multiple qualities characteristic problems. By making desirability 1 we can find out the optimal solution. Desirability function has been used to determine the optimum parameters for CNC end mill parts for optimization of surface roughness in the present investigation.Second order Box-Behnken experimental design involving four factors (Cutting speed, Feed, Depth of cut, No of flutes) each at three levels has been used to find optimum combination of factors and levels in CNC end mill machining of AISI 316 steel.Multi-objective optimization was aimed at to achieve better quality coupled with higher productivity. Accordingly optimisation criteria for each response were selected as given in Table 5.8.

Table 5.8 Constrain and condition

Response	Goal
Surface roughness	Minimum
MRR	Maximum

Best Solution satisfying the above criteria was obtained using the Minitab_16 software, which is given below and it has the overall desirability of 1.0.

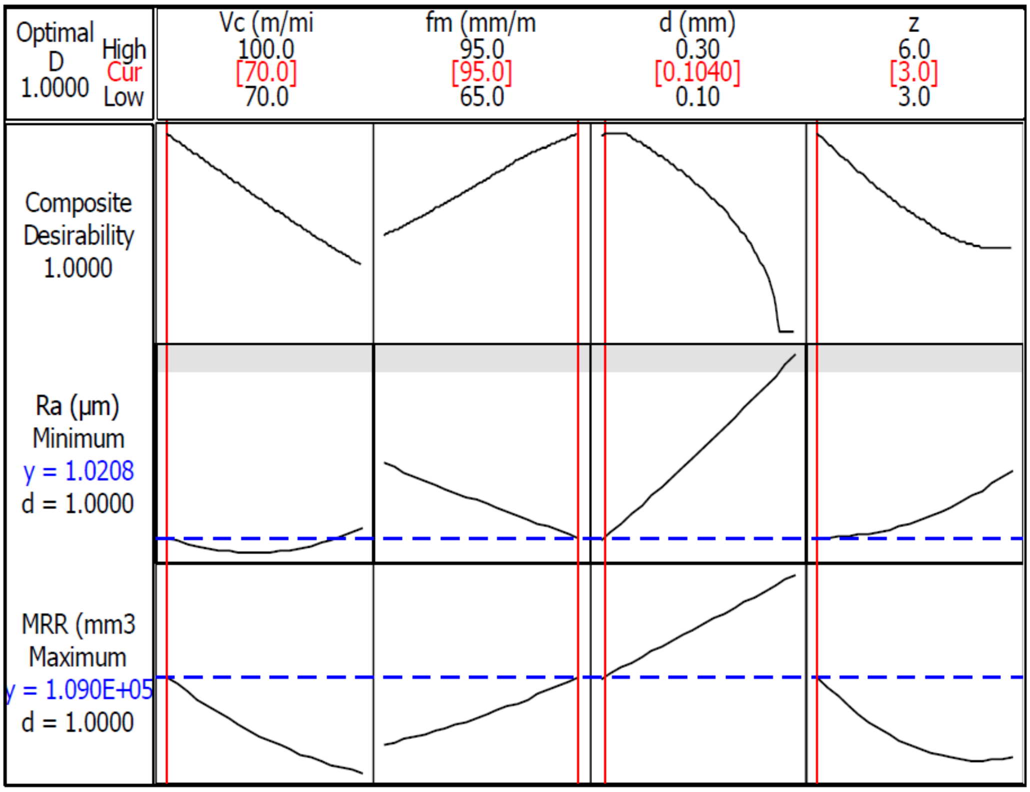


Fig. 5.3 Optimum solution for Ra and MRR

As shown for the figure 5.3 the minimum value of Ra (1.0208 µm) and MRR (109000 mm^3/min) within this range will achieve at the (Vc=70 m/min, fm=95 mm/min,d=0.1040 mm, Z=3). Figure shows by increase in the depth of cut MRR and SR will increases. Decreases feed for better finishing achieve but opposite in case of MRR. In case of depth of cut optimal condition is at 0.1040mm.

Table 5.9 Optimal condition for response

Vc (m/min)	fm (mm/min)	d (mm)	z	Exp. Ra (µm)	Exp. MRR (mm^3/min)
70	95	0.1040	3	1.087	113674

6.2.1 NORMAL PROBABILITY PLOT OF RESIDUALS FOR Ra(µm)

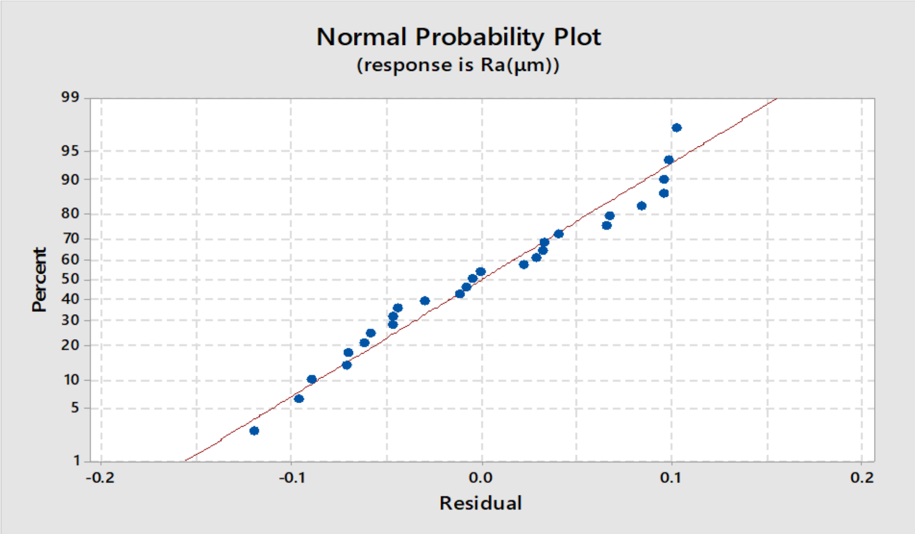


Fig 6.1 Normal probability plot for SR

It can be seen in Figure 6.1 that all the points on the normal plot lies close to the straight line (mean line). This implies that the data are fairly normal and a little deviation from the normality is observed. This shows the effectiveness of the developed model. It is noticed that the residuals fall on a straight line, which implies that errors are normally distributed.

6.2.2 MAIN EFFECTS PLOT FOR SR, Ra(µm)

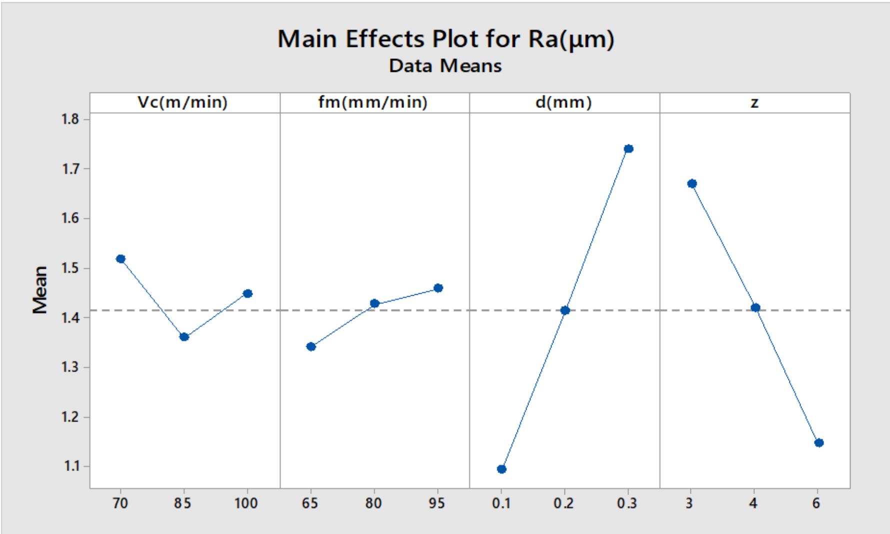


Fig. 6.2 Main effect plot for SR

The main effect plot of SR is shown in above figure 6.2. The interpretation of this figure as follows:

Surface Roughness decreases with the increasing in the value of cutting speed (Vc) from 70 m/min to 85 m/min, but after 85 m/min as we increasing cutting speed up to 100 m/min Surface Roughness decreases.

Surface Roughness increases with increasing in values of feed rate (fm) from 65 mm/min to 95 mm/min and rapidly increasing depth of cut from 0.1 mm to 0.3 mm.

Surface Roughness decreases with rapidly increasing in values of no of flues (z) from 3 to 6.

From main effect plot, it can observe that the optimum value of surface roughness is obtained which is most significant and applicable value amongst all other experimental values.

 Cutting speed, Vc at level 2 (85 m/min)

- Feed rate, fm at level 1 (65 mm/min)
- Depth of cut, d at level 1 (0.1 mm)
- No of flute, z at level 3 (6 flutes)

6.2.3 INTERACTION PLOT FOR SR, Ra(µm)

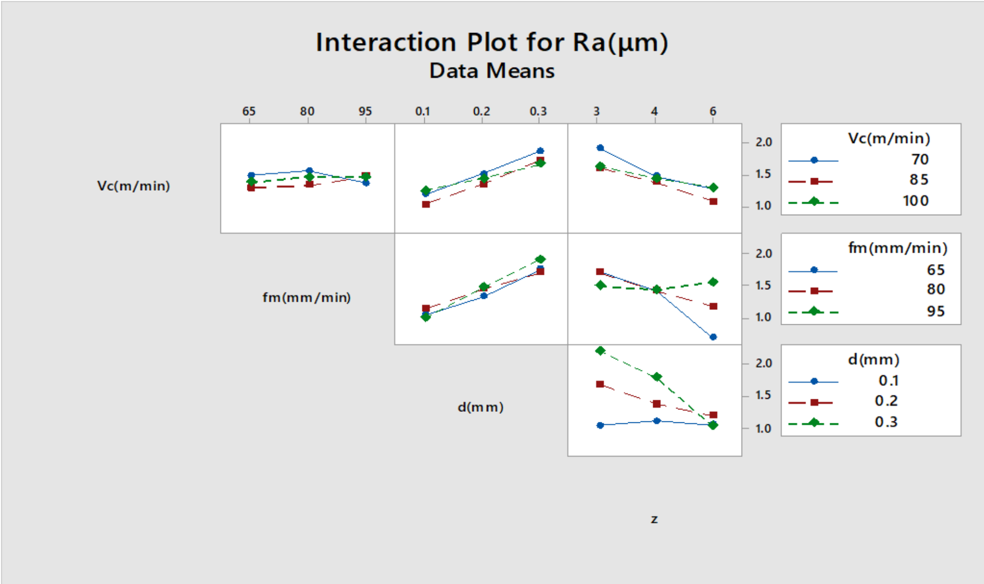


Fig. 6.3 Interaction plot for SR

Fig.6.3 indicates interaction plot confirms the significance of Vc*fm, Vc*d, Vc*z,fm*d, fm*z, d*z interactions as stated earlier. Interaction occurs when one factor does not produce the same effect on the response at different levels of another factor.

Therefore, if the lines of two factors are parallel, there is no interaction. On the contrary, when the lines are far from being parallel, the two factors are interacting. In each case of fm*z, d*z interactions, the response Ra decreases when the line moves from the left to right side.

6.2.4 CONTOUR PLOTS FOR SR, Ra(µm)

The below response surface is plotted to study the effect of process variables on the

Surface roughness and its shown in Figures 6.4(i) -6.4(v).

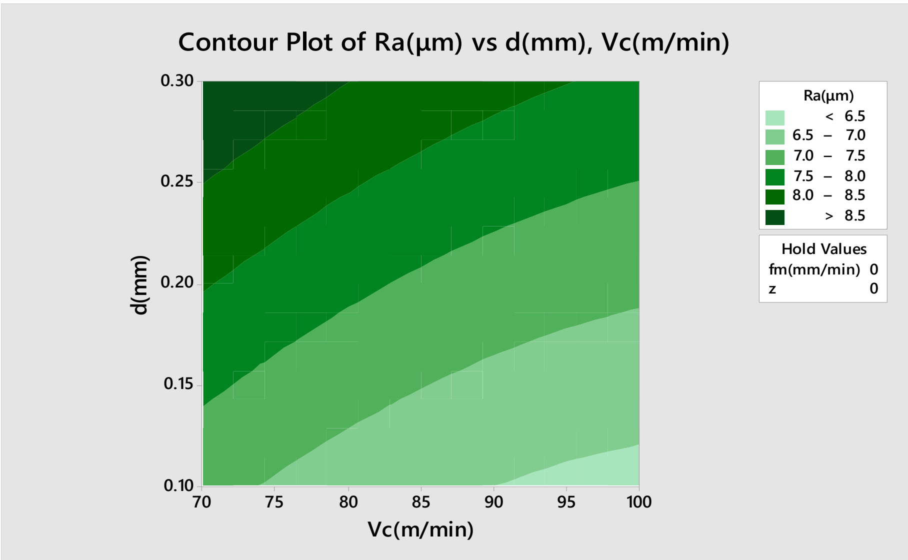


Fig.6.4 (i): Combined Effect of Ra on Vc*d

Vc*d (Speed, doc): This plot indicates that how variables, d.o.c and Speed, are related to the Surface roughness while the other factors, feed and no. of flutes Which are held constant at medium level 0. The Ra is better at bottom region,Where lower depth of cut and medium cutting speed.

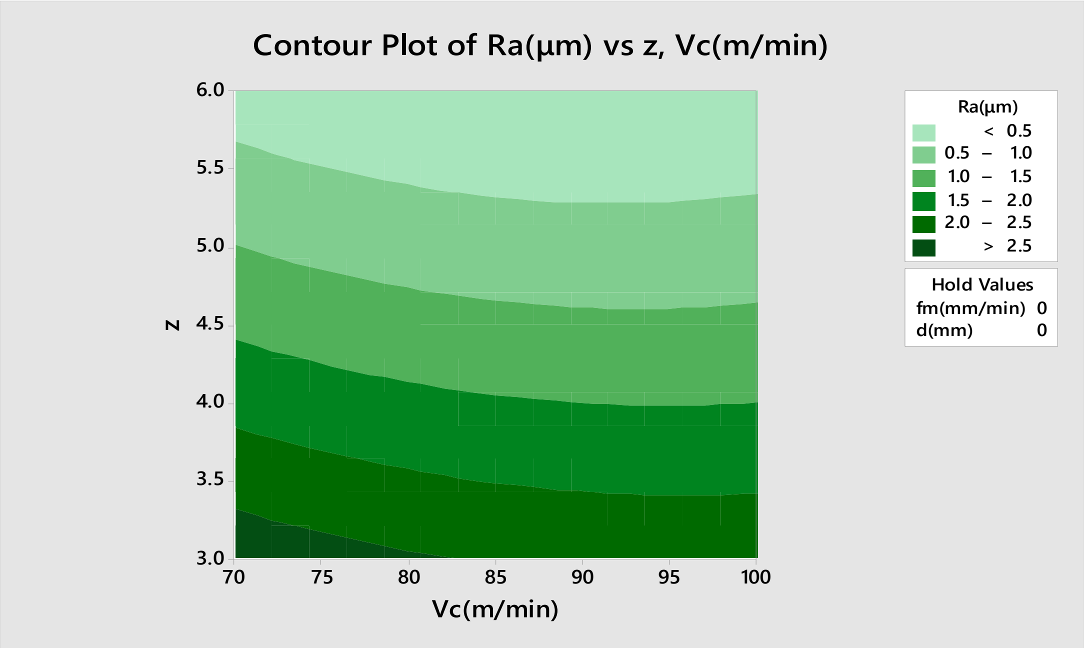


Fig. 6.4 (ii): Combined Effect of Ra on Vc*z

Vc*z (Speed, Flutes): This plot indicates that how variables, Speed and Flutes, are related to the Surface roughness while the other factors, doc and flutes, are held constant at medium level 0. The response Ra value is minimum at upper top region where, no of flutes 6 and low cutting speed 70 m/min.

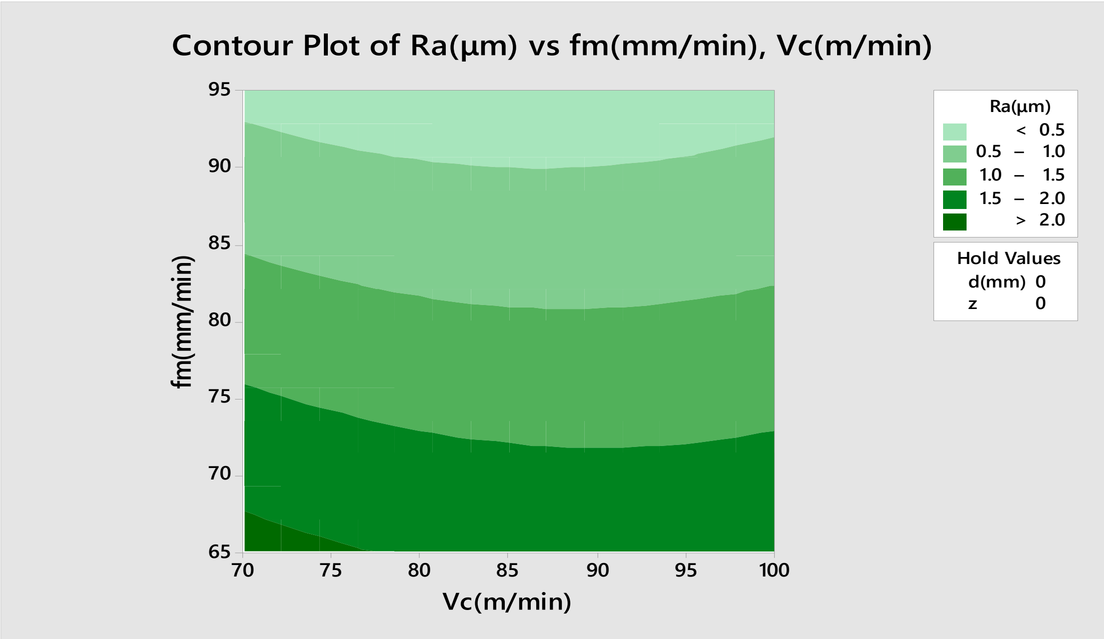


Fig.6.4 (iii): Combined Effect of Ra on Vc*fm

Vc*fm (Speed, Feed): This plot indicates that how variables, Speed and Feed, are related to the Surface roughness while the other factors, d.o.c and flutes, are held constant at medium level 0. The response is better at bottom centre region where, feed rate is low to medium range and cutting speed medium range as possible combination.

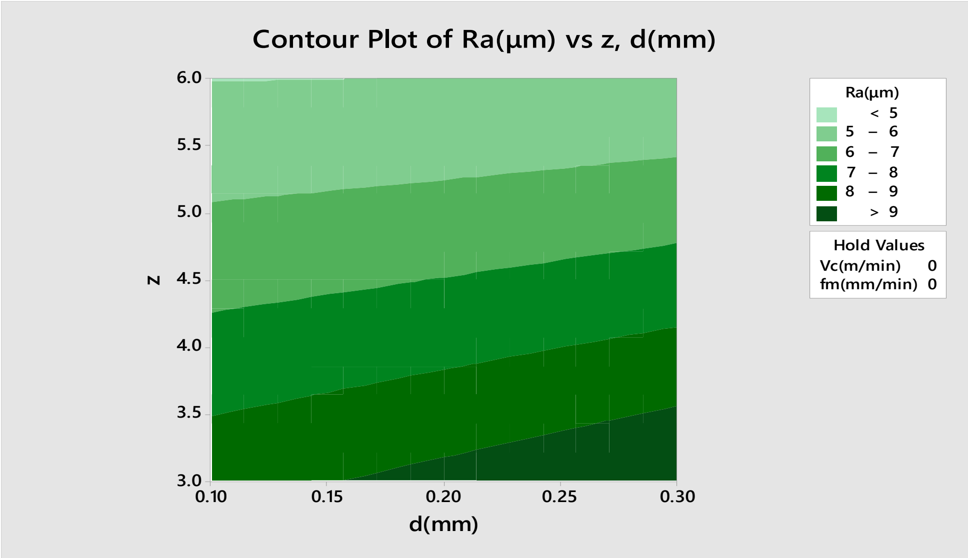


Fig. 6.4 (iv): Combined Effect of Ra on d*z

d*z (doc, flutes): This plot indicates that how variables, doc and flutes, are related to the Surface roughness while the other factors, feed and speed, are held constant at medium level 0. The response is better at left centre region where, doc at low range and cutting speed at medium range as possible combination.

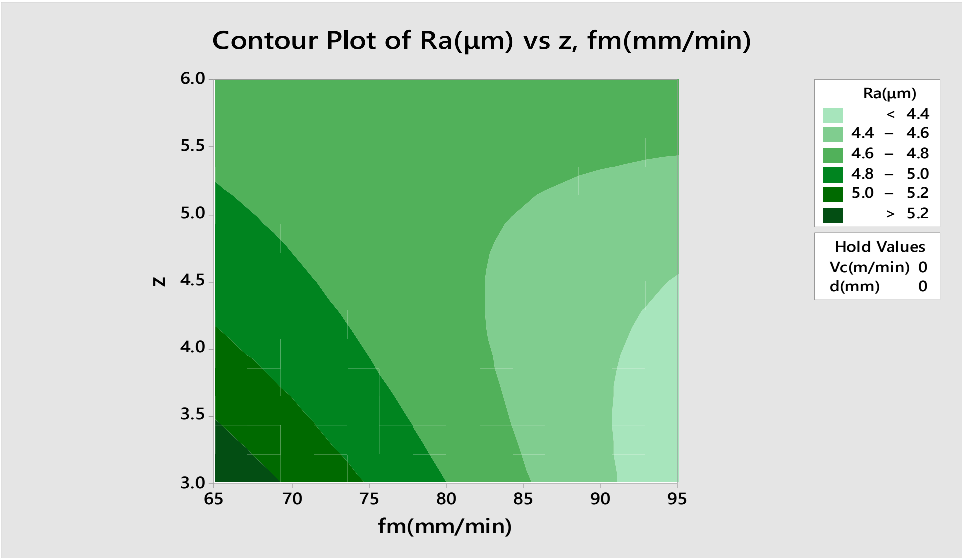


Fig.6.4 (v): Combined Effect of Ra on fm*z

fm*z (feed, flutes): This plot indicates that how variables, flutes and feed, are related to the Surface roughness while the other factors, doc and speed, are held constant at medium level 0. The response is better at upper top left corner where no of flutes 6 and feed 65 mm/min.

6.3 EFFECT OF PROCESS PARAMETERS ON MRR (mm^3/min)

The productivity plays an important role in machining industries in terms of cost effectiveness and time. The regression model of the surface roughness (Ra) is shown in the eq. (5.5). Based on this equation, the effect of the input process parameters on the MRR have been plotted in Figs. 6.5- 6.7.

6.3.1 NORMAL PROBABILITY PLOT OF RESIDUALS FOR MRR (mm^3/min)

It can be observe in Figure 6.5 that all the points on the normal plot lie close to the straight line (mean line). This implies that the data are fairly normal and a little deviation from the normality is observed. This shows the effectiveness of the developed model. It is noticed that the residuals fall around straight line, which implies that errors are normally distributed .Curve like a non linear distribution.

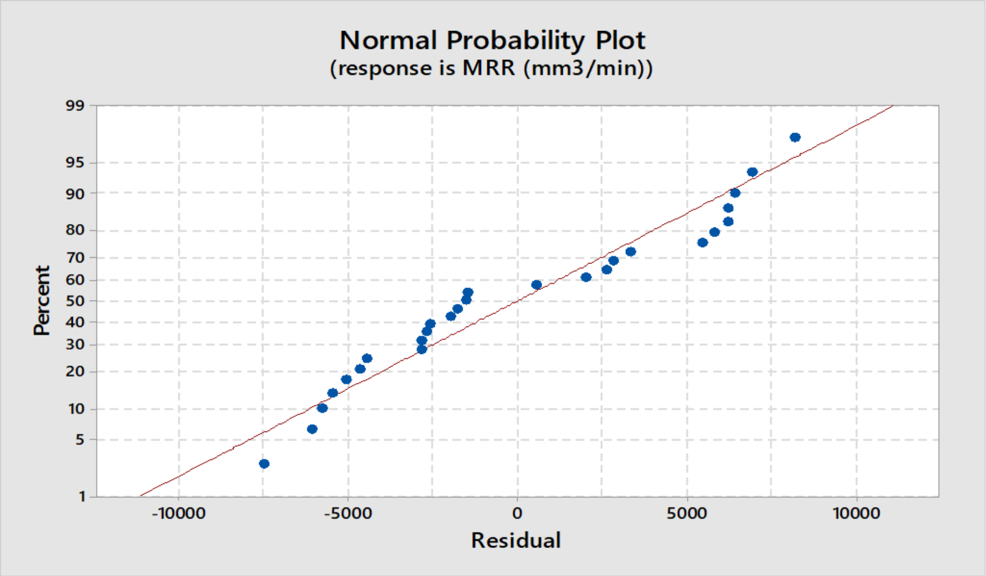


Fig. 6.5 Normal probability plot for MRR

6.3.2 MAIN EFFECTS PLOT FOR MRR (mm^3/min)

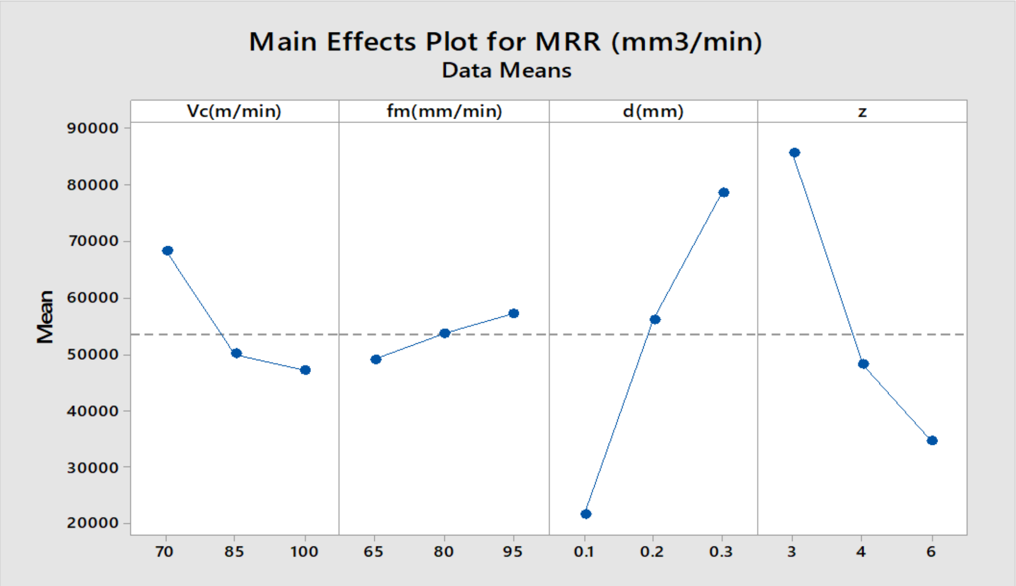


Fig. 6.6 Main effect plot for MRR

The main effect plot of MRR is shown in above Fig. 6.6. The interpretation of this figure as follows:

MRR decreases with the increasing in the value of cutting speed (Vc) from 70 m/min to 100 m/min.

MRR increases with increasing in values of feed rate (fm) from 65 mm/min to 95 mm/min and depth of cut from 0.1 mm to 0.3 mm.

MRR decreases with rapidly increasing in values of no of flues (z) from 3 to 6.

From main plot graph it can observed that the optimum value at which higher Material Removal Rate is obtained which is most significant and applicable value amongst all other experimental values.

- Cutting speed, Vc at level 1 (70 m/min)
- Feed rate, fm at level 3 (95 mm/min)
- Depth of cut, d at level 3 (0.3 mm)
- No of flute, z at level 1 (3 flutes)

6.3.3 INTERACTION PLOT FOR MRR (mm^3/min)

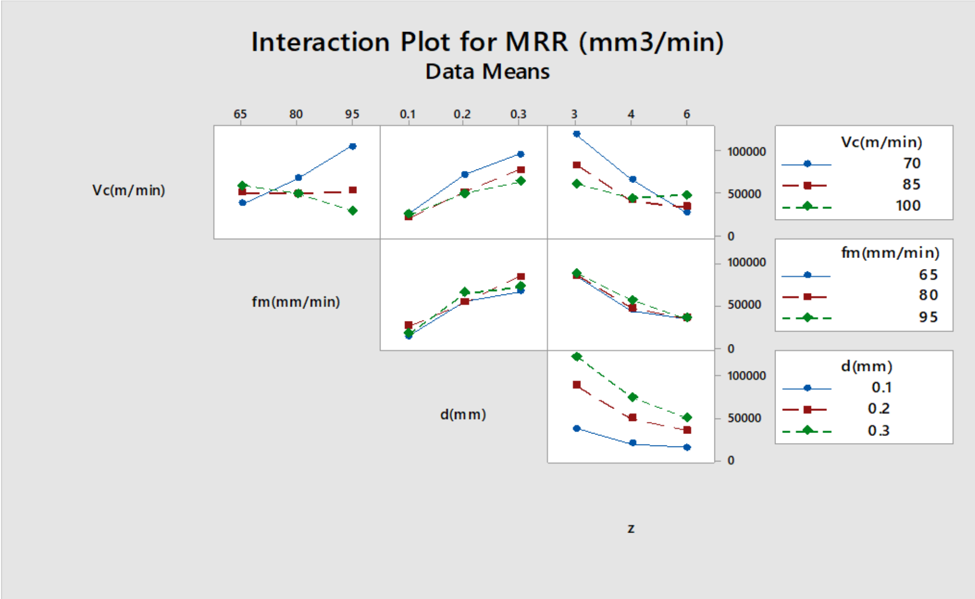


Fig. 6.7 Interaction plot for MRR

Fig.6.3 indicates interaction plot confirms the significance of Vc*fm, Vc*d, Vc*z,fm*d, fm*z, d*z interactions as stated earlier. Interaction occurs when one factor does not produce the same effect on the response at different levels of another factor.

Therefore, if the lines of two factors are parallel, there is no interaction. On the contrary, when the lines are far from being parallel, the two factors are interacting. In each case of fm*z, d*z interactions, the response MRR decreases when the line moves from the left to right side.

6.3.4 CONTOUR PLOTS FOR MRR (mm^3/min)

The below response surface is plotted to study the effect of process variables on the MRR and its shown in Figures 6.7(i) - 6.7(vi).

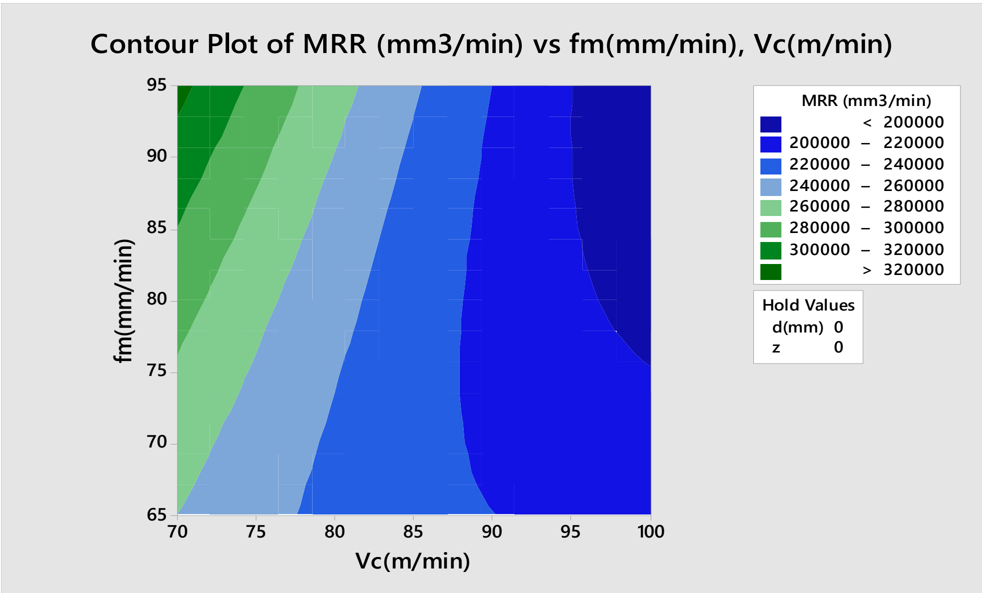


Fig. 6.7(i): Combined Effect of MRR on Vc*fm

Vc*fm (Speed, Feed): This plot indicates that how variables, speed and Feed, are related to the MRR while the other factors doc and speed are held constant at medium level 0. The higher MRR at left top corner region where speed is 70 m/min and feed is 95 mm/min.

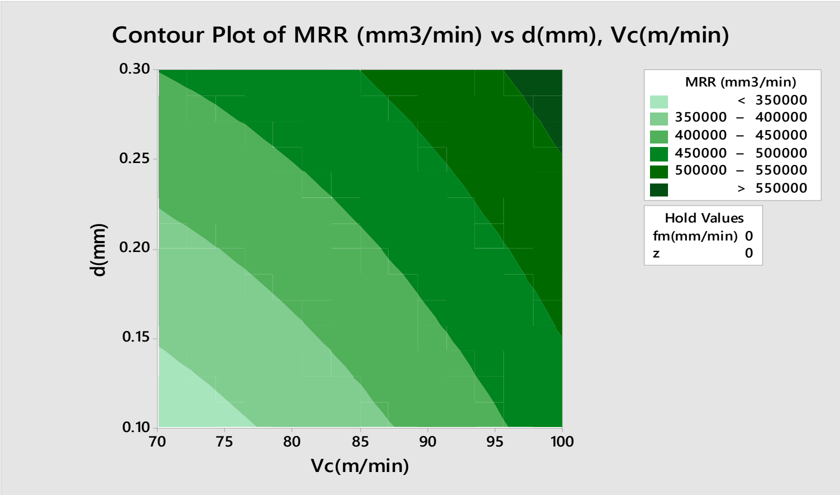


Fig. 6.7(ii): Combined Effect of MRR on Vc*d

Vc*d (Speed, doc): This plot indicates that how variables, speed and doc, are related to the MRR while the other factors, feed and flutes, are held constant at medium level 0. The higher MRR at upper left corner region where speed is 70 m/min and doc is 0.3 mm.

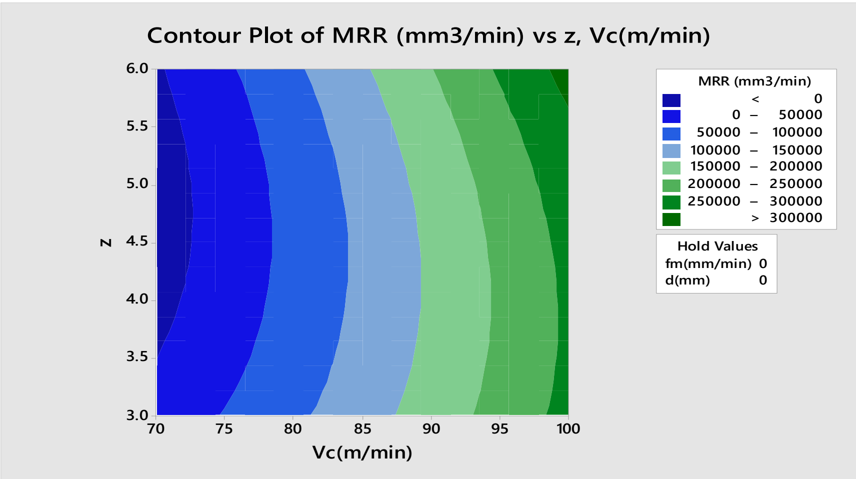


Fig. 6.7(iii): Combined Effect of MRR on Vc*z

Vc*z (Speed, Flutes): This plot indicates that how variables, flutes and speed, are related to the MRR while the other factors, doc and feed, are held constant at medium level 0. The higher MRR at lower left corner region where no of flutes is 3 and speed is 70-75 m/min.

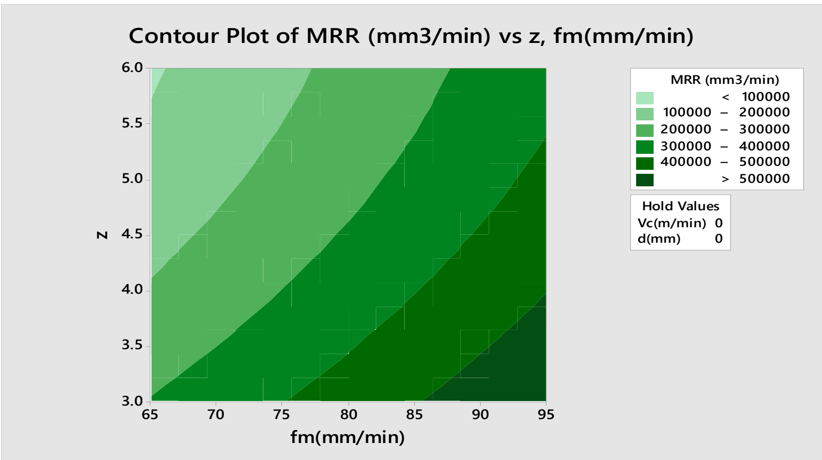


Fig. 6.7(iv): Combined Effect of MRR on fm*z

fm*z (Feed, Flutes): This plot indicates that how variables, Flutes and Feed, are related to the MRR while the other factors, doc and speed, are held constant at medium level 0. The higher MRR at lower right corner region where no of flutes is 3 and feed is 95 mm/min.

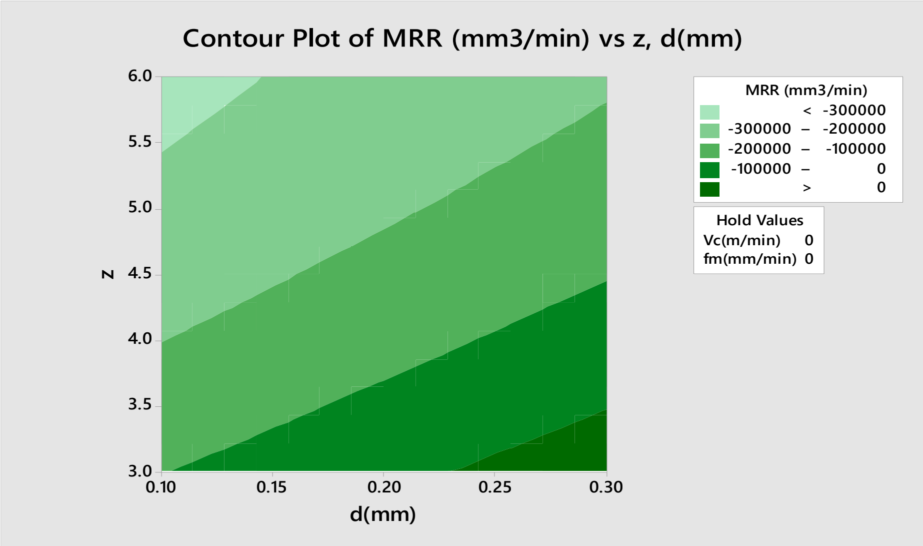


Fig. 6.7(v): Combined Effect of MRR on d*z

d*z (doc, Flutes): This plot indicates that how variables, doc and feed, are related to the MRR while the other factors, feed and speed, are held constant at medium level 0.

The higher MRR at lower right corner region where no of flutes is 3 and doc is 0.3 mm.

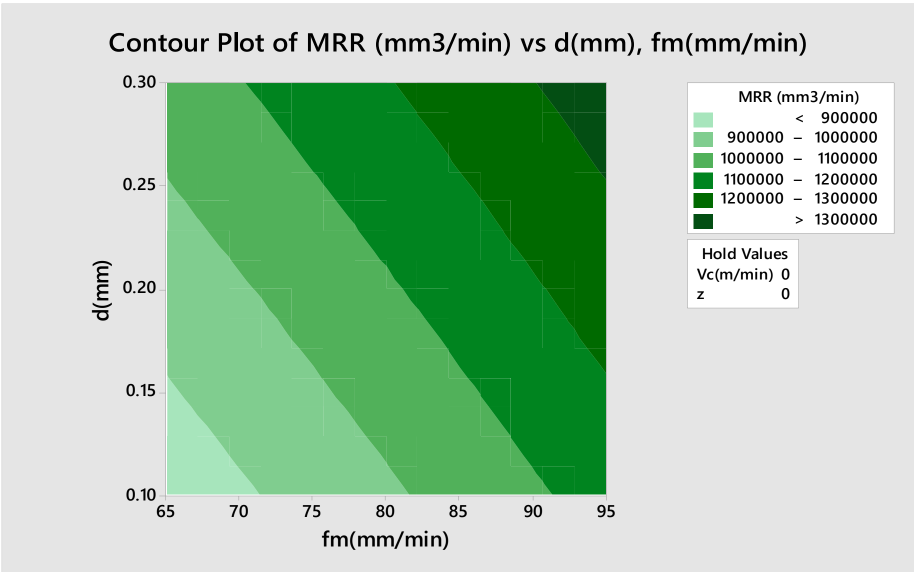


Fig. 6.7(vi): Combined Effect of MRR on fm*d

fm*d (Feed, doc): This plot indicates that how variables, doc and Feed, are related to the MRR while the other factors, Speed and flutes, are held constant at medium level 0. The higher MRR at upper right region where doc is 0.3mm and feed is 90-95 mm/min.

IV. CONCLUSION

Box Behnken design was successfully adopted and the experiments were designed choosing the input variables for the levels selected. With minimum number of experiments, data was collected and the models were developed. Response Surface Models evolved for responses show the effect of each input parameter and its interaction with other parameters, depicting the trend of response. Verification of the Fitness of each model using statical ANOVA technique shows that all the models can be used with confidence level of 95%, for navigating the design space. The research findings of the present study based on RSM models can be used effectively in machining of AISI 316 steel in order to obtain best possible CNC end milling efficiency. Minitab_16 software was used for analyze the experimental data. Following conclusions drawn after analysis.

1. Referring to the graphs 6.4 (ii), It is observed that the effect of No of flutes (z) andcutting speed (Vc) are most significant factors varying linearly with the response. The other two factors depth of cut and feed has very little effect on Ra as compared to z and Vc.

2. Three- and 4-flute tools are available for a wide range of materials, as are 5- and 6- flute, general-purpose end mills. These cutters are suitable for steels and stainless steels, but not for aluminum and non-ferrous alloys.

3. End mill of 6 fluted have significant effect on to minimum surface roughness value as compare other than 3 and 4 fluted end mill. Because of 6 fluted end mills cutting tips which are in more area of contact with machining material surfaces. In die making industries mould or cavity generate by end mill. Generally minute finishing cut for smoother surface or profile generated by 6 fluted end mills. For light finishing cuts and cuts where less than 50 percent of the tool is engaged radially, a 5- or 6-flute end mill would be a good choice. Such a tool would provide continuous tool to part contact and impart an excellent surface finish.

4. Referring to the graphs 6.7 (vi), It is observed that the No of flutes (z), feed rate and depth of cut are most significant factors which are affect on MRR. The other, cutting speed has significant effect on MRR as compare no of flutes, feed and depth of cut. End mill of 3 fluted have most significant effect on maximum MRR value as compare other than 4- and 6 fluted end mill. Because of 3 fluted end mills having more gaps or passage between cutting flutes as compare 6 fluted and 4 fluted so, when cutting is carried out at that time chip loading effect is minimum causes chips produced at cutting zone produced cut chips easy move to slice or flow over passage between flutes. Slot milling and pocket milling are difficult, due to complete or high tool topart contact. When slotting, the tool is fully engaged radially, making chip evacuation difficult. Tool selection is usually limited to 2- or 3-flute end mills because of the relatively large chip evacuation space they provide. These styles also augment coolant flow to the cutting edge.

5. Still, if heavy axial and radial DOCs greater than 50 percent of the tool diameter are taken, chip packing and evacuation problems may occur. For heavy peripheral cuts, 3- and 4-flute end mills are effective.

6. The Response surface model (RSM) by Box-Behnken approach could predict the surface roughness (Ra) with average percentage deviation of 1.553%, or 98.44% accuracy and MRR with average percentage deviation of 0.1277%, or 99.87% accuracy from Experimental data set.

7. The model was experimentally validated at other parameter settings as well. Table 5.7 shows the verifications of the model predictions for surface roughness and MRR. A good agreement is observed among the predicted and actual results. To assess the accuracy of the model, percentage errors and average percentage error were calculated. The maximum prediction error in surface roughness of 4.0% and MRR of 4.3% .The average percentage of error in surface roughness of 3.7% and MRR of 3.24% so, Validation an underlining the satisfactory performance of the prediction model.

8. Desirability function in combination with response surface methodology has been used for Multi-response (i.e. Surface roughness, MRR) optimization. Optimal sets of process parameters will achieve. The minimum value of Ra is 1.0208 µm and MRR is 109000 mm3/min within this range will achieve at the (Vc=70 m/min, fm=95 mm/min, d=0.1040 mm, Z=3).

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