Optimization of Process Parameters in Milling of Stainless Steel 316 Using Coated Insert and MEGA Coated Inserts

Ashwini B. Shelar
P.G. Student, Department of Mechanical Engineering, Karmaveer Bhaurao Patil College of Engineering, Satara, India

Aamir M. Shaikh
Assistant professor, Department of Production Engineering, Karmaveer Bhaurao Patil College of Engineering, Satara, India.

Abstract – In today's manufacturing world it is very necessary to build up bridge between quality and productivity. This study highlights optimization of face milling operation for stainless steel 316 with taguchi orthogonal array. Twenty-seven experimental runs based on an L27 orthogonal array of Taguchi method were performed spindle speed, feed rate and depth of cut are optimized with consideration of multiple performance characteristics namely surface roughness (Ra) and material removal rate (MRR). The analysis of variance (ANOVA) is also applied to identify the most significant factor. The analysis can be done by using two different insert coatings; stainless steel 316 is difficult to machine material so to obtain good surface finish two different coating are used for machining and from that best coating can be find out. Machining can be carried out on CNC vertical milling machine with 25 millimeter cutter diameter. Finally, conformation test were performed.

Index Terms – Stainless steel 316, CNC vertical milling machine, Taguchi, Surface Roughness, Material Removal Rate.

1. INTRODUCTION

Milling is the most widely used process of machining flat, curved or irregular surfaces by feeding workpiece against rotating cutter. Hardik G. Soni [01] studied the optimal machining parameters on surface roughness and tool wear in CNC end milling using AISI 316 as a work piece material and tool used is solid carbide. The machining is done on dry condition. Machining parameters used for optimization are cutting speed, feed rate, depth of cut. In this paper it is studied that there is very few investigator research worked on SS316 stainless steel material. Alpesh R. Patel A et.al [02] to studied the effect of machining parameters such as cutting speed, feed rate, depth of cut, no of cutting flute that are influences on responsive output parameters such as Surface Roughness and Material Removal Rate by using optimization philosophy in CNC end milling. This is review paper in this it is find out that there is very few investigator research worked on SS316 stainless steel material so, they want to do work on this material. Muhammmad Yasiretet.al [03] investigates the effect of cutting parameters on the surface topography of stainless steel AISI 316L with tungsten carbide tool by using response surface methodology. The experiment is conducted in dry condition. The cutting speeds, feed rates were used. Scanning electron microscope (SEM) and Mitutoyo surface tester were used to study in detail the surface topography of stainless steel AISI 316L. A. Shokrani et.al [04] presents one of the very first studies on cryogenic CNC end milling of the Inconel 718 nickel based alloy using TiAlN coated solid carbide tools. Cutting parameters selected were tool diameter, cutting speed, fees rate, depth of cut and immersion rate whereas response factors selected were surface roughness, tool wear and power consumption. Statistical analysis of the results revealed that cryogenic cooling has resulted in 33% and 40%reduction in Ra and ISO Rz surface roughness of the machined parts as compared to dry machining without noticeable (1.9%) increase in power consumption of the machine tool. Cryogenic cooling significantly reduced the tool life of the coated solid carbide end mills. V. S. Thangarasu et.al [05] proposed experimentation on AISI 304 Stainless steel material is taken for the study to determine the parameters and to optimize with Design Of Experiments (DOE) based Response Surface Method (RSM) to find the optimal parameter set as per the requirements of the user of the high speed CNC machine. Machining parameters used for optimization are cutting speed, feed rate and depth of cut. V. S. Thangarasu et.al [06] investigates the AISI 304 stainless steel by using Taguchi based Box-Behnken Response Surface Methodology (RSM) method is used to develop prediction formula and Multi Objective Genetic Algorithm (MOGA) is used for High speed CNC milling process optimization with higher Spindle speed, Feed rate and Depth of cut for better surface finish and material removal rate. Harish Holkar et.al [07] studied the end milling parameters of AISI 321 grade of stainless steel are optimized by using Taguchi method. The tests were carried out with PVD multilayer coated cemented carbide end mill tools coating consists of TiN/TiAlN/TiN coating and the experiments were conducted at three different cutting speeds, with three different feed rates and a constant depth of cut. The optimization has been done to reduce surface roughness and flank wear with maximization of MRR. Lohithaksha M. Maiyar et.al [08]investigates the parameter optimization of end milling operation for Inconel 718 super alloy with multi-response criteria based on the taguchi orthogonal array with the grey relational analysis. Cutting speed, feed rate and depth of cut are input parameters and performance characteristics namely surface roughness and material removal rate are selected. It has been observed that there is a 64.8% increase in material removal rate and at the same time a 9.52% decrease in surface roughness. Analysis of variance shows that the cutting velocity is the most significant machining parameter followed by feed rate affecting the multiple performance characteristics with 56.88% and 34.64% influence respectively. Surasit Rawangwong et.al [09] investigates the effect of the main factors of the surface roughness in aluminium semi-solid 2024 face milling. The controlled factors were the speed, feed rate and depth of cut. The surface roughness of aluminium semi-solid 2024 was significantly effect by cutting speed, and feed rate. The result also indicated that higher values of speed and lower feed tended to decrease the surface roughness.

2. MATERIAL

The workpiece material selected for this study was Stainless Steel 316 which is widely used in Springs, nuts, bolts and screws, Medical implants, Food processing equipment, Brewery, dairy and pharmaceutical production equipment, Jet engine parts, Chemical and petrochemical equipment etc. Stainless steel 316 specimens of 40 mm × 30 mm × 21 mm dimensions were used in the present study. The chemical composition of workpiece material was checked at Material Test Laboratory, Mumbai.

C	Mn	Si	S	P	Cr	Mo	Ni
0.05	1.64	0.39	0.011	0.028	16.77	2.122	10.46

Table No. 01: Chemical composition of Stainless Steel 316 (%)

3. METHODOLOGY

The Taguchi method is one of a powerful techniques for improving productivity during research and development; so that high quality products can be produced quickly and at low cost. In Taguchi's techniques, quality is measured by deviation of a characteristic from its target value. The Taguchi loss function recognizes the products that are more consistent.Since the elimination of noise factors is impractical and often impossible, the taguchi method seeks to minimize the effect of noise and to determine the optimal level of important controllable factors based on concept of robustness. Taguchi method uses a special design of orthogonal array to study the entire parameters space with only a small number of experiments. Analysis of Variance (ANOVA) was performed to find out the most significant factor that affect response.

In this study "Smaller-the-better" performance characteristics is used for Surface Roughness and "Higher-the-better" characteristics is used for Material removal rate.

The equations for calculating S/N ratio are as follows;

1. If smaller-the-better performance characteristics then;

$\frac{S}{N} = -10 \log[\frac{1}{n}] \sum_{i=1}^{n} Y^2$ …….(Eq. 1)

2. If higher-the-better performance characteristics then;

$\frac{S}{N} = -10 \log[\frac{1}{n}] \sum_{i=1}^{n} 1/Y^2$ …….(Eq. 2)

Figure no.01: Photographic view of experimental setup for machine

4. EXPERIMENTAL SETUP

Figure no. 1 shows experimental setup for machining Stainless Steel 316 using coated and MEGA coated insert. Milling experiment was conducted on CNC vertical MTAB Compact mill. All the experiments were conducted for two inserts separately; the two coated inserts used are TEKN 2204 PTTR PR830 having coating of TiAlN+TiN and TEKN 1603 PTTR PR 1225 having coating of MEGACOATE. All experiments were carried out under wet condition using emulsifable coolant.

The experiment was carried out using 3 levels and 3 factors. This study deals with 3 control parameters i.e. Spindle speed, Feed and Depth of cut and 3 performance parameters i.e. Surface Roughness (Ra), Material Removal Rate (MRR) and Flatness. Based on Taguchi's design of experiment L27 orthogonal array is considered. Total 27 experiments were carried out for each coating separately Table no.02 shows process parameters and their levels.

Sr. No.	Process parameter	Unit	Level 1	Level 2	Level 3
1	Spindle speed	rpm	1500	2000	2500
2	Feed	mm/rev	0.10	0.12	0.14
3	Depth of cut	mm	0.1	0.3	0.5

Table no. 2 Process parameter and their levels

5. RESULT AND DISCUSSION

All twenty-seven experimental runs for two different coatings separately are tabulated in Table no.3 and Table no.07 along with input parameters setting and experimental results. Reading for respective performance measure was taken. Mitutoyo surface roughness was used for measurement of surface roughness (Ra).Table no.4 and Table no. 08 shows S/N ratios for Ra and MRR.

Expt. No.	Process Parameters			Experimental result	
	Spindle Speed (rpm)	Feed (mm/rev)	Depth of cut (mm)	Surface Roughness (µm)	MRR (gm./min)
A1	1500	0.10	0.1	0.3730	2.2333
A2	1500	0.10	0.1	0.3425	1.8499
A3	1500	0.10	0.1	0.3780	2.3166
A4	1500	0.12	0.3	0.4020	4.3799
A5	1500	0.12	0.3	0.4035	3.9799
A6	1500	0.12	0.3	0.4115	4.3599
A7	1500	0.14	0.5	0.5950	7.7534
A8	1500	0.14	0.5	0.5990	7.4666
A9	1500	0.14	0.5	0.5799	7.5963
A10	2000	0.10	0.3	0.3865	1.8355
A11	2000	0.10	0.3	0.3980	2.1173
A12	2000	0.10	0.3	0.4265	2.3578
A13	2000	0.12	0.5	0.4500	6.4330
A14	2000	0.12	0.5	0.4635	6.6970
A15	2000	0.12	0.5	0.4672	6.7381
A16	2000	0.14	0.1	0.8200	6.4440

A17	2000	0.14	0.1	0.8355	5.7396
A18	2000	0.14	0.1	0.8455	5.7396
A19	2500	0.10	0.5	0.4675	4.5558
A20	2500	0.10	0.5	0.4905	4.2606
A21	2500	0.10	0.5	0.4965	4.6292
A22	2500	0.12	0.1	0.5370	5.9738
A23	2500	0.12	0.1	0.5365	6.7103
A24	2500	0.12	0.1	0.5495	6.6284
A25	2500	0.14	0.3	0.8950	6.4499
A26	2500	0.14	0.3	0.9615	6.8999
A27	2500	0.14	0.3	0.9655	6.5999

Table no.3: Taguchi L27 Orthogonal Array for experimental runs and results for TiN coated insert

Expt. No.	Experimental result		S/N ratios	
	Surface Roughness (µm)	MRR (gm./min)	Surface Roughness (µm)	MRR (gm./min)
A1	0.3730	2.2333	8.565823	6.9789413
A2	0.3425	1.8499	9.306788	5.3429650
A3	0.3780	2.3166	8.450164	7.297021
A4	0.4020	4.3799	7.915478	12.829283
A5	0.4035	3.9799	7.883129	11.997443
A6	0.4115	4.3599	7.712596	12.789530
A7	0.5950	7.7534	0.450966	17.789843
A8	0.5990	7.4666	4.451463	17.462457
A9	0.5799	7.5963	4.732937	17.612042
A10	0.3865	1.8355	8.257010	5.2750877
A11	0.3980	2.1173	8.002338	6.515647
A12	0.4265	2.3578	7.401619	7.4501392

A13	0.4500	6.4330	6.935749	16.168271
A14	0.4635	6.6970	6.679005	16.517605
A15	0.4672	6.7381	6.609943	16.570749
A16	0.8200	6.4440	1.723722	16.183110
A17	0.8355	5.7396	1.561070	15.177632
A18	0.8455	5.7396	1.457727	15.177632
A19	0.4675	4.5558	6.604367	13.171293
A20	0.4905	4.2606	6.187219	12.589415
A21	0.4965	4.6292	6.081614	13.310118
A22	0.5370	5.9738	5.400514	15.525013
A23	0.5365	6.7103	5.408605	16.534834
A24	0.5495	6.6284	5.200646	16.428174
A25	0.8950	6.4499	0.963539	16.191059
A26	0.9615	6.8999	0.341014	16.776855
A27	0.9655	6.5999	0.304954	16.390747

Table no.04: Experimental results and S/N ratios for Ra and MRR

The optimal parametric combinations for each performance measure were found by main effect plots for S/N Ratios. The level of parameter with highest S/N ratio gives the optimal level.

Figure .02 shows main effect plot for surface roughness. So the optimal process parameter setting for the Surface roughness (Ra) was N1 F1 D3. Thus, the best combination values for minimizing Surface roughness (Ra) were spindle speed of 1500 rpm, feed of 0.10 mm/rev, Depth of cut of 0.5 mm. Further ANOVA was performed Table no.05 shows ANOVA for Ra.

The experimental results were analyzed using analysis of variance (ANOVA) for identifying the significant factors affecting the performance measures. The results of ANOVA for Ra are shown in Table no.05.This analysis was carried out for a significance level of 0.05 (Confidence level of 95 %). The ANOVA result shows that, the F-value for the feed and spindle speed is larger than that of the depth of cut i.e. the largest contribution to the workpiece surface roughness or finish is due to the feed rate. Feed rate (the most significance factor) contributed 74.50 % for Ra.

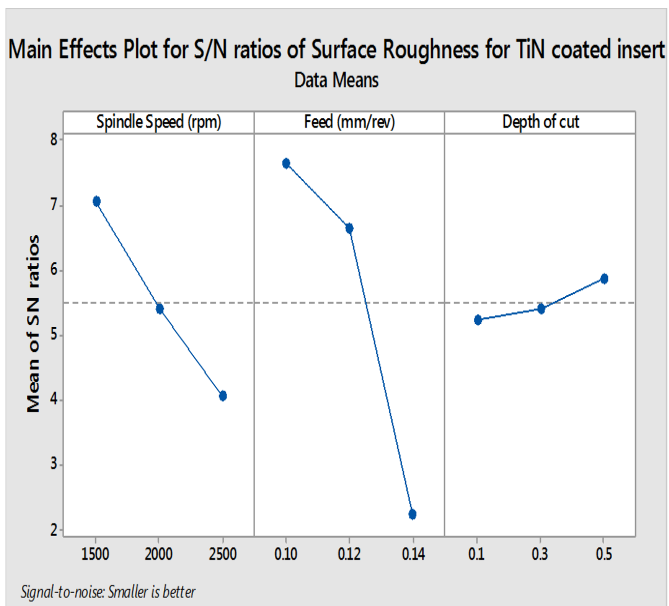

Figure no. 02 Main effects plot for S/N ratio of Ra using TiN coated insert

Source	DF	SS	MS	F-Value	% Contribution
Spindle speed	2	0.183785	0.091892	51.10	18.837
Feed rate	2	0.726936	0.363468	202.10	74.508
Depth of cut	2	0.028961	0.014481	8.05	2.968
Error	20	0.035969	0.001798		3.687
Total	26	0.975651			100

Table no. 05 ANOVA for Ra using TiN coated insert

Figure no.03 shows main effect plot for MRR. So the optimal process parameter setting for the Material Removal Rate was N3 F3 D3. Thus, the best combination values for maximizing MRR were cutting speed of 2500 rpm, feed of 0.14 mm/rev, Depth of cut of 0.5 mm. Further ANOVA was performed. Table no.06 shows

ANOVA for MRR. The analyses were made for the level of confidence 95% (the level significance is 5%). Feed rate is mostly influenced the Material Removal Rate by 72.581%. From the analysis of this Table no.06, it could be observed that feed rate and depth of cut had statistical and physical significance on the MRR.

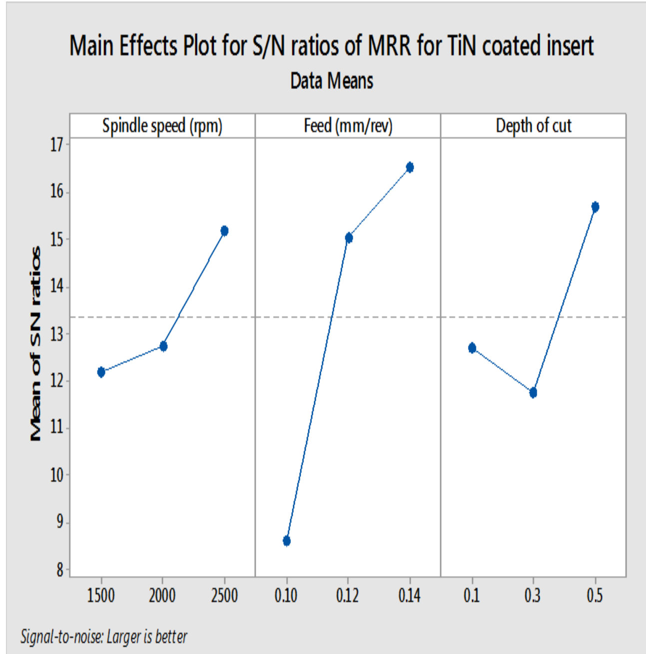

Figure no. 03 Main effects plot for S/N ratio of MRR using TiN coated insert

Source	DF	SS	MS	F- Value	% Contribution
Spindle speed	2	7.214	3.6072	30.73	7.315
Feed rate	2	71.577	35.7883	304.85	72.581
Depth of cut	2	17.478	8.7389	74.44	17.723
Error	20	2.348	0.1174		2.381
Total	26	98.617			100

Table no. 06 ANOVA for MRR using TiN coated insert

Expt. No.	Process Parameters			Experimental results	
	Spindle Speed (rpm)	Feed (mm/rev)	Depth of cut (mm)	Surface Roughness (µm)	MRR (gm./min)
B1	1500	0.10	0.1	0.1935	2.2999
B2	1500	0.10	0.1	0.2035	2.0000
B3	1500	0.10	0.1	0.2045	2.3666
B4	1500	0.12	0.3	0.2510	4.4000

B5	1500	0.12	0.3	0.2550	4.2999
B6	1500	0.12	0.3	0.2490	4.4499
B7	1500	0.14	0.5	0.3105	7.0570
B8	1500	0.14	0.5	0.3025	7.0784
B9	1500	0.14	0.5	0.3101	7.0295
B10	2000	0.10	0.3	0.1896	2.1333
B11	2000	0.10	0.3	0.1870	2.3666
B12	2000	0.10	0.3	0.1870	2.2333
B13	2000	0.12	0.5	0.2190	4.0593
B14	2000	0.12	0.5	0.2095	4.0964
B15	2000	0.12	0.5	0.2145	4.4008
B16	2000	0.14	0.1	0.3716	6.9397
B17	2000	0.14	0.1	0.3755	6.9397
B18	2000	0.14	0.1	0.3745	7.0962
B19	2500	0.10	0.5	0.1965	4.7735
B20	2500	0.10	0.5	0.2105	4.4400
B21	2500	0.10	0.5	0.2016	4.5799
B22	2500	0.12	0.1	0.3020	4.9799
B23	2500	0.12	0.1	0.2980	5.5646
B24	2500	0.12	0.1	0.3130	5.3464
B25	2500	0.14	0.3	0.4005	7.9692
B26	2500	0.14	0.3	0.4010	7.9899
B27	2500	0.14	0.3	0.4015	7.9578

Table no.07: Taguchi L27 Orthogonal Array for experimental runs and results for MEGA coated insert

Expt. No.	Experimental results		S/N ratios	
	Surface Roughness (µm)	MRR (gm./min)	Surface Roughness (µm)	MRR (mm^3/min)
B1	0.1935	2.2999	14.266380	7.2341790
B2	0.2035	2.0000	13.828711	6.0205999

B3	0.2045	2.3666	13.786133	7.4824972
B4	0.2510	4.4000	12.006525	12.869053
B5	0.2550	4.2999	11.869196	12.669167
B6	0.2490	4.4499	12.076013	12.967005
B7	0.3105	7.0570	10.158767	16.972402
B8	0.3025	7.0784	10.385492	16.998702
B9	0.3101	7.0295	10.169964	16.938488
B10	0.1896	2.1333	14.443233	6.5810386
B11	0.1870	2.3666	14.563167	7.4824972
B12	0.1870	2.2333	14.563167	6.9789413
B13	0.2190	4.0593	13.19111	12.169022
B14	0.2095	4.0964	13.576319	12.248047
B15	0.2145	4.4008	13.371454	12.870632
B16	0.3716	6.9397	8.5984858	16.826813
B17	0.3755	6.9397	8.5078011	16.826813
B18	0.3745	7.0962	8.5309635	17.020516
B19	0.1965	4.7735	14.132748	13.576738
B20	0.2105	4.4400	13.534958	12.94765
B21	0.2016	4.5799	13.910189	13.217119
B22	0.3020	4.9799	10.399861	13.944412
B23	0.2980	5.5646	10.515674	14.908679
B24	0.3130	5.3464	10.089113	14.561228
B25	0.4005	7.9692	7.9479495	18.028294
B26	0.4010	7.9899	7.9371125	18.050826
B27	0.4015	7.9578	7.9262890	18.015860

Table no.08: Experimental results and S/N ratios for Ra and MRR

The optimal parametric combinations for each performance measure were found by main effect plots for S/N Ratios. The level of parameter with highest S/N ratio gives the optimal level.

Figure no.04 shows main effect plot for surface roughness. So the optimal process parameter setting for he Surface roughness (Ra) was N2 F1 D3. Thus, the best combination values for minimizing Surface roughness (Ra) were spindle speed of 2000 rpm, feed of 0.10 mm/rev, Depth of cut of 0.5 mm.

Further ANOVA was performed. Table no.09 shows ANOVA for Ra. The experimental results were analyzed using analysis of variance (ANOVA) for identifying the significant factors affecting the performance measures. The results of ANOVA for Ra are shown in Table no.09.This analysis was carried out for a significance level of 0.05 (Confidence level of 95 %). Feed rate is most influenced the surface roughness (Ra) by 82.138% From the analysis of this table.It could be observed that feed rate has statistical and physical significance on the surface roughness (Ra).

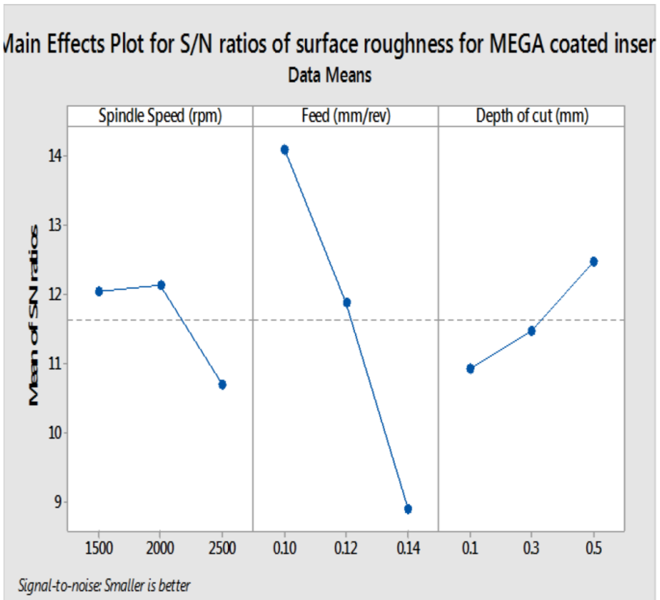

Figure no. 04 Main effects plot for S/N ratio of Ra using MEGA coated insert

Source	DF	SS	MS	F-Value	% Contribution
Spindle speed	2	0.013241	0.006621	161.33	8.795
Feed rate	2	0.123658	0.061829	1506.61	82.138
Depth of cut	2	0.012827	0.006414	156.28	8.520
Error	20	0.000821	0.000041		0.545
Total	26	0.150548			100

Table no. 09 ANOVA for Ra using MEGA coated insert

Figure no.05 shows main effect plot for MRR. So the optimal process parameter setting for the Material Removal Rate was N3 F3 D3. Thus, the best combination values for maximizing MRR were cutting speed of 2500 rpm, feed of 0.14 mm/rev, Depth of cut of 0.5 mm.

Further ANOVA was performed. Table no.10 shows ANOVA for MRR. The analyses were made for the level of confidence 95% (the level significance is 5%). Feed rate is mostly influenced the Material Removal Rate by 84.669%. From the analysis of this Table 5.14 it could be observed that feed rate and cutting speed had statistical and physical significance on the MRR.

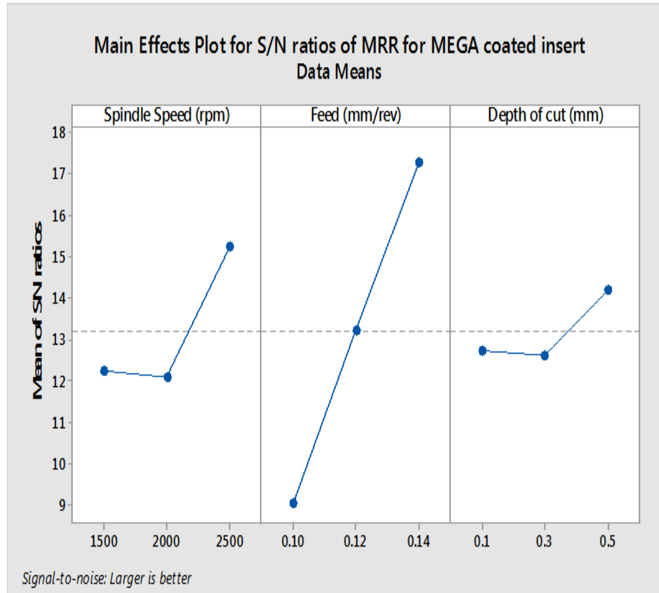

Figure no. 05 Main effects plot for S/N ratio of MRR using MEGA coated insert

Source	DF	SS	MS	F-Value	% Contribution
Spindle speed	2	12.505	6.2523	64.87	12.342
Feed rate	2	85.785	42.8927	445.05	84.669
Depth of cut	2	1.101	0.5505	5.71	1.087
Error	20	1.928	0.0964		1.0786
Total	26	101.318			100

Table no. 10 ANOVA for MRR using MEGA coated insert

6. CONCLUSION

In this study, the effects of Spindle speed, feed and depth of cut on surface roughness, material removal rate during CNC vertical milling of Stainless Steel 316 were investigated using Taguchi's experimental design. The final conclusion arrived, at the end of this work are as follows:

- From this analysis, the optimal parametric combinations for Ra and MRR were found for each insert separate.

- The optimal parametric combination for Ra and MRR in TiN coated insert is N1 F1 D3 and N3 F3 D3 respectively.
- The optimal parametric combination for Ra and MRR in MEGA coated insert is N2 F1 D3 and N3 F3 D3 respectively.
- ANOVA was performed; Ra for TiN and MEGA coated insert is the most significantly affected by feed rate.
- ANOVA was performed; MRR for TiN and MEGA coated insert is the most significantly affected by feed rate.
- Maximum Surface Roughness was obtained as 0.9655 µm and minimum as 0.3425 µm for TiN coated insert. For MEGA coated insert maximum Surface Roughness was 0.4015 µm and minimum was 0.1870 µm.
- Maximum Material Removal Rate for TiN coated insert is obtained as 7.7534 gm./min and minimum is 1.8355 gm./min. For MEGA coated insert maximum Material Removal Rate was 7.9899 gm./min and minimum is 2.0000 gm./min.

REFERENCES

[1] Hardik G. Soni (2015) "*A Review on Optimization of end milling for Stainless Steel (AISI 316)*", Volume: 5 | Issue: 5 | May 2015 | ISSN - 2249-555X.

[2] Alpesh R. Patel, Prof. N. K. Prajapati "*A Review On Optimization Of Machining Parameters For Surface Roughness And Material Removal Rate For SS 316 In CNC End Milling Process*", Int. Journal of Engineering Research and Applications, ISSN : 2248-9622, Vol. 3, Issue 6, Nov-Dec 2013, pp.1965-1969.

[3] Muhammmad Yasir, Turnad Lenggo Ginta "*Effect Of Cutting Speed And Feed Rate On Surface Roughness Of AISI 316L SS Using End-Milling*" , ARPN Journal of Engineering and Applied Sciences , VOL. 11, NO. 4, February 2016.

[4] Shokrani, V. Dhokia, S.T Newman, R. Imani-Asrai "*An Initial Study of the Effect of Using Liquid Nitrogen Coolant on the Surface Roughness of Inconel 718 Nickel-Based Alloy in CNC Milling*", 45th CIRP Conference on Manufacturing Systems 2012, Procedia CIRP 3 (2012) 121 – 125.

[5] V. S. Thangarasu , G. Devaraj , R. Sivasubramanian "*High speed CNC machining of AISI 304 stainless steel; Optimization of process parameters by MOGA*", International Journal of Engineering, Science and Technology Vol. 4, No. 3, 2012, pp. 66-77 .

[6] V.S Thangarasu, R. Sivasubramanian "*High Speed CNC Machining Of AISI 304Stainless Steel; Optimization Of Process Parameters*" International Journal of Mechanical Engineering and Robotics Research Vol. 1, No. 3, October 2012.

[7] Harish Holkar, Mudigonda Sadaiah "*Optimization of End Milling Machining Parameters of AISI 321 Stainless Steel using Taguchi Method*", International Journal on Recent and Innovation Trends in Computing and Communication ISSN: 2321-8169 Volume: 4 Issue: 420 - 23.

[8] Lohithaksha M Maiyar, Dr.R.Ramanujam, K.Venkatesan, Dr.J.Jerald "*Optimization of Machining Parameters for End Milling of Inconel 718 Super Alloy Using Taguchi Based Grey Relational Analysis*", International Conference on DESIGN AND MANUFACTURING, IConDM 2013, Procedia Engineering 64 (2013) 1276 – 1282.

[9] Surasit Rawangwong, Jaknarin Chatthong, Worapong Boonchouytan and Romadorn Burapa "*An Investigation of Optimum Cutting Conditions in Face Milling Aluminum Semi Solid 2024 Using Carbide Tool*", 10th Eco-Energy and Materials Science and Engineering (EMSES2012), Energy Procedia 34 (2013) 854 – 862.

[10] "*Milling machine operations*", The army institute for professional development, sub-course no. OD1644, edition 08.

[11] Phillip J. Ross "*Taguchi Techniques for Quality Engineering*", second edition, McGraw Hill Education (India) Private Limited.

[12] Douglas C. Montgomery "*Design and Analysis of Experiments*", eighth edition, book.

[13] A. B. Shelar, A. M. Shaikh "*Optimization of CNC Milling Process by using Different Coatings –A Review* ", International Advanced Research Journal in Science, Engineering and Technology, Vol. 4, Special Issue 1, January 2017.