

Evaluation of dry cutting performance of coated carbide tool on 17-4PH stainless steel

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Abstract. This paper presents dry turning performance of coated carbide Tool on 17-4PH stainless steel bright bar (Aerospace metal), which is high strength and extremely corrosion resistant. The presence of different alloying elements and their precipitation hardening makes it a difficult to machine material. 17-4PH metal available at different properties based on heat treatment conditions. But the base metal coming from mill is 17-4PH condition A, which is having hardness of 35RC. Cutting Tool Insert (**KCP10B**) is a specially engineered cobalt enriched carbide grade with thick MTCVD-TiCN-Al₂O₃-TiOCN coating for maximum wear resistance. The input parameters considered for this experiment are Velocity (V), feed (F) and Depth of cut (d). In this study, the influence of cutting parameters are aimed when turning 17-4PH condition A SS bright bar with KCP10B tool on a CNC Lathe (Maxturn plus+) without coolants. It is optimized that the Material Removal Rate (MRR) and cutting Forces (F₁, F₂) generated during dry turning of hardened steel (17-4PH) using carbide insert in a possible range of selected parameters by using TAGUCHI and ANOVA.

Key Words: 17-4PH metal, Coated Carbide tool, CNC Dry Turning, MRR, Cutting Force, Feed Force and TAGUCHI.

1. Introduction

Dry machining technique gives lot of benefits to the metal cutting industries such as primarily the usage of coolant lubricants completely reduced and the secondary is that problems associated with environment and health will be reduced. Dry machining is considered as the best approach to eliminate the use of cutting fluids in manufacturing enterprises and thus reduce the machining costs and ecological hazards [1, 2]. In order to improve machinability *a minimum quantity lubricant (MQL)* could be penetrated into the cutting zone. Although MQL reduces the coolant lubricants (CLs) consumption, it still uses them in the form of mist or droplets which increases health hazards for the workers [3]. However dry cutting is not applicable in all metal cutting operations mainly due to excessive tool wear or low surface quality. To make use of all the benefits of dry cutting performance, experimentation needs to be carried out on metals with available cutting tools to identify suitability of dry machining of particular metal, tool and its cutting parameters combination. Based on this idea, dry machining tests are performed on hard steel 17-4PH condition A with coated carbide tool to evaluate dry turning results using CNC Lathe machine



2. Work piece, Tool Materials and Machine

Metal selection is very important criteria for research on machining with tool and metal combination to evaluate corresponding machining performance. This selection will be depends on various criteria such as the ease of manufacturing, physical properties, Area of applications, machining difficulty etc., of a metal. 17-4PH stain less steel is most popular martensitic PH steel and have excellent corrosion resistance, high strength and high hardness. Precipitation-hardened (PH) stainless steels have been widely used in aerospace, chemical, pulp and paper industries, food processing, petro chemical, structural materials and related applications in marine environments, power plants (light-water and pressurized water reactors), and general metal working industries because of their good fabricating characteristics and can be age hardened by a single step at low temperature treatment[4].

A cemented carbide tool with a MTCVD-TiCN-Al₂O₃-TiOCN coating for maximum wear resistance was used in this tests and which is made from Kennametal [5]. The insert type or ISO catalogue Number TNMG160408FW and its grade is KCP10B. The type of the tool holder used in these tests for holding cutting insert is MTJNL2525M16.

A CNC Turning Centre (Model MAXTURN++) was used in this experiment, which was made by the MTAB Company, India. Dry cutting was carried out in this experiment.

3. Experimental procedure

For finding optimum parameters for Higher MRR and Lower cutting forces we used Taguchi method for design of experiments and ANOVA. The parameters selected for experimentation are Velocity (V), Feed (f) and DOC (d) as these are highly influence parameters for machining operations. **Work piece Specifications:** 17-4PH SS Aerospace Metal, Initial Diameter=19.4mm and machining length = 60mm.

Table 1.Composition of 17-4PH (Aerospace metal)

general composition of 17-4PH	Selected 17-4PH metal composition
Carbon-0.07%	Carbon-0.07%
Manganese-1.00%	Manganese-1.00%
Sulphur-0.03%	Sulphur-0.03%
Phosphorous-0.040%	Phosphorous-0.04%
Silicon-1.00%	Silicon-1.00%
Tantalum and Colombium-0.15-0.45%	Tantalum and Colombium-0.13%
Chromium-15-17.50%	Chromium-15.68%
Nickel-3.00-5.00%	Nickel-3.57%
Copper-3.00-5.00%	Copper-3.58%

Table 2. Mechanical properties of 17-4PH Condition A

Properties	value
Shear modulus	70GPA
Elastic Modulus	190-210GPA
Poission's Ratio	0.27-0.30
Hardness Brinell	352
Hardness Rockwell	36

Table 3. The range of parameters selected Cutting data recommendations for hard turning of SH4 Turning Insert from Ceram Tech industry

Parameter	Range
Velocity(v)	80-180m/min
Feed(f)	0.1- 0.3mm
Depth of cut(d)	0.1 - 0.5mm

The same cutting data used for dry machining of 17-4PH metal with KCP10B insert for evaluating Cutting forces and MRR using TAGUCHI and ANOVA.

An experiment with 3 parameters and 3 levels of each parameter ($P = 3$ and $L = 3$), two Taguchi arrays for this case are available

1. 6-run array for testing each level of each parameter *twice*
2. 9-run array for testing each level of each parameter *three times*

The 9-run array is more desirable (if cost and time permit) because for each level of any one parameter, *all three levels of the other parameters are tested*. Of course, either array here costs less to run than a full factorial analysis, since the number of required runs for a full factorial analysis is $N = L^P = 3^3 = 27$. We call a Taguchi array an **orthogonal array** (some authors call it a **full orthogonal array**) when *for each level of a particular parameter, all L levels of each of the $(P-1)$ other parameters are tested at least once*. The required number of runs is therefore $3 (L = 3 \text{ levels}) * 3$ (each level of each parameter tested 3 times) = 9 required runs for this orthogonal array. Here we used Taguchi Orthogonal array (L9) as the degree of freedom ($3*(3-1) = 6$) is near to L6, but L9 Array is more desirable as explained above.

Table 4. Cutting Parameters and its levels

Parameter	Level-1	Level-2	Level-3
Speed ,V m/min	80	130	180
Feed ,f mm	0.1	0.2	0.3
Depth of cut(Doc),d mm	0.1	0.3	0.5

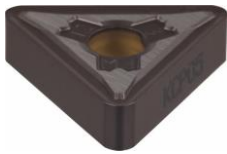
By using Taguchi L9 design, the experiments can be written by using above levels as shown in 'Table 5' and all the 9 experiments were performed. The responses such as material removal rate (MRR) measured in mm^3/sec and Force in Newtons (N) for Each and every experiment. The MRR is measured by using formula $f*d*v$. The forces are measured by using Dynamometer along with DAQ device and force responses taken by lab view software.

4. Results and Discussions

The below table shows that all experiments according to Taguchi L9 design and the corresponding responses such as Material Removal Rate (MRR), Cutting Force (F1) and Feed force (F2).

Table 5. Shows L9 Taguchi design and corresponding responses

Velocity (V)	Feed(f)	Doc(d)	DIA (D)	SPEED N	MRR(mm ³ /s)	F1	F2
80	0.1	0.1	19.4	1305	13.33	59.071	56.867
80	0.2	0.3	19.1	1312	80	168.193	165.343
80	0.3	0.5	18.6	1333	200	228.201	309.852
130	0.1	0.3	18.3	2224	65	246.990	165.527
130	0.2	0.5	17.8	2261	216.66	418.228	323.172
130	0.3	0.1	17.7	2324	65	281.204	226.975
180	0.1	0.5	17.2	3237	150	271.850	250.250
180	0.2	0.1	17.1	3331	60	111.671	119.890
180	0.3	0.3	16.8	3350	270	143.296	179.804

**Figure 1.** Coated carbide tool
TNMG160408FW**Figure 2.** Tool holder used for
holding cutting insert and its
specification is MTJNL2525-M16**Figure 3.** Shows the Surface Roughness of
17-4 PH metal at Lower cutting speeds**Figure 4.** Shows smooth finish at higher cutting
speeds

4.1 Material Removal Rate (MRR) Response verses velocity, feed and depth of cut

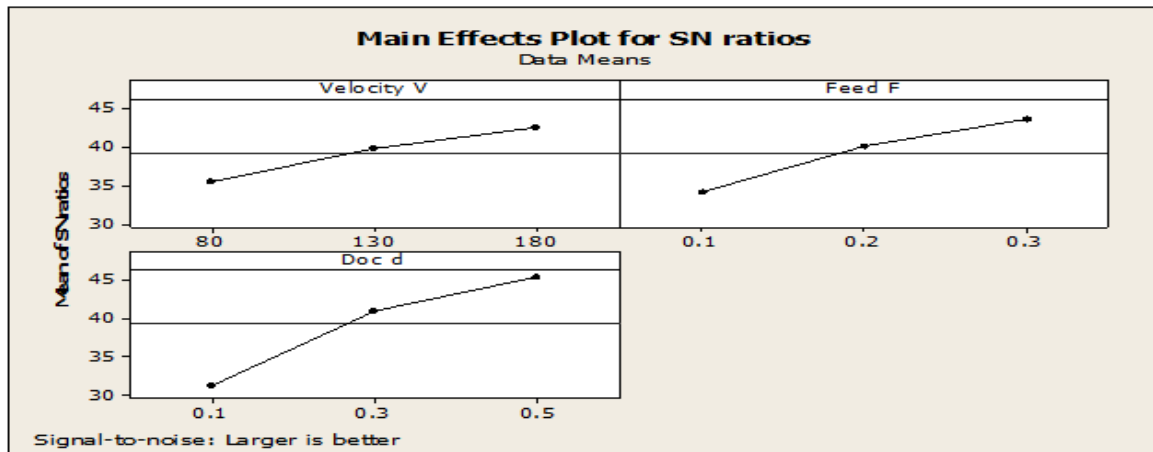


Figure 5. Shows Signal to Noise Ratios for MRR verses velocity, feed and depth of cut

Table 6. Response Table for Signal to Noise Ratios FOR HIGH MRR (Larger is better)

Level	A=Velocity V	B=Feed F	C=Doc d
1	35.53	34.09	31.44
2	39.74	40.11	40.98
3	42.57	43.64	45.42
Delta	7.04	9.542	13.979
Rank	3	2	1

Based upon the response table for MRR we get the optimal setting as per S/N ratio as A3B3C3 it

Means that Velocity =180, feed=0.3, depth of cut = 0.5

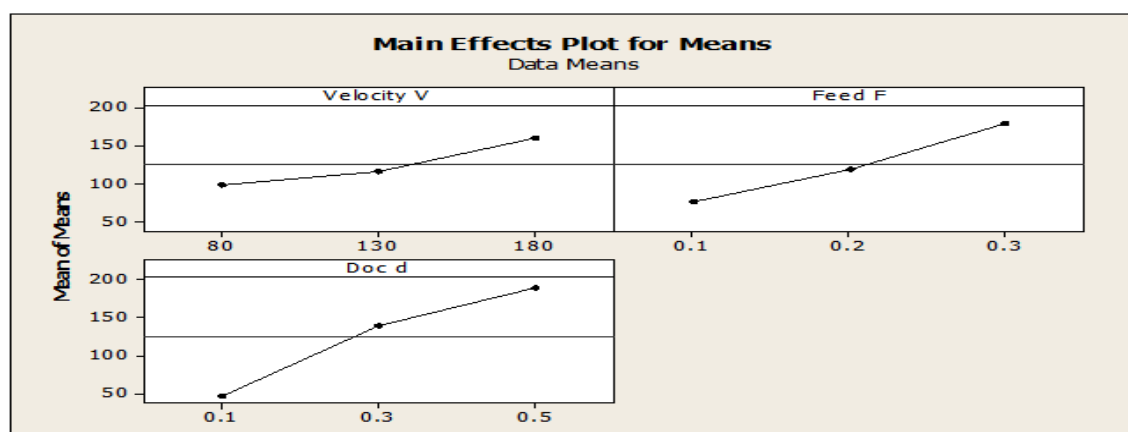


Figure 6. Shows means of means for MRR verses velocity, feed and depth of cut.

Table 7. Response table for Means of means for HIGH MRR.

Level	Velocity V	Feed F	Doc d
1	97.78	76.11	46.11
2	115.55	118.89	138.33
3	160.00	178.33	188.89
Delta	62.22	102.22	142.78
Rank	3	2	1

Based upon the response table for MRR we get the optimal setting as per Means of means plot as A3B3C3 it Means that Velocity =180, feed=0.3, depth of cut = 0.5.

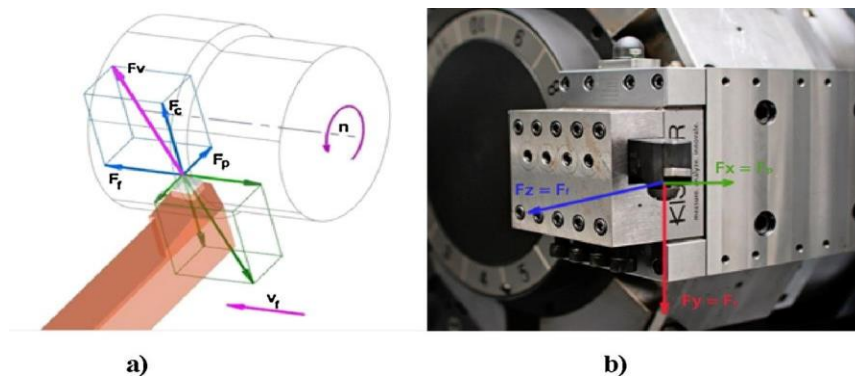


Figure 7. (a) Cutting forces components during turning. (b) Three-component piezoelectric dynamometer in a CNC lathe and component force measurement system.



Figure 8. Shows the complete set up including Dynamometer, DAQ instruments and

Lab view software for identifying Force responses.

4.2 Taguchi Force Analysis

By using the Force responses F1 and F2, the parameters are analyzed by Taguchi method and the results are optimized. The cutting forces in the machining always trying to be reduced to reduce power requirements, so that the efficiency of machining will be improved. For analyzing the forces, by using Taguchi which is always smaller the better for S/N ratios.

4.2.1 Cutting Force (F1) response versus velocity, feed and depth of cut

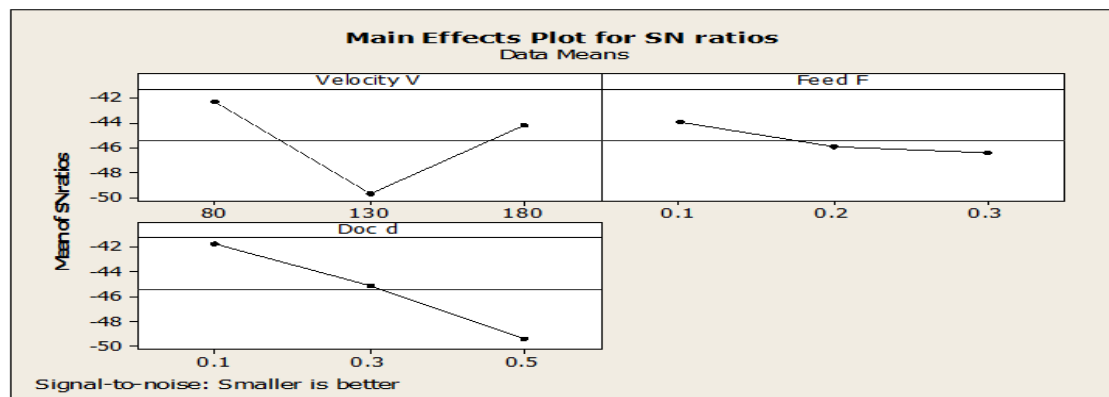


Figure 9. Shows Signal to Noise Ratios for F1 Force.

Table 8. Response Table for Signal to Noise Ratios (Smaller is better) for F1

Level	A	B	C
1	-42.37	-43.99	-41.79
2	-49.75	-45.97	-45.16
3	-44.26	-46.42	-49.43
Delta	7.38	2.43	7.64
Rank	2	3	1

By analyzing the S/N response table for low cutting force in X-direction **F_x or cutting force F1**, the optimal setting comes as A2B3C3 i.e. Velocity=130, feed=0.3 and depth of cut=0.5 and by analyzing the Rank of the parameters the most significant one for influencing F_x force is Depth of cut (d) then feed (f) and speed (v).

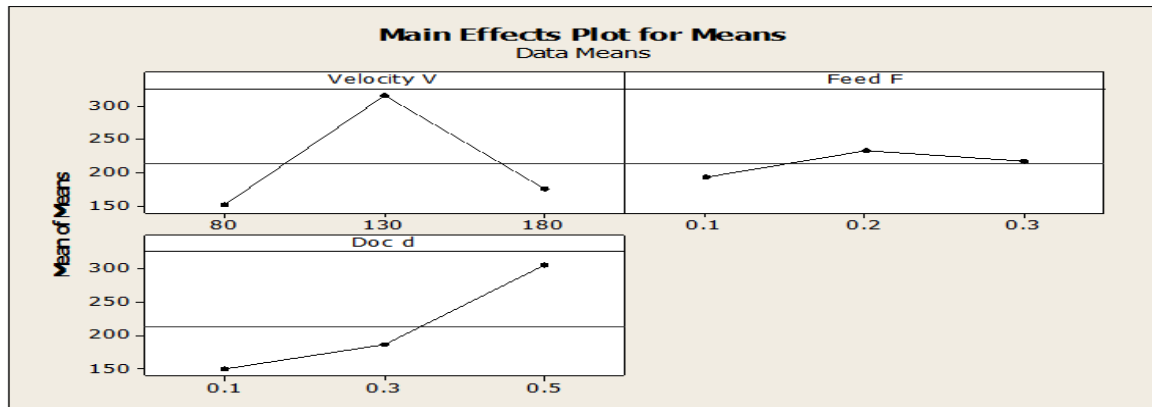


Figure 10. Shows means of means for F1 force

Table 9. Response table for Means of F1

Level	A=velocity V	B=feed F	C= doc d
1	151.8	192.6	150.6
2	315.5	232.7	186.2
3	175.6	217.6	306.1
Delta	163.7	40.1	155.4
Rank	1	3	2

4.2.2 Feed force (F2) response versus velocity, feed and depth of cut

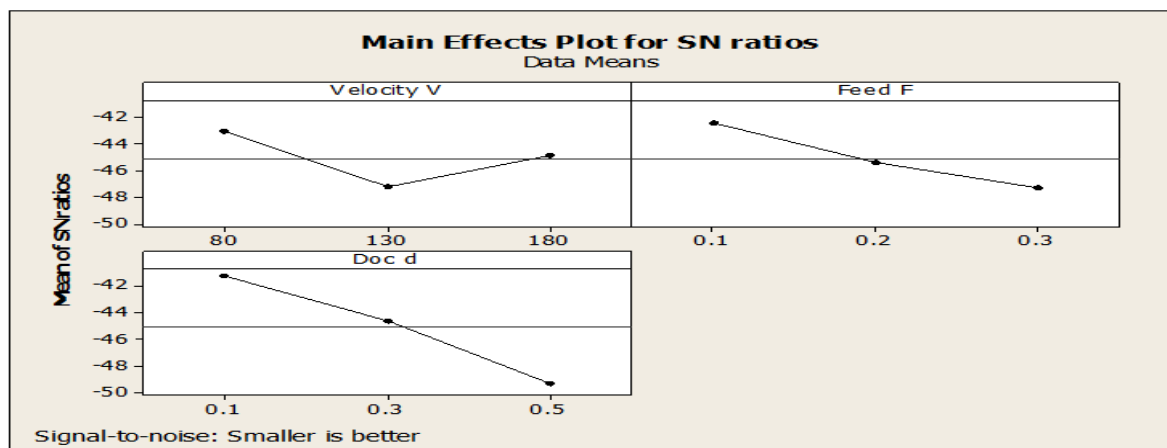
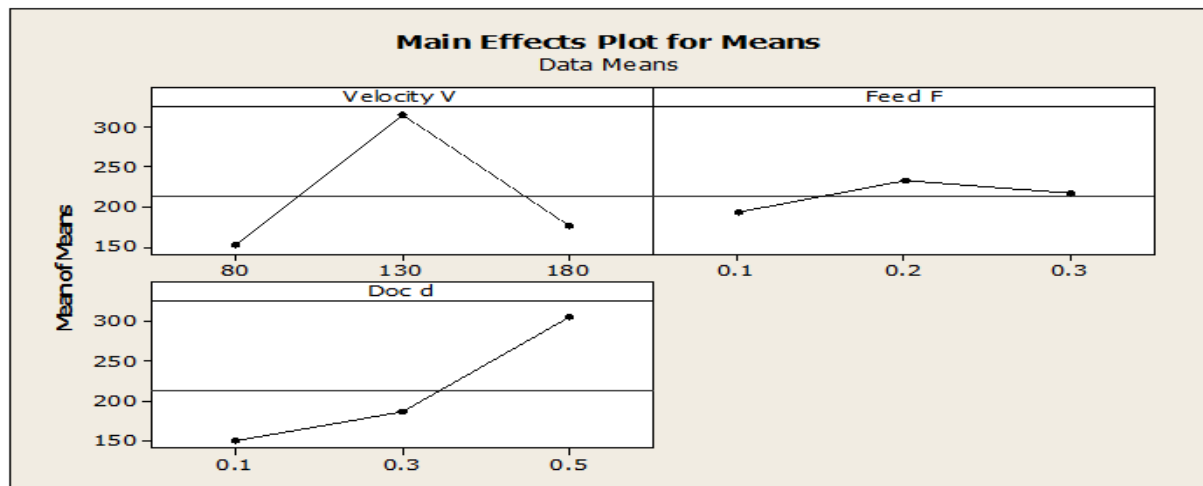


Figure 11. Shows Signal to Noise Ratios for F2 Force.

Table 10. Response Table for Signal to Noise Ratios (Smaller is better)

Level	A=Velocity V	B=Feed F	C=Doc d
1	-43.10	-42.48	-41.26
2	-47.23	-45.38	-44.61
3	-44.88	-47.35	-49.33
Delta	4.13	4.87	8.06
Rank	3	2	1

By analyzing the S/N response table for low cutting force in X-direction F_z , the optimal setting comes as A2B3C3 i.e. Velocity=130, feed=0.3 and depth of cut=0.5 and by analyzing the Rank of the parameters the most significant one for influencing F_x force is Depth of cut(d) then feed(f) and speed(v).

**Figure 12.** Shows means of means for F_2 force**Table 11.** Response Table for Means

Level	Velocity V	Feed F	Doc d
1	177.4	157.5	134.6
2	238.6	202.8	170.2
3	183.3	238.9	294.4
Delta	61.2	81.3	159.8
Rank	3	2	1

Table 12. All the values of parameters and responses of trial experiments are tabulated below

Velocity V	Feed f	doc d	snra1	mean1	snra2	mean2	snra3	mean3
80	0.1	0.1	22.4966	13.33	-35.4275	59.071	-35.0972	56.867
80	0.2	0.3	38.0618	80.00	-44.5162	168.193	-44.3677	165.343
80	0.3	0.5	46.0206	200.00	-47.1664	228.201	-49.8231	309.852
130	0.1	0.3	36.2583	65.00	-47.8536	246.990	-44.3774	165.527
130	0.2	0.5	46.7156	216.66	-52.4283	418.228	-50.1887	323.172
130	0.3	0.1	36.2583	65.00	-48.9804	281.204	-47.1196	226.975
180	0.1	0.5	43.5218	150.00	-48.6866	271.850	-47.9675	250.250
180	0.2	0.1	35.5630	60.00	-40.9588	111.671	-41.5757	119.890
180	0.3	0.3	48.6273	270.00	-43.1247	143.296	-45.0960	179.804

Where SNRA stands for Signal to Noise ratio and MEAN for mean values corresponding to MRR, F1 and F2. SNRA1 and MEAN1 for MRR, SNRA2 and MEAN2 for Cutting force F1 and SNRA3 and MEAN3 for Feed Force F2.

5. Conclusion

From above results The S/N ratio says that the MRR is higher at higher values of speed, feed and depth of cut for a given range of parameters and which are maximized at A3B3C3 in a considered range of cutting parameters. As per Rank given by S/N ratio depth of cut (d) is more influences on high MRR, then feed and speed.

From the results of Cutting Force (F1) and Feed Force (F2), both are minimized at A2B3C3 i.e. Velocity=130, feed=0.3 and depth of cut=0.5.

6. References

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