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Machining Studies of EN-353 Steel Using Taguchi Technique by Turning Operation

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***Abstract*—This paper presents an optimization method of the cutting parameters like cutting speed, feed rate and depth of cut in dry turning of EN-353 steel in order to study the performance of coated and uncoated ceramic cutting tool inserts. Experiments are designed and conducted based on Taguchi's L_9 orthogonal array carried out under dry cutting conditions. The force measured are feed force, tangential force and to achieve minimum flank wear measured by optical tool wear microscope. The depth of cut was identified as the most influential process parameters in the responses of both feed force and tangential force. The cutting speed has a significant contribution for flank wear. Finally, the feed rate was identified as the most influential process parameter in the responses of both feed force and tangential force.**

Keywords—Feed force; tangential force; flank wear; Taguchi; ceramic cutting tool inserts.

I. INTRODUCTION

Recent improvements in machine tool rigidity and the development of ceramic and CBN cutting tools have allowed the machining of hardened steel to replace many grinding operations due to the numerous advantages of hard turning. Even through small depths of cut and feed rates are required for hard turning, material removal rates in hard turning can be much higher than grinding. It has been estimated that resulting reduction in machining time could be as high as 60%.

Aspect such as tool life, surface finish, cutting forces, material removal rate, power consumption, cutting temperature decide the production rate, product quality, overall economy in manufacturing. The consumed power is largely converted into heat resulting high temperature near the cutting edge of the tool.

II. LITERATURE REVIEW

Singh and Kumar,[1] studied on optimization of feed force through setting of optimal value of process parameters namely speed, feed and depth of cut in turning of EN-24 steel with TiC coated Tungsten carbide inserts. The authors used Taguchi's parameters design and concluded that the effect of depth of cut and feed variations of feed force affected more as compared to speed

Hamdan et.al.,[2] has studied tool life and wear, surface finish, cutting forces, material removal rate, power consumption, cutting temperature (on tool and workpiece surface) decide the productivity, product quality, overall economy in manufacturing by machining and quality of machining. During machining, the consumed power is largely converted into heat resulting high cutting temperature near the cutting edge of the tool. The amount of heat generated varies with the type of material being machined and machining parameters specially cutting speed, which had the most influence on the temperature.

Mahesh J. Patil [3], investigated the tool life and wear behaviour of carbide tools at various machining parameters. Coated and uncoated carbide tools were used in turning tool steel A1S1D2 bar with hardness of 25 HRc. Machining test were performed on dry cutting condition at various cutting speeds and feed rates. Taguchi's design of experiment was employed to accommodate the machining parameters of various cutting speeds and feed rates. Result show that the wear progression for both types of carbide tools experienced three stages of wear rate namely initial, gradual and abrupt stages of wear mechanism. Slow wear rate and uniform flank wear observed at low feed rate of 0.05 mm/rev. Generally coated tool performed better as compared to uncoated tool. A good surface finish and longer tool life were achieved using coated tool.

Harisingh and Pradeep Kumar [4], adopted the design of experiment based approach to obtain an optimal setting of turning process parameters (cutting speed, feed rate and depth of cut) that may yield optimal flank wear of Titanium carbide coated carbide inserts while machining EN-24 steel (0.4% C), a difficult-to-machine material. The effects of the selected process parameters on tool wear and subsequent optimal settings of the parameters have been accomplished using Taguchi's parameters design approach. The results indicate that the selected process parameters affect significantly the tool wear characteristics of TiC coated carbide tool. The predicted optimal value of flank wears width of coated carbide tool while machining EN-24 steel is 0.172 mm. The result is further confirmed by conducting further experiment.

S.R.Das et.al.,[5] adopted Taguchi L_9 design an optimization method of the cutting parameters (cutting speed, depth of cut and feed) in dry turning of AISI D2 steel to achieveminimum tool wear and low workpiece surface temperature. The results showed that depth of cut and cutting speed are the most important parameters influencing the tool wear. The minimum tool wear was found at cutting speed of 150 m/min, depth of cut of0.5 mm and feed rate of 0.25mm/rev.

J.PauloDavim and Luis Figueira[6], were investigated the machinability evaluation in hard turning of cold work steel(D2) with ceramic tools using statistical techniques. It was concluded that the tool wear was highly influenced by the cutting velocity, and in a smaller degree, by cutting time. The specific cutting pressure was also strongly influenced by the feed rate.

Y.Kevin Chou et.al., [7] studied that precision hard turning provides an alternative to grinding in some finishing applications. Rapid tool wear, however remains an impediment to the process being economically viable. This experimental study investigates microstructural aspect of Cubic Boron Nitride (CBN) tool wear finish hard turning.

Ty G.Dawson and Thomas R.Kurfess, [8] studied wear rates and tool lives under varing cutting parameters along the abilities and limitations of the hard turning process to produce finished surfaces with acceptable roughness and integrity.in an attempt to optimize the hard turning process in terms of tool life, thirteen different life tests were run with different CBN cutting tool materials at varing conditions. Results from this study indicated that low CBN content tools were capable of machining more material before failure.

Y.Kevin Chou.et.al., [9] studied that micro-structural aspects of CBN tool wear in finish hard turning. Results indicate the following- carbide sizes of the workpiece have sufficient effects on tool wear; the flank wear rate can be correlated with mean carbide diameter of the workpiece,the wear resistance increases monotonically with decreasing CBN grain size.

BalaMurugan Gopalsamy.et.al., [10] applied the Taguchi method to find the optimum process parameters in hard machining of hardened steel. An L_{18} array, signal to noise ratio and ANOVA were applied to study the performance characteristics of machining parameters with consideration of surface roughness and tool life.

III. EXPERIMENTAL DETAILS

Experimental evaluation was carried out by using uncoated and coated ceramic cutting tool inserts, to perform turning operations on hard steel material EN-353 of hardness 60 HRC at different cutting conditions for evaluating the machining characteristics. The following process parameters were selected for the present work Cutting speed - (A), feed rate – (B) and depth of cut – (C), Environment – Dry cutting, Tool material - coated and uncoated ceramic cutting tool insert (Kennametal Widia) make, Tool holder- MTJNR 2020K16,Insert geometry- MTJNR 2020M12 and Tool over hang – 20 mm.

The EN-353 steel rods of 60 mm diameter and length of 300 mm was machined on HMT A28-2847 lathe using coated and uncoated ceramic cutting tool inserts having the designation of TNGA332T0420. The workpiece is machined as per the process parameters listed in the Table 1 using L_9 orthogonal array. The feed force (F_x) and tangential force (F_Y) was measured for each trial using lathe tool dynamometer. For each trial the new insert is used in order to have the uniformity of cutting conditions. The results for the experiments for 9 trials were reported in Table 2 for uncoated ceramic cutting tool insert and Table 3 for coated ceramic cutting tool insert.

For the evaluation of flank wear (V_b) on both uncoated and coated ceramic cutting tool inserts, the EN-353 steel rod was machined for the total machining time of 15 minutes for each trial. After machining, the inserts is removed from the tool holder and observed under the Tool Maker's Microscope for the measuring of flank wear rate (V_b) and readings are tabulated in Table 4 for uncoated ceramic cutting tool inserts and for coated ceramic cutting tool inserts listed in Table 5.

The ANOVA& Signal –to-Noise (S/N) ratio results for feed force and tangential force for uncoated ceramic & coated ceramic cutting tool inserts is tabulated from Table 6 to Table 13. Similarly the ANOVA &Signal – to – Noise (S/N) ratio results for flank wear of uncoated ceramic & coated ceramic cutting tool inserts is tabulated in Table 14 to Table 17.

The Signal – to – Noise ratio for Lower the Better (LB) characteristics are calculated using

$$S/N_{LB} = -10 \log \left(\frac{1}{r}\sum_{i=1}^{r} y_i^{\,2}\right) \qquad (1)$$

Table 1 Values of test variables considered for machining EN-353 steel using coated and uncoated ceramic cutting tool inserts:

Process parameters	**Level - 1**	**Level – 2**	**Level – 3**
Cutting speed (m/min) - A	101.78	131.94	171.54
Feed rate (mm/rev) - B	0.125	0.148	0.187
Depth of cut (mm) - C	0.2	0.4	0.6

Table 2 Experimental values of feed force, tangential force using uncoated ceramic cutting tool insert.

Sl.no.	**A**	**B**	**C**	**F_x (N)**	**F_y (N)**
1	101.78	0.125	0.2	20	145
2	101.78	0.148	0.4	40	305
3	101.78	0.187	0.6	65	485
4	131.94	0.125	0.4	45	285
5	131.94	0.148	0.6	85	470
6	131.94	0.187	0.2	30	155
7	171.54	0.125	0.6	65	425
8	171.54	0.148	0.2	25	120
9	171.54	0.187	0.4	50	275

Table 3 Experimental values of feed force (F_x), tangential force (F_y) for coated ceramic cutting tool insert.

Sl.no.	**A**	**B**	**C**	**F_x (N)**	**F_y (N)**
1	101.78	0.125	0.2	75	160
2	101.78	0.148	0.4	35	255
3	101.78	0.187	0.6	120	145
4	131.94	0.125	0.4	40	215
5	131.94	0.148	0.6	70	415
6	131.94	0.187	0.2	20	105
7	171.54	0.125	0.6	145	450
8	171.54	0.148	0.2	30	75
9	171.54	0.187	0.4	55	285

Table 4 Experimental values of flank wear were measured for uncoated ceramic cutting tool insert using the optical microscope.

Sl.no.	**A**	**B**	**C**	**Flank wear V_b(mm)**
1	101.78	0.125	0.2	0.07
2	101.78	0.148	0.4	0.30
3	101.78	0.187	0.6	0.33
4	131.94	0.125	0.4	0.10
5	131.94	0.148	0.6	0.37
6	131.94	0.187	0.2	0.46
7	171.54	0.125	0.6	0.7
8	171.54	0.148	0.2	0.6
9	171.54	0.187	0.4	0.46

Table 5Experimental values of flank wear were measured for coated ceramic cutting tool insert using the optical microscope.

Sl.no.	**A**	**B**	**C**	**Flank wear V_b(mm)**
1	101.78	0.125	0.2	0.14
2	101.78	0.148	0.4	0.11
3	101.78	0.187	0.6	0.40
4	131.94	0.125	0.4	0.27
5	131.94	0.148	0.6	0.25
6	131.94	0.187	0.2	0.19
7	171.54	0.125	0.6	0.62
8	171.54	0.148	0.2	0.47
9	171.54	0.187	0.4	0.35

Table 6 ANOVA for Feed force (F_x) using uncoated ceramic cutting tool insert.

Factors	**DOF**	**SS**	**M_{SS}**	**F_{cal}**	**F_{tab} 95% CI**	**P %**
A	2	205.5	102.7	2.313	3.49	5.63
B	2	72.23	36.11	0.813	3.49	1.97
C	2	3289	1644	37.00	3.49	89.9
Error	2	88.88	44.44	1.00		2.43
Total	8	3655				100

Table 7ANOVA for Feed force (F_x) using Signal – to – Noise (S/N) ratio for uncoated ceramic cutting tool insert.

Factors	**DOF**	**SS**	**M_{SS}**	**F_{cal}**	**F_{tab} 95% CI**	**P %**
A	2	7.91	3.995	27.27	3.49	5.68
B	2	3.5	1.75	12.06	3.49	2.51
C	2	127.4	63.74	439.5	3.49	91.5
Error	2	0.29	0.145	1.00		0.21
Total	8					100

Table 8 ANOVA for Feed force (F_x) using coated ceramic cutting tool insert.

Factors	**DOF**	**SS**	**M_{SS}**	**F_{cal}**	**F_{tab} 95% CI**	**P %**
A	2	2222	1111.1	100	3.49	15.4
B	2	2605	1302.7	117.2	3.49	18.0
C	2	9572	4786.1	430.7	3.49	66.3
Error	2	22.2	11.11			0.15
Total	8					100

Table 9 ANOVA for Feed force (F_x) using Signal – to – Noise (S/N) ratio for coated ceramic cutting tool insert.

Factors	**DOF**	**SS**	**M_{SS}**	**F_{cal}**	**F_{tab} 95% CI**	**P %**
A	2	41.00	20.5	3.26	3.49	16.1
B	2	43.3	21.6	3.45	3.49	17
C	2	157.56	78.7	12.5	3.49	61.9
Error	2	12.55	6.27			4.93
Total	8	254.41				100

Table 10 ANOVA for Tangential force (F_y) using uncoated ceramic cutting tool insert.

Factors	**DOF**	**SS**	**M_{SS}**	**F_{cal}**	**F_{tab} 95% CI**	**P %**
A	2	2.78	1.39	5.91	3.49	1.66
B	2	0.5	0.25	1.06	3.49	0.3
C	2	163.95	81.9	348	3.49	97.7
Error	2	0.47	0.23			0.28
Total	8	167.7				100

Table 11 ANOVA for Tangential force (F_y) using Signal – to – Noise (S/N) ratio for uncoated ceramic cutting tool insert.

Factors	**DOF**	**SS**	**M_{SS}**	**F_{cal}**	**F_{tab} 95% CI**	**P %**
A	2	2438.89	1919.4	440.4	3.49	1.55
B	2	622.24	311.12	112.3	3.49	0.39
C	2	153872	76936	27790	3.49	98.0
Error	2	5.536	2.7684			0.03
Total	8	156938				100

Table 12 ANOVA for Tangential force (F_y) using coated ceramic cutting tool insert.

Factors	DOF	SS	M_{SS}	F_{cal}	F_{tab} 95% CI	P %
A	2	10971.8	5485.9	0.30	3.49	7.94
B	2	14955.5	7477.7	0.41	3.49	10.8
C	2	76238.8	38119	2.11	3.49	55.2
Error	2	35972.6	17986			26.0
Total	8	138138				100

Table 13 ANOVA for Tangential force(F_y) using Signal – to – Noise (S/N) ratio for coated ceramic cutting tool.

Factors	DOF	SS	M_{SS}	F_{cal}	F_{tab} 95% CI	P %
A	2	3.74	1.87	0.06	3.49	1.7
B	2	20.3	10.15	0.33	3.49	9.24
C	2	134.6	67.3	2.20	3.49	61.29
Error	2	60.96	30.48			27.7
Total	8	219.6				100

Table 14 ANOVA for flank wear using uncoated ceramic cutting tool insert.

Factors	DOF	SS	M_{SS}	F_{cal}	F_{tab} 95% CI	P %
A	2	149.05	74.5	2.48	3.49	40
B	2	116.30	58.1	1.94	3.49	31.2
C	2	47.414	23.7	0.79	3.49	12.7
Error	2	59.953	29.9			16.0
Total	8	372.73				100

Table 15 ANOVA using Signal – to - Noise ratio (S/N) for flank wear using uncoated ceramic tool insert.

Factors	DOF	SS	M_{SS}	F_{cal}	F_{tab} 95% CI	P %
A	2	0.280	0.140	7.335	3.49	70.6
B	2	0.052	0.026	1.371	3.49	13.2
C	2	0.025	0.012	0.664	3.49	6.44
Error	2	0.038	0.019			9.63
Total	8	0.396				100

Table 16 ANOVA forflank wear using coated ceramic cutting tool insert.

Factors	DOF	SS	M_{SS}	F_{cal}	F_{tab} 95% CI	P %
A	2	0.128	0.064	4.842	3.49	58.6
B	2	0.006	0.003	0.248	3.49	3.04
C	2	0.057	0.028	2.157	3.49	26.1
Error	2	0.026	0.013			12.1
Total	8	0.219				100

Table 17 ANOVA for Signal – to - Noise ratio (S/N) of flank wear using coated ceramic cutting tool insert.

Factors	DOF	SS	M_{SS}	F_{cal}	F_{tab} 95% CI	P %
A	2	106.6	53.3	3.26	3.49	54.6
B	2	7.49	3.74	0.22	3.49	3.83
C	2	48.48	24.2	1.48	3.49	24.8
Error	2	32.62	16.3			16.5
Total	8	195.2				100

IV. RESULT AND DISCUSSION

Table 6 indicates that for the feed force, the depth of cut has a significant contribution (89.9%) compared to the cutting speed (5.63%) and the feed rate (1.97%). The S/N ratio also exhibits similar trends as shown in Table 7 for uncoated ceramic cutting tool inserts.

Table 8 indicates that for feed force, the depth of cut has a significant contribution (66.3%) compared to the feed rate (18.0%) and the cutting speed (15.4%). The S/N ratio also exhibits similar trends as shown in Table 9 for coated ceramic cutting tool inserts.

Table 10 indicates that for tangential force, the depth of cut has a significant contribution (97.7%) compared to the cutting speed (1.66%) and the feed rate (0.3%). The S/N ratio also exhibits similar trends as shown in Table 11 for uncoated ceramic cutting tool inserts.

Table 12 indicates that for tangential force, the depth of cut has a significant contribution (55.2%) compared to the feed rate (10.8%) and the cutting speed (7.94%). The S/N ratio also exhibits similar trends as shown in Table 13 for coated ceramic cutting tool inserts.

Therefore the depth of cut plays an important role during the machining of EN-353, using coated & uncoated ceramic cutting tool insert.

Table 14 indicates that for flank wear, the cutting speed has a significant contribution (40%) compared to the feed rate (31.2%) and the depth of cut (12.7%). The S/N ratio also exhibits similar trends as shown in Table 15 for uncoated ceramic cutting tool inserts.

Table 16 indicates that for flank wear, the cutting speed has a significant contribution (58.6%) compared to the depth of cut (26.1%) and the feed rate (3.04%). The S/N ratio also exhibits similar trends as shown in Table 17 for coated ceramic cutting tool inserts.

V. CONCLUSION

1. The depth of cut has a significant contribution for both feed force and tangential force using both uncoated and coated ceramic cutting tool inserts.
2. The cutting speed has a significant contribution for flank wear using both uncoated and coated ceramic cutting tool inserts.
3. During the experimental investigation, it is observed from the table of ANOVA that the feed rate is the most influential control factor among three turning process parameters for minimization of tangential force and flank wear when simultaneously considered.

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