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Parametric Analysis and multi objective optimization of process parameters of turning of AISI (4140) with PVD & CVD cutting tool

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ABSTRECT : *Modern manufacturers, seeking to remain competitive in the market, Relay on their Manufacturing engineers and production quality. CNC is most vital machine that can produce machine part with desire surface quality and higher productivity with less time and cost constrain. This work present multi response optimisation of turning parameters for turning on AISI 4140 Alloy Steel with both PVD & CVD coated tool. For that purpose take cutting speed, depth of cut & feed rate as an input parameters and measure the surface roughness, material removal rate & tool life. Full factorial method used for design of experiment and ANOVA used for finding contribution of each parameter which are taking here. It gives best significant parameter for surface roughness is feed rate for both approaches PVD & CVD cutting tool & depth of cut is most significant parameter for tool life for both approaches. Grey relation analysis is multi objective optimization technique which taking here for optimization for finding out Optimum parameter among various parameters which gives best result regarding surface roughness, MRR & tool life constrain.*

Key word: *cutting speed, depth of cut, MRR, surface roughness, tool life, full factorial, ANOVA*

I. INTRODUCTION

Turning is the machining process in which material remove from work piece by moving the cutting tool in the direction of axis of rotation. Turning can be done on the external surface of the part as well as internally (boring). Many articles addressed experimental and theoretical optimization processes discussed during dissertation work Muammer Nalbant et al. [1] investigate the effects of machining of AISI 1030 steel (i.e. orthogonal cutting) uncoated, PVD- and CVD-coated cemented carbide insert with different feed rates, cutting speeds by keeping depth of cuts constant without using cooling liquids has been accomplished. Harun akku et al. [2] predicting surface roughness of AISI 4140 steel in hard turning process through artificial neural network, fuzzy logic and regression model From whole procedure they concluded that optimum predictive model is the fuzzy logic model because it produced small error which consider sufficiently accurate. C.J.Rao et al [3] Analysis of Tool Life during Turning Operation by Determining Optimal Process Parameters In order to determine the optimum cutting conditions, one has to estimate the tool life and cutting forces with a reasonable degree of accuracy since many of the constraints those are applying on a process are influenced by these parameters. Ilhan asilturk et al [4] determining the effect of cutting parameter on surface roughness in hard turning using the taguchi methodin this study focuses on optimizing turning parameter based on the taguchi method to minimizes surface roughness so, for investigator have been conducting experiment using L9 orthogonal array in CNC turning machine. for that purpose They carried out dry turning on hardened AISI 4140 (51 HRC) with Al2O3 and Tic coated insert. they uses signal to noise ratio (SNR) and ANOVA. At the end they concluded that the feed rate has most significant effect on Ra and Rz and effect of two factor interaction of feed rate – cutting speed and depth of cut- cutting speed appear.

The chemical composition of AISI 4140 tool steel is given in below Table 1.AISI 4140 is used in Adapters, Arbors, Axle Shafts, Bolts, Crankshafts, Connection Rods, and Chuck Bodies.

Table 1 chemical composition of AISI 4140

Iron, Fe	96.78-97.77%
Chromium	0.80 - 1.10%
Manganese	0.75 - 1.0%
Carbon	0.380 - 0.430%
Silicon	0.15 - 0.30%

Molybdenum	0.15 - 0.25%
Sulfur	0.040%
Phosphorous	0.035

Table 2 tool material

COATING LAYER	ISO GRADE	GEOMETRIC SHAPE	MANUFACTURER	GRADE	Coating thickness
CVD – TiN compound Golden insert	M 30	TNMG160408 MA	Mitsubishi	US735	6 micron
PVD- Al-Tin coated	M 01	TNMG160408 MJ	Mitsubishi	VP10RT	3 micron

II. DESIGN OF EXPERIMENT

Design of experiments was developed in the early 1920s by Sir Ronald Fisher at the Rothamsted Agriculture field Research Station in London, England. His initial experiments were concerned with determining the effect of various fertilizers on different plots of land. The final condition of the crop was not only dependent on the fertilizer but also on the number of other factors (such as underlying soil condition, moisture content of the soil, etc.) of each of the respective plots. Fishers used DOE which could differentiate the effect of fertilizer and the effect of other factors. Since that time the DOE has been widely accepted in agricultural as well as Engineering Science. Design of experiments has become an important methodology that maximizes the knowledge gained from experimental data by using a smart positioning of points in the space. This methodology provides a strong tool to design and analyze experiments; it eliminates redundant observations and reduces the time and resources to make experiments. We have used factorial design, and used full factorial design. For a full factorial design, if the numbers of levels are same then the possible design N is N = Lm Where, L = number of levels for each factor, and m= number of factor.

Table 3 Factors and their levels in CNC straight turning factors.

Factors	Level 1	Level 2	Level 3
Speed (m/min)	180	150	120
Feed (mm/rev)	0.1	0.2	0.3
D.O.C (mm)	0.2	0.4	0.6

From the above table according to design of experiments with full factorial design total numbers of experiments to be performed are 27 by PVD coated tool & 27 experiments are performed by CVD coated tool.

III. EXPERIMENTAL SET UP

In order to achieve the goal of this experimental work the cutting tests were carried out in a CNC machine having spindle speed up to the 3000 rpm, maximum machining diameter up to 100 mm & maximum turning length up to 250 mm.

Table 3 Data obtained from experimental work for surface roughness, MRR & tool life by PVD coated tool.

Sr no	Speed	Feed	d.o.c	S.R	MRR	Tool life
1	180	0.1	0.2	1.21	145.7	24
2	180	0.1	0.4	1.37	179.8	10
3	180	0.1	0.6	1.32	204.9	7
4	180	0.2	0.2	1.53	348.8	16
5	180	0.2	0.4	1.58	398.5	7
6	180	0.2	0.6	1.62	465.3	5
7	180	0.3	0.2	3.43	667.2	11
8	180	0.3	0.4	2.85	519	5
9	180	0.3	0.6	3.82	613.4	4
10	150	0.1	0.2	1.73	148.5	37
11	150	0.1	0.4	0.81	153.5	16
12	150	0.1	0.6	1.49	182	11
13	150	0.2	0.2	1.66	262.3	25
14	150	0.2	0.4	1.82	315.7	11
15	150	0.2	0.6	1.69	342.2	8
16	150	0.3	0.2	3.65	515.8	18
17	150	0.3	0.4	4.03	568.3	8
18	150	0.3	0.6	3.47	527.7	6
19	120	0.1	0.2	1.54	140.2	64
20	120	0.1	0.4	0.93	128.4	28
21	120	0.1	0.6	1.73	177.8	20
22	120	0.2	0.2	2.01	252.8	44
23	120	0.2	0.4	2.35	262.9	19
24	120	0.2	0.6	2.48	333.6	13
25	120	0.3	0.2	3.59	410.6	31
26	120	0.3	0.4	3.81	470.1	13
27	120	0.3	0.6	3.68	470.1	10

Table 4: Data obtained from experimental work for surface roughness, MRR & tool life by CVD coated tool.

Sr no	Speed(m/min)	Feed(mm/rev)	d.o.c(mm)	S.R(µm)	MRRmm3/s	Tool life (min)
1	180	0.1	0.2	1.13	131.8	64

2	180	0.1	0.4	1.46	183	21
3	180	0.1	0.6	1.26	190.4	14
4	180	0.2	0.2	1.48	364	38
5	180	0.2	0.4	1.52	409.5	13
6	180	0.2	0.6	1.57	485.3	8
7	180	0.3	0.2	3.52	495.4	25
8	180	0.3	0.4	2.85	519	8
9	180	0.3	0.6	3.82	613.4	5
10	150	0.1	0.2	1.63	151.7	116
11	150	0.1	0.4	0.73	151.7	38
12	150	0.1	0.6	0.82	188	25
13	150	0.2	0.2	1.54	262.3	70
14	150	0.2	0.4	1.73	299.7	23
15	150	0.2	0.6	1.63	362.2	15
16	150	0.3	0.2	3.63	501.8	45
17	150	0.3	0.4	3.82	598.3	15
18	150	0.3	0.6	3.28	559.7	10
19	120	0.1	0.2	1.42	143.2	242
20	120	0.1	0.4	0.93	133.3	80
21	120	0.1	0.6	0.58	177.8	51
22	120	0.2	0.2	1.9	273	146
23	120	0.2	0.4	2.3	283.1	48
24	120	0.2	0.6	2.45	333.6	31
25	120	0.3	0.2	3.49	424.6	94
26	120	0.3	0.4	3.69	500.5	31
27	120	0.3	0.6	3.65	470.1	20

IV. ANOVA ANALYSIS

ANOVA performed to find out percentage contribution of each parameter. Here two table mention below which shows summary table.

Table 5: summary of ANOVA SR for PVD

Source of variation	F	Sum of squares	Variance (Mean square)	Variance ratio F	Percentage contribution

Factor-A, Speed	2	0.62	0.31	3.2124	2.2%
Factor-B, Feed	2	24.88	12.44	128.91	90.17%
Factor-C, Depth Of cut	2	0.16	0.8	8.29	0.57%
Error – E	20	1.93	0.0965	1	6.9%

- From the above summary table we shows that feed is the most significant factor (90.17%) which contribute more on surface roughness

Table 6: summary of ANOVA for MRR PVD

Source of variation	**F**	**Sum of squares**	**Variance (Mean square)**	**Variance ratio F**	**Percentage contribution**
Factor-A, Speed	2	45067.78	22533.89	11.35	6.4
Factor-B, Feed	2	606753.76	303376.88	152.8	86.7
Factor-C, Depth Of cut	2	7907.44	3953.72	1.99	1.13
Error – E	20	39702.356	1985.11	1	5.67

- From the above summary table we shows that feed is the most significant factor (86.7%) which contribute more on material removal rate.

Table 7: summary of ANOVA for SR CVD

Source of variation	**F**	**Sum of squares**	**Variance (Mean square)**	**Variance ratio F**	**Percentage contribution**
Factor-A, Speed	2	0.22	0.11	0.8627	0.71
Factor-B, Feed	2	28.394	14.017	109.93	91
Factor-C, Depth Of cut	2	0.04	0.02	0.15	0.12
Error – E	20	2.55	0.1275	1	8.3

- From the above summary table we shows that feed is the most significant factor (91%) which contribute more on SR.

Table 8: summary of ANOVA for MRR CVD

Source of variation	**F**	**Sum of squares**	**Variance (Mean square)**	**Variance ratio F**	**Percentage contribution**
Factor-A, Speed	2	23606.9	11803.5	7.8	3.6
Factor-B, Feed	2	5802580	290129	190.8	88.4

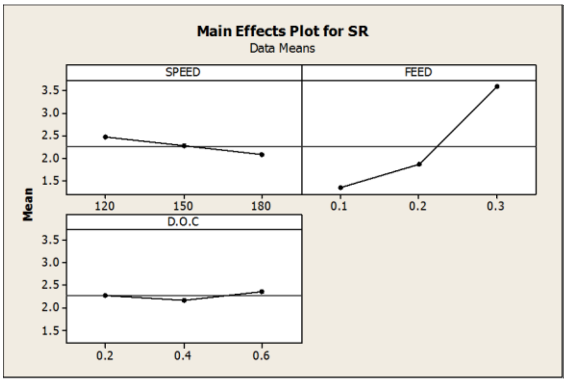
Factor-C, Depth Of cut	2	22158.5	11092.8	7.3	3.4
Error –E	20	30389	1519.5	1	4.6

- From the above summary table we shows that feed is the most significant factor (88.4%) which contribute more on material removal rate

Main Effect Plots for ANOVA

Main effect plot generated with the help of a software package MINITAB 16. The main effect plots are shown in Fig. These show the variation of individual response with the three parameters i.e. cutting speed, feed, and depth of cut separately. In the plots, the x-axis indicates the value of each process parameter at three level and y-axis the response value. Horizontal line indicates the mean value of the response. The main effects plots are used to determine the optimal design conditions to obtain the optimum surface finish & MRR

FIG 1: MAIN EFFECT PLOT FOR SR (PVD) **FIG 2: MAIN EFFECT PLOT FOR MRR (PVD)**



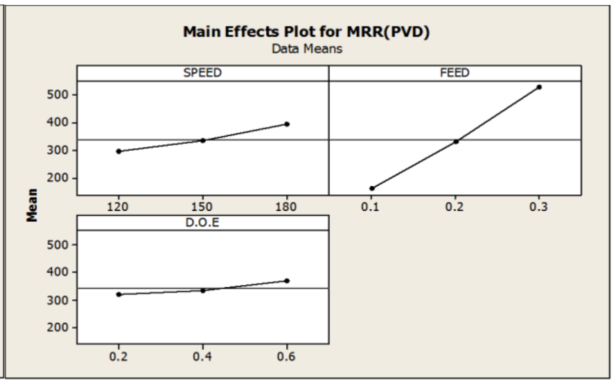
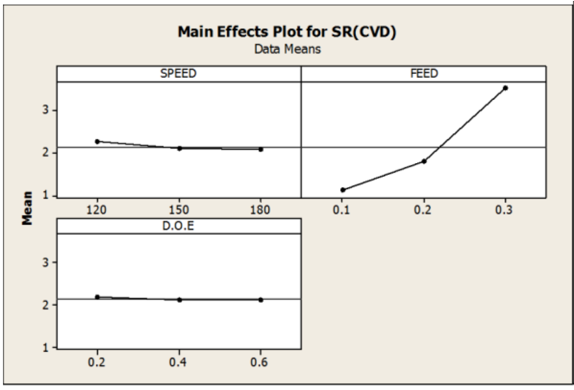
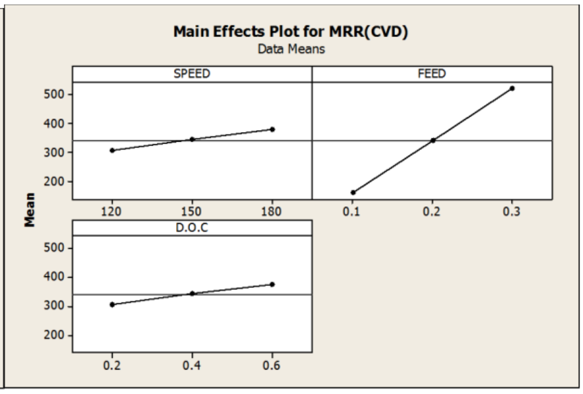


FIG .3 MAIN EFFECT PLOT FOR SR (CVD) **FIG 4: MAIN EFFECT PLOT FOR MRR (CVD)**





According to this main effect plot fig.1, the optimal conditions for minimum surface roughness are:

conditions for minimum surface roughness are:

- Cutting speed at (180m/min),
- Feed rate at (0.1 mm/ rev),
- Depth of cut at (0.4 mm)

According to this main effect plot fig.2, the optimal conditions for maximum material removal rate are:

- Cutting speed at (180m/min),
- Feed rate at (0.3 mm/ rev),
- Depth of cut at (0.6 mm)

According to this main effect plot fig.3, the optimal conditions for minimum surface roughness are:

- Cutting speed at (180m/min),
- Feed rate at (0.1 mm/ rev),
- Depth of cut at (0.6 mm)

According to this main effect plot fig.4, the optimal conditions for maximum material removal rate are:

- Cutting speed at (180m/min),
- Feed rate at (0.3 mm/ rev),
- Depth of cut at (0.6 mm)

V. GRAY RELATIONAL ANALYSIS

In grey relational generation, the normalized data corresponding to Lower-the-Better (LB) criterion can be expressed as:

$$Xi\ (k) = \frac{\max yi(k) - yi(k)}{\max yi(k) - \min yi(k)}$$

For Higher-the-Better (HB) criterion, the normalized data can be expressed as:

$$Xi\ (k) = \frac{yi(k) - \min yi(k)}{\max yi(k) - \min yi(k)}$$

For grey relation coefficient criterion, the data can be expressed as:

$$\xi i(k) = \frac{\min \Delta + \theta \max \Delta}{\Delta i\ (k) + \theta \max \Delta}; \quad 0 \leq \xi i(k) \leq 1$$

Table 9: calculation of GRC & GRG value for PVD

EXPERIMENT NO	GRC OF SR	GRC OF MRR	GRC OF TOOL LIFE	GRG	GRADE NO
1	0.800995025	0.340624605	0.428571429	0.5234	6
2	0.741935484	0.355972516	0.357142857	0.4850	14
3	0.759433962	0.368183682	0.344827586	0.4908	13
4	0.690987124	0.458319156	0.384615385	0.5113	8
5	0.676470588	0.500650437	0.344827586	0.5073	9
6	0.665289256	0.571610439	0.337078652	0.5247	5
7	0.380614657	1	0.361445783	0.5807	2
8	0.44109589	0.645114943	0.337078652	0.4744	16
9	0.348484848	0.833539604	0.333333333	0.5051	10
10	0.636363636	0.341834793	0.526315789	0.5015	11
11	1	0.344017367	0.384615385	0.5762	3
12	0.703056769	0.357010337	0.361445783	0.4738	17
13	0.654471545	0.399525434	0.434782609	0.4963	12
14	0.614503817	0.433886294	0.361445783	0.4699	19

15	0.646586345	0.453230148	0.348837209	0.4829	15
16	0.361797753	0.640209125	0.394736842	0.4656	20
17	0.333333333	0.731468911	0.348837209	0.4712	18
18	0.37704918	0.658840792	0.340909091	0.4589	22
19	0.688034188	0.338272225	1	0.6754	1
20	0.930635838	0.333333333	0.454545455	0.5728	4
21	0.636363636	0.355034265	0.405405405	0.4656	21
22	0.572953737	0.393974846	0.6	0.5223	7
23	0.511111111	0.399881253	0.4	0.4370	24
24	0.490853659	0.446766169	0.37037037	0.4360	25
25	0.366742597	0.5121673	0.476190476	0.4517	23
26	0.349240781	0.577491961	0.37037037	0.4324	26
27	0.359375	0.577491961	0.357142857	0.4313	27

Table 10: calculation of GRC & GRG value for CVD

EXPERIMENT NO	GRC OF SR	GRC OF MRR	GRC OF TOOL LIFE	GRG	GRADE NO
1	0.746543779	0.333333333	0.399662732	0.4932	13
2	0.648	0.358760429	0.34904271	0.4519	24
3	0.704347826	0.362759867	0.341991342	0.4697	18
4	0.642857143	0.49122807	0.36744186	0.5005	12
5	0.6328125	0.541488644	0.341007194	0.5051	11
6	0.620689655	0.652751423	0.336170213	0.5365	6
7	0.355263158	0.671125975	0.353204173	0.4599	21
8	0.416452442	0.718377088	0.336170213	0.4903	14
9	0.333333333	1	0.333333333	0.5556	3
10	0.606741573	0.342775801	0.484662577	0.4781	17
11	0.915254237	0.342775801	0.36744186	0.5418	4
12	0.870967742	0.361453017	0.353204173	0.5285	7
13	0.627906977	0.406825477	0.407917384	0.4809	15

14	0.584837545	0.434265104	0.351111111	0.4567	22
15	0.606741573	0.489430894	0.342981187	0.4797	16
16	0.346895075	0.683314415	0.375594295	0.4686	19
17	0.333333333	0.940992575	0.342981187	0.5391	5
18	0.375	0.817657046	0.338088445	0.5102	9
19	0.658536585	0.338677918	1	0.6657	1
20	0.822335025	0.333980583	0.422459893	0.5263	8
21	1	0.356002365	0.382875606	0.5796	2
22	0.551020408	0.41431521	0.552447552	0.5059	10
23	0.48502994	0.421642444	0.3792	0.4286	26
24	0.464183381	0.421642444	0.359635812	0.4152	27
25	0.357615894	0.560521415	0.444652908	0.4543	23
26	0.342494715	0.68080294	0.359635812	0.4610	20
27	0.345415778	0.626920073	0.348017621	0.4401	25

In grey relational analysis higher the grey relational grade of experiment says that the corresponding experimental combination is optimum condition for multi objective optimization and gives better product quality. From table 7 we get experiment 19 which has best multiple characteristic among 27 experiments due to its highest grey relation grade 0.6657. From table 8 We get experiment no 19 among 27 experiments which has best multiple characteristic due to its highest grey relation grade.

VI. CONCLUSION

In this dissertation work, we carried out turning on AISI 4140 alloy steel material by PVD & CVD cutting tool on CNC lathe. For turning we take three input parameters namely, cutting speed, feed rate & depth of cut. Influence of this parameters on output parameters namely, surface roughness & material removal rate and also find out the influence on tool life

SURFACE ROUGHNESS:

- Cutting speed, depth of cut & feed rate may create influence on material surface roughness & its removal rate during turning.
- By create turning on AISI 4140 with PVD cutting tool on CNC lathe, we found that cutting speed, feed rate & depth of cut may create significant effect on surface roughness but feed rate is the most significant parameter for surface roughness.
- The percentage contribution of (on the bases of ANOVA for PVD cutting tool) most significant parameter (feed) is 90.17% for surface roughness during turning.
- After the grey relation analysis we found better optimal process parameter for turning with PVD cutting tool are 120m/min cutting speed, 0.1 mm feed(mm/rev), 0.2 D.O.C.
- By create turning on AISI 4140 with CVD cutting tool on CNC lathe, we found that cutting speed, feed rate & depth of cut may create significant effect on surface roughness but feed rate is the most significant parameter for surface roughness.
- The percentage contribution of (on the bases of ANOVA for CVD cutting tool) most significant parameter (feed) is 91% for surface roughness during turning.
- After the grey relation analysis we found better optimal process parameter for turning with CVD cutting tool are 120m/min cutting speed, 0.1 mm feed(mm/rev), 0.2 D.O.C

MATERIAL REMOVAL RATE:

- With PVD & CVD cutting tool we create turning on AISI 4140 material, during experiment we found that as feed rate, d.o.c may going ton increase M.R.R goes on increase.
- After ANOVA (for PVD) we found most significant parameter which influence the material removal rate is the feed rate whose percentage contribution 86.7%.
- After ANOVA (for CVD) we found most significant parameter which influence the material removal rate is the feed rate whose percentage contribution 88.4%.

TOOL LIFE:

- As the turning creates at different speed, feed & depth of cut may do influence on tool life.
- After tool life analysis we found that as the cutting speed, feed rate & depth of cut are increases the tool life may gradually decrease.
- After ANOVA for PVD tool we found most significant parameter which influence the tool life is depth of cut whose percentage contribution is 44.2%.

After ANOVA for CVD tool we found most significant parameter which influence the tool life is depth of cut whose percentage contribution is 40%.

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