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Experimental Analysis of Cutting Forces Under Different Machining Parameters and Carbide Inserts During Turning of Hardened AISI 4340 Steel

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Abstract

Turning of hardened materials with an advanced coated carbide insert has numerous advantages over the grinding process, e.g., reduced process cost, high material removal rate, and less environmental concern due to the elimination of the cutting fluid. Process parameters in conventional machining operations like cutting speed, feed, and depth of cut play the most crucial role behind the generation of heat which also leads to microstructural changes, improved tool life, better surface finish, metal removal rate, and the most important is cutting force. In the present work, turning has been done on hardened AISI 4340 steel (42 HRC) using three different inserts of coated carbide (Titanium carbide coated groove-type SNMG-120408-PM, TiC-coated plain SNMA-120408-315/K15 and Al_2O_3 *coated groove SNMG-120408-THM) under the dry condition with a constant depth of cut. The cutting force has been analyzed under the different cutting conditions, chip profile, chatter, built-up edge, and chip reduction coefficient (CRC). A comparative study has been presented among different tool inserts to get desired performance such as material removal rate, tool wear, and profile of chips. In comparison with* Al_2O_3 *coated carbide insert the groove-type TiC-coated carbide inserts have shown better machining results at higher cutting velocity and feed rate while turning cylindrical workpiece. No built-up edge has formed at TiC-coated carbide insert but SNMG-120408-THM insert results in a built-up edge chip. TiC-coated groove-type (SNMG-120408-PM) insert has shown longer tool life than the other two tool insert used in this work. Favorable chip formation, that is flat continuous-type chip, is obtained at TiC-coated groove-type insert and may be recommended.*

Keywords: Carbide inserts, turning, cutting force, machinability, AISI 4340 SS, chip

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INTRODUCTION

Removal of excess material from preformed blank through machining is a well-versed process in most of the manufacturing industries. Surface finish is the most desirable characteristic in the machining operation, which depends on the machine tool, cutting parameter, and workpiece material. Achieving a better surface quality with a higher rate of production turning is the best-suited method. Traditionally, grinding is employed for finishing and semi-finishing of hard materials, but it involves a low metal removal rate (MRR), long manufacturing lead time, greater Chip-tool contact zone, and highly negative rake than turning, resulting in reduced heat dissipation at the cutting zone and higher power requirement. Further, plastic deformation occurs and the tool is burned and a deep thick white layer is formed [1–2].

Cutting force is a factor in machining parameters and tool configuration. In the case of hard turning, radial cutting force mostly dominates when the depth of cut is lower than the tool nose radius. [3–5]. The formation of a built-up edge at a lower speed of machining can cause higher cutting forces whereas, in the case of high-speed machining, the generation of high temperature can cause thermally softening of the work material [6]. The performance of coated tools also depends on the work materials to be machined, and the thickness and uniformity of the coating.

The coating materials generally used on carbide tool substrates are; As single layer: TiC, TiN, TiCN, Al_2O_3, TiB_2, BC, and diamond. In multiple layers TiN on TiC, Al_2O_3 on TiN or TiCN, TiC within the two layers of TiN, TiCN on TiC, Al_2O_3 within two layers of TiN, TiCN on Al_2O_3 and finally TiN, and a few combinations [7]. TiC is more compatible with WC and provides abrasion-type wear resistance. On the other hand, TiN-coated inserts perform better in case of wear behavior over Cr-N. TiN is more chemically stable and resistant to adhesion diffusion wear, friction, and built-up edge (BUE) formation. As investigated by researchers, carbide insert of multilayer chemically vapor-deposited TiN shows a lower coefficient of friction than Al_2O_3 in the machining of austenitic stainless steel in the dry environment [8–9]. A comparative study was conducted by some researchers at a higher cutting velocity on AISI 4340 using different coated and uncoated carbides to determine machining force, chip profile, surface roughness, etc. [10]. Compared to TiN, TiAlN is not only more ductile and thermally conductive but also hotter and hard, thermochemically stable, and wear-resistant. The passive oxide layer formed during machining due to Al present in TiAlN offers additional lubricity and wear resistance [11–12]. During the study of AISI 4340 materials with various nose radii of cutting tools. Their result shows that an increase in nose radius decreases surface roughness up to an optimum level. The critical value of the nose radius is 1.2 mm to get favorable chip formation. At this condition, the cutting force is found minimum compared to the other condition [13]. Based on the review, it has been identified that cutting force is one of the major concerns to optimize the machining parameters. In this paper, a comparative study has been conducted among different tool inserts to optimize the power requirements.

EXPERIMENTAL DETAILS

This study is performed using a preformed hardened blank of AISI 4340 steel (42HRC). In this turning operation, HMT Machine Tools Ltd., Bangalore, India, made an 11 kW lathe is used whose range of speed is 40-2040 RPM and range of feed is 0.08 to 0.14. The workpiece is held between a three-jaw self-centering chuck and revolving tail stock. Experimental setup details are inserted in Table 1. Three sets of experiments have been performed with three different coated inserts and at typical cutting velocities of 240, 315, and 410 in m/min and four different feed rates whereas the depth of cut and nose radius is fixed at 2.05 mm and 0.8 mm respectively. Case-I has been performed with workpiece diameter 107 mm whereas Case-II is carried out with 105 mm diameter, and Case-III is carried out with 85 mm diameter. Three different coated carbide tools as shown in Figure 1, spindle speed, feed rate, and cutting velocity are chosen as input parameters whereas chip reduction coefficient, the average thickness of chips and uncut thickness of chips, horizontal cutting force, and main cutting force is selected as output parameters. Chip thickness is measured at three different places by micrometer and forces are measured by Equations (1), (2), and (3).

Main cutting force $P_z = ts_0\tau_s\ (\xi - \tan\gamma_0 + 1)$ (1)

Horizontal force $P_{xy} = ts_0\tau_s(\xi - \tan\gamma_0 - 1)$ (2)

Chip reduction coefficient (CRC) $\xi = \frac{a_2}{a_1}\ and\ as\ a_2 > a_1, \xi > 1.00\ \&\ a_1 = S_0 \sin\emptyset$ (3)

Where t denotes the depth of cut in mm, s_0 denotes feed in mm/rev, τ_s denotes the shear strength of the material, γ_0 denotes the orthogonal rake angle of the tool, a_1 represents the thickness of the uncut layer or chip before the cut, a_2 represents the thickness of the chip after the cut, Φ denotes the principal cutting-edge angle.

RESULTS AND DISCUSSIONS

Case-I of turning operation is conducted by Titanium carbide coated grove type SNMG-120408-PM tool insert on AISI 4340 cylindrical workpiece. Table 2 shows the values of uncut chip thickness (a_1), chip thickness (a_2) and chip reduction coefficient (ξ) which varies from 1.05 to 1.73. The main cutting force and horizontal cutting force are also tabulated. Formation of BUE is not found in this experiment. It may be due to higher cutting velocity.

Table 1. Experimental setup.

Machine specification	Model-NH22, Make-HMT ltd., Power-11 kw, Speed range-40-2040 rpm, Feed range-0.04-2.24 mm/rev.
Workpiece description	AISI 4340 steel, Diameter-120mm, Length-275 mm, Hardness value-42HRC
Chemical composition of the workpiece	C-0.7815%, Si-0.2163%, P-0.0285%, Ni-0.2987%, Cr-1.1326%,
Machining condition	Dry environment
Insert details	Two nos. TiC-coated insert, SNMG 120408 PM & SNMA 120408 315/K15, and one no Al_2O_3 coated insert SNMG 120408 THM, Make-Sandvik Asia Ltd., India
Tool holder details	$Geometry$: $-6^0, -6^0, 6^0, 6^0, 15^0, 75^0, 0.8\ mm$ (NRS), Sandvik Asia Ltd., India, Grade-Coromant T max-P
Details of measuring instrument	Pointed micrometer, range 0-25 mm, least count 0.01 mm

Figure 1. Photographs of inserts used (a) SNMG-120408-PM, (b) SNMG-120408-THM, (c) SNMA-120408-315/K15.

Table 2. Experimental results for turning of AISI 4340 steel using SNMP-120408-PM under dry conditions (Case-I).

Experiment no.	Process parameters			Responses				
	Spindle speed N (RPM)	*Cutting velocity, V_c (m/min)*	*Feed, S_o (mm/rev)*	*Average chip thickness, a2 (mm)*	*Uncut chip thickness, a1(mm)*	*Chip reduction coefficient, ξ*	*Main Cutting Force (Pz), N*	*Horizontal Cutting Force (Pxy), N*
1	1210	410	0.08	0.126	0.077	1.64	292.2	79.0
2	1210	410	0.1	0.152	0.096	1.58	358.2	91.7
3	1210	410	0.12	0.164	0.116	1.41	402.8	83.0
4	1210	410	0.14	0.142	0.135	1.05	402.4	29.3
5	930	315	0.08	0.131	0.077	1.73	299.2	86.0
6	930	315	0.1	0.152	0.096	1.58	358.2	91.7
7	930	315	0.12	0.178	0.116	1.53	422.1	102.3
8	930	315	0.14	0.20	0.135	1.48	482.5	109.4
9	715	240	0.08	0.121	0.077	1.57	285.3	72.1
10	715	240	0.1	0.152	0.096	1.58	358.2	91.7
11	715	240	0.12	0.133	0.116	1.15	360.0	40.2
12	715	240	0.14	0.182	0.135	1.35	457.7	84.6

Chatter marks are observed at medium cutting velocity (315 m/min) and feed (0.08, 0.1 mm/rev). This may be due to the effect of vibration in machining.

Figure 2 shows a variation of cutting force with a change in cutting velocity at four feeds (0.08, 0.1, 0.12, 0.14 mm/rev). It is observed that at three feed values (0.08, 0.12, 0.14 mm/rev), the horizontal cutting force and main cutting force initially increase to a velocity of 315 m/min and after that, it decreases. At high cutting, velocity workpiece becomes softened due to high temperature, and hence force is decreased. At a feed of 0.1 mm/rev, cutting forces show no variation noticeable. As noticed increase in feed increases cutting forces at all cutting velocities, except a feed of 0.14 mm/rev. This may be due to an increase in the feed that increases the uncut chip area. At the high velocity of 410 m/min and higher feed of 0.14 mm/rev, cutting forces decrease rapidly. At higher feed and cutting velocity conditions, cutting force reduces considerably. This may be due to increased uncut chip area at higher feed, and simultaneous increase in velocity and temperature of the cutting zone. Hence workpiece becomes softer and as a result, a lower cutting force is obtained.

The formation of the chip is noticed, as depicted in Figure 3(a) to (l). Chip are mostly continuous, C-type, half round, full round, and few are flat, ribbon type. It is noticed that continuous-type chips are produced at a low feed of 0.08 mm/rev, but C-type and full round-type chips are observed at a high feed of 0.1 mm/rev or above it. No chip-breaking action is observed at a low feed.

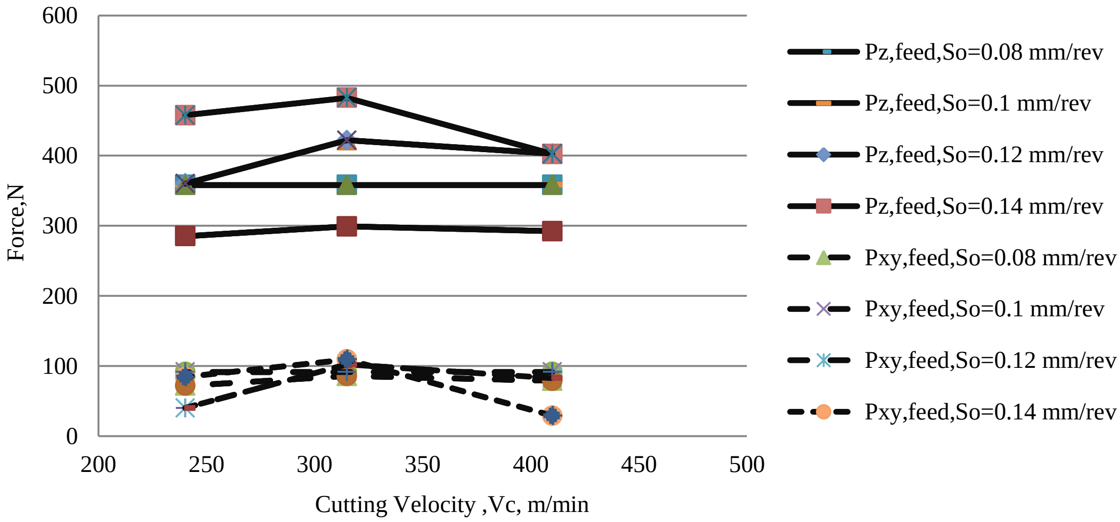


Figure 2. variation of force component and cutting velocity (Vc) at multiple rates of feed (s_0) for Case-I using insert SNMG–120408–PM.

(a) At v_c= 410 m/min, s_0 = 0.08 m/min, & t = 2.05 mm

(b) At v_c= 410 m/min, s_0 = 0.1 m/min, & t = 2.05 mm


(c) At v_c= 410 m/min, s_0 = 0.12 m/min, & t = 2.05 mm


(d) At v_c= 410 m/min, s_0= 0.14 m/min, & t = 2.05 mm


(e) At v_c = 315 m/min, s_0 = 0.08 m/min, & t = 2.05 mm


(f) At v_c= 315 m/min, s_0 = 0.1 m/min, & t = 2.05 mm


(g) At v_c = 315 m/min, s_0 = 0.12 m/min, & t = 2.05 mm


(h) At v_c = 315 m/min, s_0 = 0.14 m/min, & t = 2.05 mm


(i) At v_c = 240 m/min, s_0 = 0.08 m/min, & t = 2.05 mm


(j) At v_c = 240 m/min, s_0 = 0.1 m/min, & t = 2.05 mm

(k) At v_c = 240 m/min, s_0 = 0.12 m/min, & t = 2.05 mm

(l) At v_c = 240 m/min, s_0 = 0.14 m/min, & t = 2.05 mm

Figure 3. (a) to (l). Observed chip for AISI 4340 steel using SNMG-120408-PM inserts under dry condition (Case-I).

Table 3. Experimental data for turning of AISI 4340 steel using SNMG-120408 THM under dry condition (Case-II)

Experiment no.	Process parameters			Responses				
	Spindle speed N (RPM)	*Cutting velocity, Vc (m/min)*	*Feed, So (mm/rev)*	*Chip thickness, a2 (mm)*	*Uncut chip thickness, a1*	*Chip reduction coefficient, ξ*	*Main Cutting Force (Pz), N*	*Horizontal Cutting Force (Pxy), N*
1	1210	410	0.08	0.177	0.077	2.30	362.8	149.6
2	1210	410	0.1	0.235	0.096	2.45	473.4	206.9
3	1210	410	0.12	0.222	0.116	1.91	482.7	162.9
4	1210	410	0.14	0.235	0.135	1.74	530.9	157.8
5	930	315	0.08	0.128	0.077	1.66	295.0	81.8
6	930	315	0.1	0.182	0.096	1.90	399.9	133.4
7	930	315	0.12	0.168	0.116	1.45	408.3	88.5
8	930	315	0.14	0.265	0.135	1.96	572.3	199.2
9	715	240	0.08	0.145	0.077	1.88	318.5	105.3
10	715	240	0.1	0.195	0.096	2.03	417.9	151.4
11	715	240	0.12	0.222	0.116	1.91	482.7	162.9
12	715	240	0.14	0.22	0.135	1.63	510	137.1

In Case-II, the turning test is done on AISI 4340 cylindrical workpiece with coated carbide groove-type (SNMG-120408-THM) tool insert under dry conditions.

Table 3 specifies chip thickness uncut (a_1), chip thickness (a_2), and chip reduction coefficient (ξ). The chip reduction coefficient (ξ) varies from 1.45 to 2.45. The main cutting force and horizontal cutting force are also tabulated. BUE is found in this experiment at low velocity and medium velocity (240 m/min, 410 m/min) and medium feed (0.1 mm/rev, 0.12 mm/rev). It is observed that the tool is broken at high cutting velocity (410 m/min) and all feed conditions.

It is also observed that at medium cutting velocity (315 m/min) and high feed (0.14 mm/rev), the tool is broken. Due to increased feed, uncut chip area is increased and increased cutting velocity results in increased tool work interface temperature. Combining the effects of these two, more heat is generated at the cutting zone which creates rapid tool wear. Chip reduction coefficient seen at lower velocity is much higher.

The discontinuation of chips due to a higher degree of curling within a small radius may be the reason for increased cutting force. Figure 4 shows that variations of cutting forces are there with changes in cutting velocity, at four feeds (0.08, 0.1, 0.12, 0.14 mm/rev). It is observed that at three feed values (0.08, 0.1,0.12 mm/rev), the horizontal cutting force and main cutting force initially decrease up to a cutting velocity of 315 m/min, after that it is increased. This can be due to the thermal softening phenomenon of the workpiece with a medium velocity of cutting so forces are reduced at a higher velocity. At this high velocity, the tool is getting worn out fast causing the force to increase. At 0.14 mm/rev while cutting velocity increases initially cutting force is also increased after 315 m/min cutting velocity, cutting forces decrease.

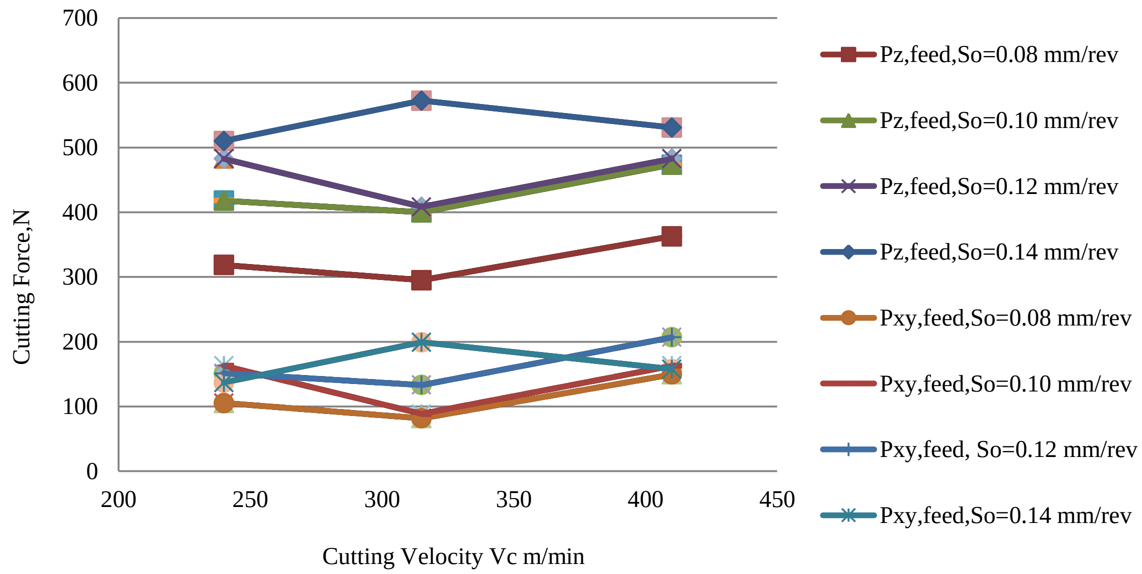


Figure 4. Variation of forces and cutting velocity at multiple feed rates for Case-II using SNMG-12048-THM Inserts.

(a) At v_c = 410 m/min, s_0 = 0.08 m/min, & t = 2.05 mm

(b) At v_c = 410 m/min, s_0 = 0.1 m/min, & t = 2.05 mm

(c) At v_c = 410 m/min, s_0 = 0.12 m/min, & t = 2.05 mm

(d) At v_c = 410 m/min, s_0 = 0.14 m/min, & t = 2.05 mm

At v_c = 315 m/min, s_0 = 0.08 m/min, & t = 2.05 mm

At v_c = 315 m/min, s_0 = 0.1 m/min, & t = 2.05 mm

(g) At v_c = 315 m/min, s_0 = 0.12 m/min, & t = 2.05 mm

(h) At v_c = 315 m/min, s_0 = 0.14 m/min, & t = 2.05 mm

(i) At v_c = 240 m/min, s_0 = 0.08 m/min, & t = 2.05 mm

(j) At v_c = 240 m/min, s_0 = 0.1 m/min, & t = 2.05 mm

(k) At v_c = 240 m/min, s_0 = 0.12 m/min, & t = 2.05 mm

(l) At v_c = 240 m/min, s_0 = 0.14 m/min, & t = 2.05 mm

Figure 5. (a) to (l). Observed chip for AISI 4340 steel with SNMG-120408-THM under dry condition (Case-II).

Chips formed are observed and found that long continuous-type chips are formed at the low feed of 0.08 mm/rev and low velocity at 240 m/min as depicted in Figure 5(a) to (l). Saw-type chips are observed at high cutting velocities and high feed conditions.

In Case-III, the turning operation is performed on AISI 4340 cylindrical workpiece with TiC-coated carbide with plain (SNMA-120408-K15) tool insert under dry condition. Results obtained from this experiment are presented in Table 4. Values of chip thickness, chip reduction coefficient, and forces are evaluated detailed in the table. The chip reduction coefficient (ξ) varies from 1.48 to 1.82. Principal and horizontal cutting forces are also tabulated. No BUE is found in this experiment. This may be due to high cutting velocity.

Figure 6 indicates the deviation of cutting forces with change in cutting velocity on various feed rates (0.08, 0.1, 0.12, 0.14 mm/rev). It is observed that the variation of a horizontal cutting force and main cutting force is marginal with cutting velocity. This is a usual tendency in machining where there is no remarkable effect of thermal softening. However, an increase in feed is expected to require high force due to the high shear area. Chips are seen to be of the long irregular continuous-type of feed at 0.08, 0.1, and 0.12 mm/rev as depicted in Figure 7(a) to (l).

Table 4. Experimental data for machining of AISI 4340 stainless steel with SNMA-120408-315/K15 under dry condition.

Experiment. no.	**Process parameters**			**Responses**				
	spindle speed N (RPM)	***Cutting velocity, (m/min)***	***Feed, So (mm/rev)***	***Chip thickness, a2 (mm)***	***Uncut chip thickness, a1(mm)***	***Chip reduction coefficient, ξ***	***Main Cutting Force (Pz) N***	***Horizontal Cutting Force (Pxy) N***
1	1210	410	0.08	0.125	0.077	1.62	290.9	77.7
2	1210	410	0.1	0.16	0.096	1.67	369.3	102.8
3	1210	410	0.12	0.185	0.116	1.59	431.7	111.9
4	1210	410	0.14	0.20	0.135	1.48	482.5	109.4
5	930	315	0.08	0.14	0.077	1.82	311.6	98.4
6	930	315	0.1	0.155	0.096	1.61	362.4	95.9
7	930	315	0.12	0.19	0.116	1.64	438.6	118.8
8	930	315	0.14	0.209	0.135	1.55	495.0	121.9
9	715	240	0.08	0.13	0.077	1.69	297.8	84.6
10	715	240	0.1	0.145	0.096	1.51	348.5	82.0
11	715	240	0.12	0.20	0.116	1.72	452.4	132.6
12	715	240	0.14	0.21	0.135	1.56	496.3	123.2

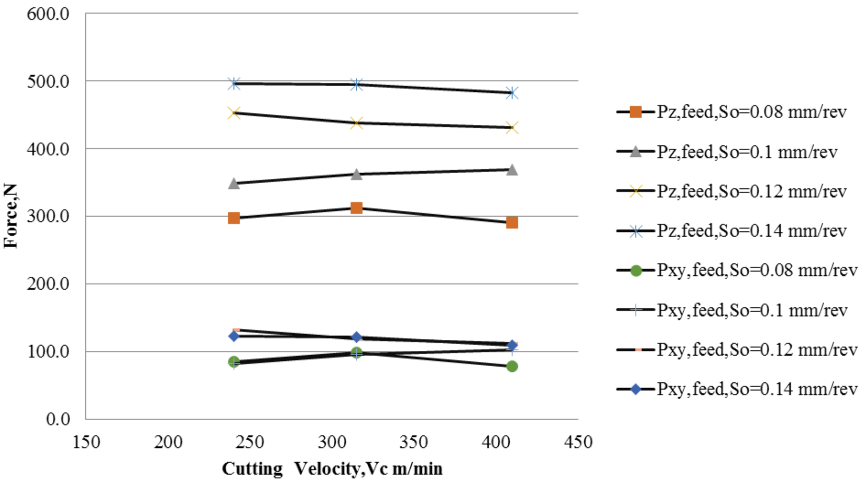


Figure 6. variation of cutting force and cutting velocity (Vc) at different feed (So) for Case-III using SNMA-12048-315/K15 inserts.

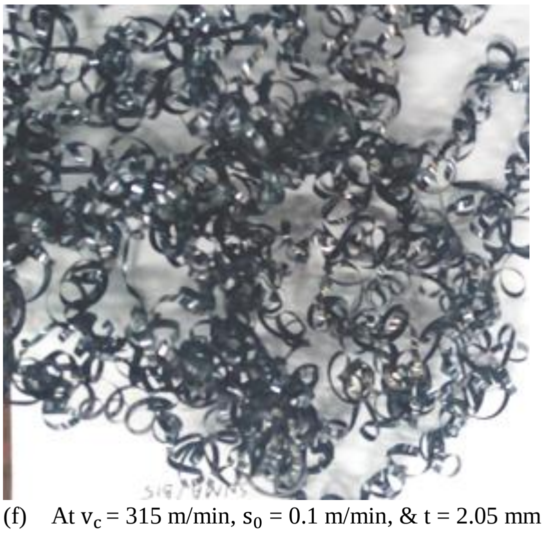
(a) At v_c = 410 m/min, s_0 = 0.08 m/min, & t = 2.05 mm

(b) At v_c = 410 m/min, s_0 = 0.1 m/min, & t = 2.05 mm

(c) At v_c = 410 m/min, s_0 = 0.12 m/min, & t = 2.05 mm

(d) At v_c = 410 m/min, s_0 = 0.14 m/min, & t = 2.05 mm

(e) At v_c = 315 m/min, s_0 = 0.08 m/min, & t = 2.05 mm



(f) At v_c = 315 m/min, s_0 = 0.1 m/min, & t = 2.05 mm

(g) At v_c = 315 m/min, s_0 = 0.12 m/min, & t = 2.05 mm

(h) At v_c = 315 m/min, s_0 = 0.14 m/min, & t = 2.05 mm

(i) At v_c= 240 m/min, s_0 = 0.08 m/min, & t = 2.05 mm

(j) At v_c = 240 m/min, s_0 = 0.1 m/min, & t = 2.05 mm

(k) At v_c = 240 m/min, s_0 = 0.12 m/min, & t = 2.05 mm

(l) At v_c = 240 m/min, s_0 = 0.14 m/min, & t = 2.05 mm

Figure7. (a) to (l). Observed chip for AISI 4340 steel with SNMA-120408-315/K15 under dry conditions.

CONCLUSIONS

In the present work, experimental analysis has been conducted to analyze cutting forces under different machining parameters and carbide inserts during the turning of hardened AISI 4340 steel. At higher cutting velocity and feed rate, groove-type TiC-coated carbide insert has shown better performance while turning cylindrical workpieces. A broken chip has been observed in the case of turning using a groove-type insert. No BUE has formed at TiC-coated carbide insert but SNMG-120408-THM insert results in a BUE chip. TiC-coated groove-type (SNMG-120408-PM) insert has shown longer tool life than the other two tool insert used in this work. Favorable chip formation, that is flat continuous-type chip, is obtained at TiC-coated groove-type insert and may be recommended.

REFERENCES

1. Han S, Melkote SN, Haluska MS, Watkins TR. White layer formation due to phase transformation in orthogonal machining of AISI 1045 annealed steel. Mater Sci Eng A. 2008; 488(1-2): 195–204. doi: 10.1016/j.msea.2007.11.081.
2. Uhlmann E, Stawiszynski B, Leyens C, Heinze S, Sammler F. Hard Turning of Hot Work and Cold Work Steels with HiPIMS and DCMS TiAlN Coated Carbide Inserts. Procedia CIRP. 2016; 46: 591–4. doi: 10.1016/j.procir.2016.03.231.
3. Yallese MA, Chaoui K, Zeghib N, Boulanouar L, Rigal J. Hard machining of hardened bearing steel using cubic boron nitride tool. J Mater Process Technol. 2009; 209(2): 1092–104. doi: 10.1016/j.jmatprotec.2008.03.014.
4. Huang Y, Liang SY. Modeling of cutting forces under hard turning conditions considering tool wear effect. Transactions of the ASME. J Manuf Sci Eng. 2005; 127(2): 262–70. doi: 10.1115/1.1852571.
5. Zhou JM, Andersson M, Stahl JE. The monitoring of flank wear on the CBN tool in the hard turning process. Int J Adv Manuf Technol. 2003; 22(9-10): 697–702. doi: 10.1007/s00170-003-1569-2.
6. Nayak M, Sehgal R. Effect of Tool Material Properties and Cutting Conditions on Machinability of AISI D6 Steel During Hard Turning. Arab J Sci Eng. 2015; 40(4): 1151–64. doi: 10.1007/s13369-015-1578-0.
7. Guo YB, Warren AW, Hashimoto F. The basic relationships between residual stress, white layer, and fatigue life of hard turned and ground surfaces in rolling contact. CRIP J Manuf Sci Technol. 2010; 2(2): 129–34. doi: 10.1016/j.cirpj.2009.12.002.
8. Ciftci I. Machining of austenitic stainless steels using CVD multi-layer coated cemented carbide tools. Tribol Int. 2006; 39(6): 565–9. doi: 10.1016/j.triboint.2005.05.005.
9. Schwach DW, Guo YB. Feasibility of producing optimal surface integrity by process design in hard turning. Mater Sci Eng. 2005; 395(1-2): 116–23. doi: 10.1016/j.msea.2004.12.012.
10. Sahoo AK, Sahoo B. Experimental investigations on machinability aspects in finish hard turning of AISI 4340 steel using uncoated and multilayer coated carbide inserts. Measurement. 2012; 45(8): 2153–65. doi: 10.1016/j.measurement.2012.05.015.
11. Chattopadhyay AB. Machining and Machine Tools. New Delhi: Wiley India Pvt Ltd; 2013.
12. Javidi A, Rieger U, Eichlseder W. The Effect of Machining on the Surface Integrity and fatigue Life. Int J Fatugue. 2008; 30(10-11): 2050–5. doi: 10.1016/j.ijfatigue.2008.01.005.
13. Mondal K, Das S. An investigation on machinability during turning hardened steel in dry condition. J Inst Eng (India) S C. 2018; 99(6): 637–44. doi: 10.1007/s40032-017-0370-1.

