EFFECT OF COATING THICKNESS WITH CARBIDE TOOL IN HARD TURNING OF AISID3 COLD WORK STEEL

Gurjeet Singh[1], Harjit Singh[2], Jatinder Kumar[3]

[1] Research Scholar, Mechanical Engg. Dept, CTIEMT Jalandhar, Punjab, India. 144001
[2] Assistant Professor, Mechanical Engg. Dept., CTIEMT Jalandhar, Punjab, India. 144001
[3] Assistant Professor, Mechanical Engg. Dept., SSIET Jalandhar, Punjab, India. 144001

Abstract - *In modern days, turning process plays an essential role among material removal techniques. The cutting parameters and tool configuration plays as essential role in turning as these parameters decide the cost and time of process and in turn the quality of the product. The researchers have considered numerous aspects in turning of hard materials. In the present study, under unstable machining conditions the performance of multilayer coated carbide inserts with different thicknesses was experimentally investigated using a Taguchi L18 OA. The TiN/TiCN/Al2O3/TiN multi-layer coated inserts with different thickness are used for turning AISI D3 Die steel. Taguchi's mixed level Design of Experiments (DoE) is used to perform the experiments. The significance of the process parameters was evaluated using analysis of variance (ANOVA). Experiments were conducted on conventional turning centre and output responses like surface roughness and Material Removal Rate (MRR) are determined. For multi-response optimization, initially Signal-to-Noise (S/N) ratio is calculated and is applied to simultaneously optimize the output responses.*

Key Words: Multilayer coated inserts, Taguchi Method, AISI D3.

1. INTRODUCTION

Turning is a process of removing unwanted material from a rotating work piece to obtain a desired shape and size of component. Hard turning deals with turning materials with a hardness of above 45 HRC, typically in the hardness range of 58 to 68 HRC [1]. Hard turning operation is performed with coated carbide, cermet, ceramic, PcBN and PCD tools. In recent years, application of single-layer coated and multi-layered coated cutting tools are used for machining hardened materials to improve the tribological conditions at the tool-workpiece interface and at the tool-chip interface. In these days, the manufacturers are more concentrate on final product accuracy and quality rather than tool wear or cutting force [18]. Today 85% of carbide cutting inserts used in industry are coated, to obtain better results and great number of coating materials and methods are also available. By practical approach the type of tool wear mechanism should be identified and a suitable coating on cutting insert has to be selected by correlating the coating materials and their performance before choosing a cutting insert [2]. Coating does change the dimensions of the cutting tool. Coatings are often applied in multiple alternating layers since the hardness increases as its grain size decreases. Varaprasad et al. [1] optimized several machining parameters to minimize tool wear during the turning of AISI D3 steel with different Al_2O_3/TiC mixed ceramic tools. Similarly Varaprasad et al. [2] investigated the effect of machining parameters on tool wear and nodal temperature during turning of same material using CC6050 ceramic inserts, and reported that the RSM design is an effective way of determining the optimal cutting parameters for achieving low tool wear and low Nodal temperature. Dureja et al. [3] reported cutting speed and federate are significant parameters to minimize tool wear and roughness in turning AISI D3 using TiSiN-TiAlN coated carbide tools. Senthilkumar et al. [4] used hybrid Taguchi-Grey relational technique and cuckoo search algorithm for multi-criteria optimization in hard turning AISI D3. Alaattin Kacal et al. [5] conducted experiments on high speed turning of AISI S1 (60WCrV8) Cold Work Tool Steel with ceramic and CBN cutting tools. Results revealed that CBN cutter exhibited a better performance than the ceramic cutter. Bouchelaghem et al. [6] Experimental investigation and Performance analysis of CBN insert in hard turning of cold work tool steel (D3). The results indicated that CBN is resistant to wear despite of aggressiveness of AISI D3 steel. Wang [7] investigated the effect of the multi-layer hard surface coating of cutting tools on the cutting forces in steel turning with different commercially available carbide inserts and tool geometries over a range of cutting conditions. Bouzakis et al. [8] worked on failure mechanism of physically vapor deposited TiAlN coated hard metal cutting inserts in turning. The results show that a progressive local coating decomposition occurs while the cutting forces remain practically stable. Li et al. [9] studied the tool wear and cutting force variation in the end milling of Inconel 718 with coated carbide inserts. The experimental result showed that significant flank wear was the predominant failure mode affecting the tool life. More et al. [10] experimented and analyzed the effect of cutting speed and feed rate on tool wear, surface roughness and cutting forces of the CBN-TiN coated carbide inserts in turning AISI4340 hardened steel. Quian et al. [11] performed numerical simulation of high speed orthogonal machining to study the finish hard turning process as a function of cutting speed, feed, cutter geometry, and work piece hardness using AISI 52100 bearing steel AISI

H13 hot work tool steel, AISI D2 cold work steel, and AISI4340 low alloy steel as workpiece and CBN insert as cutting tool. Kharis and Lin [12] worked on wear mechanism and tool performance of TiAlN coated inserts during machining of AISI 4140 steel and investigated the tribological influences of PVD-applied TiAlN on the wear of cemented carbide inserts and the microstructure wear behaviors of the coated tools under dry and wet machining. Nalbant et al. [13] experimented the effects of uncoated, PVD-and CVD-coated cemented carbide inserts and cutting parameters on surface roughness in CNC turning and its prediction using artificial neural networks on AISI 1030 steel at variable cutting speeds & feeds and at constant depth of cut without using cooling liquids. The experimental values and ANN predictions were compared by statistical error analyzing methods and reported that the surface roughness had been determined by the ANN within acceptable accuracy. Gill et al. [14] experimented on wear behavior of cryogenically treated TiAlN coated tungsten carbide inserts in orthogonal turning. Major outcome of the study included a substantial decrease in tool life of deep cryogenically treated inserts as compared to untreated inserts indicating the destructive effect of deep cryogenic temperature (-196°c) on TiAlN coated inserts which is further supported by VDI-3198 indentation test. Darshan et al. [15] analyzed and optimized Ceramic Cutting Tool in Hard Turning of En-31 using Factorial Design. They investigated the effects of machining parameters on flank wear and surface roughness with 95% of confidence. Andriya et al. [16] experimented on dry machining of Ti-6Al-4V material using PVD coated TiAlN tools. The experimental analysis was carried out using Response Surface Methodology (RSM). The detailed experiments under dry conditions using the PVD coated TiAlN tools. Results revealed that 2FI (2 Factor Interaction) model was found to be fitted for cutting force prediction under dry cutting environment.

2. EXPERIMENTAL CAMPAIGN

2.1 Work piece material

The experiments were performed on conventional Lathe. The orthogonal turning was performed on cylindrical bar of AISI D3 with initial diameters of 60 mm and length around 400 mm. initially, the work piece diameter reduced to 58 mm to remove the rust layer and make the wok piece with uniform diameter throughout. The full length work piece was divided into seven parts of 50 mm size and remaining portion was inserted in the lathe jaw.

Table -1: Chemical composition of AISI D3 tool steel

C	Si	Mn	P	S	Cr	Ni	Mo
2.06	0.55	0.44	0.03	0.05	11.09	0.27	0.20
Al	Cu	Zn	Fe				
0.003	0.13	0.27	84.87 16				

Table -1 illustrated the chemical composition of AISI D3 tool steel.

2.2 Cutting tool inserts

In the experiments, The TiN/TiCN/Al2O3/TiN multi-layered coated of ISO designated carbide inserts with different thickness has been selected based upon the previous literature.

2.3 Experimental procedure

The experiments were performed on AISI D3 cold work steel under dry condition. The tests were conducted using conventional Lathe Centre LB 17/20 Machine (Chamundi Machine Tools Limited, India) which have a maximum spindle speed of 3000 rpm and maximum power of 7.5 kW. A hole was drilled on the face of work piece to allow it to be supported at the tailstock. Prior to actual machining, the rust layers were removed by a new cutting insert in order to minimize any effect of inhomogeneity on the experimental results.

2.4 Design of experiments

The main purpose of this study was to illustrate the influence of several process parameters viz. cutting speed, feed and coating thickness on surface roughness and material removal rate during turning of AISI D3 tool steel. The experiments were performed as per Taguchi L18 OA (1*2, 2*3) which helps in reducing the total number of experiments. The input parameters were selected based upon the pilot study and review of previous literature. The control log of experiments, experimental set up and conditions are given in forthcoming tables.

Table -2: Input parameters and their levels

Parameter / Level	Level 1	Level 2	Level 3
Cutting Speed (m/min)	120	180	240
Feed Rate (mm/rev)	0.1	0.3	-
Coating thickness (μm)	5	8	14

Table -2 illustrated the various input parameters and their levels. The input parameters were selected on the basis of pervious literature, while their levels on the outcomes of pilot study.

2.5 Analysis of surface roughness

The surface roughness of the work materials was measured using surface roughness testing machine.

Table -3: Observation of final experimentation for Surface Roughness and S/N ratio

S. No.	Feed (mm/rev)	Cutting Speed (m/min)	Coating Thickness (μm)	Ra (μm)	S/N Ratio
1	0.1	120	5	0.85	1.41162
2	0.1	120	8	0.83	1.61844
3	0.1	120	14	0.88	1.11035
4	0.1	180	5	0.88	1.11035
5	0.1	180	8	0.85	1.41162

6	0.1	180	14	0.9	0.91515
7	0.1	240	5	0.94	0.53744
8	0.1	240	8	0.87	1.20961
9	0.1	240	14	0.95	0.44553
10	0.3	120	5	0.92	0.72424
11	0.3	120	8	0.89	1.0122
12	0.3	120	14	0.97	0.26457
13	0.3	180	5	1.01	-0.08643
14	0.3	180	8	0.88	1.11035
15	0.3	180	14	0.94	0.53744
16	0.3	240	5	0.97	0.26457
17	0.3	240	8	0.88	1.11035
18	0.3	240	14	1.03	-0.25674

The surface roughness was analyzed using Taguchi method (L18) using Minitab software. Table 03 indicated the values of surface roughness and corresponding S/N ratio for the different experiments. Figure 01 illustrated the main effect plots for surface roughness with S/N ratio of smaller is better. The figure also indicated the best setting for minimum surface roughness as f1-s1-t2 i.e. the AISI D3 material turned with a coating thickness around 8 micron, having feed about 0.1 mm/m at 120 rpm will give minimum surface roughness.

Main effects plot for S/N ratio for Surface Roughness

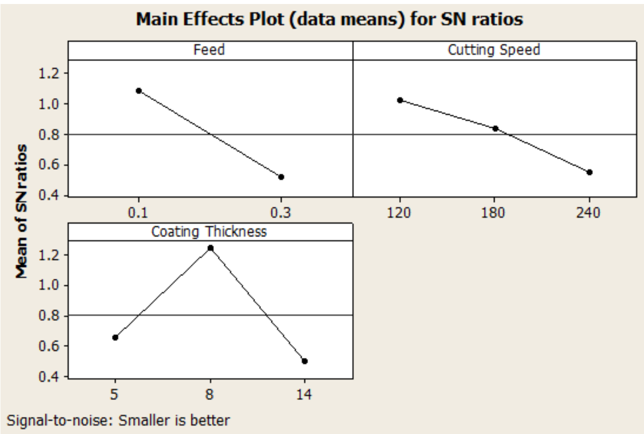

Fig -1: Main effects plot for Surface Roughness

The Table -4 illustrated that federate and coating thickness were the most significant parameters with 95% confidence level to obtained minimum surface roughness. Moreover, cutting speed and interactions between various parameters are insignificant ones.

Table -4: ANOVA table for Surface Roughness

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Cont.
Feed (mm/rev)	1	1.439 1	1.43 91	1.43 91	24.57	0.008	30.14
Cutting Speed (m/min)	2	0.676 0	0.67 60	0.33 798	5.77	0.066	14.16
Coating Thickness (µm)	2	1.837 7	1.83 77	0.91 883	15.69	0.013	38. 49
Feed (mm/rev)*Cutting Speed (m/min)	2	0.102 5	0.10 25	0.05 127	0.88	0.484	2.15
Feed (mm/rev)*Coating Thickness (µm)	2	0.123 4	0.12 34	0.06 170	1.05	0.429	2.58
Cutting Speed (m/min)* Coating Thickness (µm)	4	0.361 4	0.36 14	0.09 035	1.54	0.342	7.57
Residual Error	4	0.234 2	0.23 42	0.05 856			4.91
Total	17	4.774 3					

Percentage Contribution of Input Parameters for minimum Surface Roughness

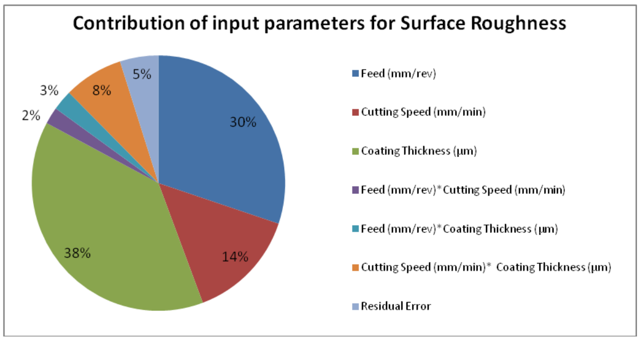

Fig -2: Contribution of Input Parameters for minimum Surface Roughness

On the basis of ANOVA Table -4, Fig. -2 illustrated that coating thickness contributed highest to achieve minimum surface roughness, followed by feed and cutting speed. Moreover, the interactions of input parameters indicated no much contribution for the same.

2.6 Analysis of Material Removal Rate

The analysis of material removal rate has been carried out using same software as that of surface roughness. The material removal rate was calculated using the following relation:

$$MRR = \frac{\pi/4\,(D_i^2 - D_f^2) * \text{Length of workpiece}}{\text{Machining Time}}$$

Where: Di initial diameter of the workpiece
Df final diameter of the workpiece

Table -5 indicated the values of material removal rate and corresponding S/N ratio for the different runs.

Table -5: Observation of final experimentation for MRR and S/N ratio

S. No.	Feed (mm/rev)	Cutting Speed (m/min)	Coating Thickness (µm)	MRR (mm^3/min)	S/N Ratio
1	0.1	120	5	370.28	51.3706
2	0.1	120	8	368.59	51.3308
3	0.1	120	14	372.85	51.4307
4	0.1	180	5	501.91	54.0126
5	0.1	180	8	500.35	53.9854
6	0.1	180	14	506.68	54.0947
7	0.1	240	5	1019.81	60.1704
8	0.1	240	8	1032.97	60.2818
9	0.1	240	14	1047.03	60.3992
10	0.3	120	5	1268.28	62.0643
11	0.3	120	8	1288.58	62.2022
12	0.3	120	14	1331.18	62.4847
13	0.3	180	5	1505.35	63.5527
14	0.3	180	8	1482.51	63.4199
15	0.3	180	14	1539.52	63.7477
16	0.3	240	5	2893.62	69.2288
17	0.3	240	8	3120.57	69.8847
18	0.3	240	14	3247.94	70.2322

Fig -3 illustrated the main effect plots for MRR with S/N ratio of larger is better. The figure also indicated the best setting for maximum MRR f2-s3-t3 i.e. the AISI D3 material turned with a coating thickness around 14 micron, having feed about 0.3 mm/m at 240 rpm will give maximum material removal rate.

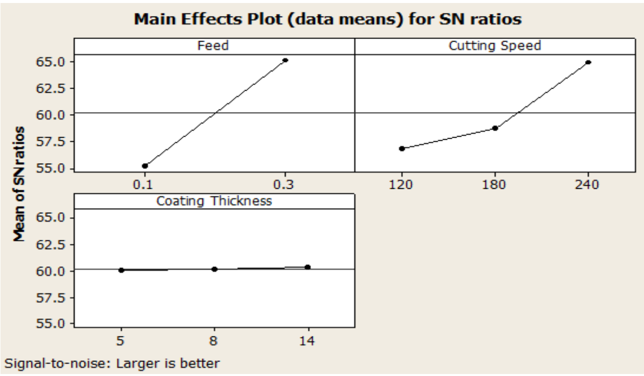

Fig -3: Main effect plots maximum MRR

The table 6 indicated that all input parameter along with interaction between feedrate and cutting speed were the most significant parameters with 95% confidence level in order to achieve maximum material removal rate.

Table -6: ANOVA table for MRR

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Cont.
Feed (mm/rev)	1	447.415	447.415	447.415	24559.42	0.000	66.72
Cutting Speed (mm/min)	2	220.651	220.651	110.325	6055.96	0.000	32.90
Coating Thickness (µm)	2	0.339	0.339	0.170	9.31	0.031	0.05
Feed (mm/rev)*Cutting Speed (mm/min)	2	1.831	1.831	0.916	50.26	0.001	0.27
Feed (mm/rev)*Coating Thickness (µm)	2	0.130	0.130	0.065	3.56	0.129	0.02
Cutting Speed (mm/min)* Coating Thickness (µm)	4	0.161	0.161	0.040	2.21	0.230	0.02
Residual Error	4	0.073	0.073	0.018			0.01
Total	17	670.600					

Percentage contributions of input parameters for Material removal rate

On the basis of ANOVA Table -6, Fig.-4 illustrated that federate contributed highest to achieve maximum MRR, followed by cutting speed. Moreover, the coating thickness along with interactions indicated negligible contribution for the same

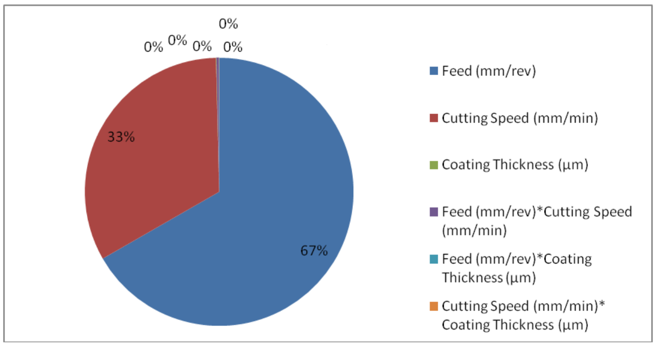

Fig -4: Contributions of input parameters maximum MRR

3. CONCLUSION

On the basis of experimental observations made on turning of AISI D3, following conclusions can be drawn.

- Optimized setting of input parameters for the minimum surface roughness is Feed- 0.1mm/rev, speed- 120 rpm and coating thickness 8 µm. The coating thickness has highest contribution (38.49%) in surface roughness followed by feed rate (30.14%) and cutting speed (14.16%). The ANOVA table (Table 07) indicates that feed and coating thickness are most significant parameters to achieve minimum surface roughness. Moreover speed and interactions between input parameters are insignificant.
- Optimized setting of input parameters for the maximum MRR is Feed- 0.3mm/rev, speed- 240 rpm and coating thickness 14 µm. The feed contributes highest percentage (66.72%) followed by cutting speed (32.90%). To achieve maximum MRR. Moreover, the coating thickness and

interactions between input parameters shows no significant contribution. The ANOVA table for MRR (Table 10) indicates that feed, cutting speed coating thickness were most significant parameters to achieve maximum MRR.
- The confirmatory experiments were conducted and result of study shows percentage improvement in tensile strength, elongation and hardness is 4.46%, 6.25% and 7.89% respectively.

4. SCOPE FOR FUTURE WORK

Present work can be extended by:-
- Further studies may be focused on more number of input parameters and their levels.
- In the present work, analysis was carried out for AISI D3. Further studies may be focused on other types of tool materials.
- In this study analysis was carried out using three values coating thickness of TiN/TiCN/Al2O3/TiN on carbide tool. It may be extended for other types of coatings and for their different thickness values.
- Experiments were conducted under dry condition. It may be extended by using different lubrication techniques and lubricants.

REFERENCES

[1] Varaprasad Bh, Rao. Srinivasa, Vinay P.V (2014) , “Effect of Machining Parameters on Tool Wear in Hard Turning of AISI D3 Steel” Journals of Procedia Engineering , pp 338-345.

[2] Varaprasad Bhemuni, Rao Chelamalasetti Srinivasa, Kondapalli Siva Prasad (2014), “Effect of Machining Parameters on Tool Wear and Nodal Temperature in Hard Turning of AISI D3 Steel.” Journal of open access library. pp 1-12.

[3] Dureja J.S., Singh Rupinder & Bhatti Manpreet S. (2014), “Optimizing flank wear and surface roughness during hard turning of AISID3 steel by Taguchi and RSM methods” Journal of manufacturing research” Vol. 2, No. 1, 767–783.

[4] Senthilkumar N, Tamizharasan T, Anandakrishnan V (2014), “An hybrid Taguchi-Grey relational technique and cuckoo search algorithm for multi-criteria optimization in hard turning AISI D3” journal of Advanced Engineering Research ISSN: 2393-8447 Volume 1, Issue 1, 2014, pp.16-31

[5] Kaçal Alaattin, Yıldırım Ferhat,(2013) “High Speed Hard Turning of AISI S1 (60WCrV8) Cold Work Tool Steel” journal of Acta Polytechnica Hungarica Vol. 10, No. 8.

[6] Bouchelaghem H., Yallese M. A, Mabrouki T., Amirat A., and Rigal J. F. (2010), “Experimental investigation and Performance analysis of CBN insert in hard turning of cold work tool steel (D3)” Machining Science and Technology: An International Journal, 14:4, pp 471-501.

[7] Wang J., (2000) “The effect of the multi-layer surface coating of carbide inserts on the cutting forces in turning operations”, Journals of Materials Processing Technology, pp.114-119

[8] Bouzakis K.-D, Michailidis N,Vidakis N, Efstathiou K., (2001) “Failure mechanism of physically vapor deposited coated hard metal cutting inserts in turning”, Wear ,Vol. 248, pp20-37

[9] Li H.Z., Zeng H.Chen X.Q.,(2006) An experimental study of tool wear and cutting forces variation in the end milling of Inconel 718 with coated carbide inserts,’’ Journals of Materials Processing Technology, Vol.180, pp 296-304

[10] More Abhijit S., jiang Wenping,Brown W.D. and Malshe Ajay P.(2006), “Tool wear and machining performance of Cbn-TiN coated carbide inserts and PCBN compact inserts in turning AISI 4340 hardened steel” , Journals of Materials Processing Technology, Vol.180, pp 253-262.

[11] Qian Li, Hossan Mohammad Robiul(2007) ‘’Effect on cutting forces in turning hardened tool steel with CBN inserts”, Journals of Materials Processing Technology, Vol.-191, pp 274-278.

[12] Kharis Samir K.,Lin Y.J.(2007),”Wear mechanism and tool performance of TiAlN PVD coated inserts during machining of AISI 4140 steel,” Wear , Vol.262, pp 64-69

[13] Nalbant Muammer, Gokkaya Hasan, Toktas Ihsan and Sur Gokhan (2009), “The experimental investigation of the effects of uncoated, PVD-and CVD-coated cemented carbide inserts and cutting parameters on surface roughness in CNC turning and its prediction using artificial neural networks”,Robotics and Computer Integrated Manufacturing, Vol-25, pp 211-223.

[14] Gill Simranpreet Singh, Singh Jagdev, Singh Harpreet, Singh Rupinder(2011), “Investigation on wear behavior of cryogenically treated TiAlN coated tungsten carbide inserts in turning”,International Journal of Machine Tools & Manufacture 51(2011), pp 25-33

[15] Darshan Chetan, Singh Lakhvir & Sethi A.P.S.(2012), “Analysis and optimization of Ceramic Cutting Tool in Hard Turning of En-31 using Factorial Design” International Conference on Mechanical and Industrial Engineering(ICMIE 2012), pp40-45

[16] Andriya Narasimhulu, Member,IAENG, Rao P. Venkateswara, and Sudarsan Ghosh(2012), Dry Machining of Ti-6Al-4V using PVD Coated TiAlN Tools, Proceedings of the World Congress on Engineering 2012, Vol III,London,U.K.

[17] Arsecularatne J.A., Zhang L.C.,Montross C,Mathew P.(2006), On machining of hardened AISID2 steel with PCBN tools, Journals of Materials Processing Technology, Vol.-171, pp 244- 252.

[18] Van Luttervelt, C.A., Childs, T.H.C., Jawahir,I.S.; Klocke, F., Venuvinod, P.K. (1998), Present situation and future trends in modeling of machining operations – progress report of the cirp working group “modeling of machining operations”. Annals of CIRP, Vol. 47, pp 587–626