Exploring Machinability of AISI 4340 Steel with Coated Carbide Inserts

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Abstract: Turning is widely employed as a material removal process for roughing or semi-finishing operation. However, turning of a workpiece material needs use of an appropriate cutting tool insert. Insert material and its geometry play quite significant role in obtaining desired machinability. For obtaining better finish of machined surface, nose radius also plays an important role. In the present work, two coated carbide cutting tool inserts with two different nose radii of 1.2 mm and 1.6 mm are used under two cutting velocity and four feed of low values to explore machinability of AISI 4340 steel during turning in dry condition. Type of chip formation, cutting forces required, etc. are noted during the experiment. The condition corresponding to good machinability is finally recommended.

Keywords*: machining, turning, machinability, carbide insert, cutting force***

1 Introduction

Material and geometry of a tool insert play vital role to have desired machinability under appropriate machining conditions. Different researchers carried out investigations to explore machinability corresponding to a workpiece-cutting tool combination. Different optimisation algorithms were also tried [1-7] to find out appropriate machining parameters. This author and his team explored turning experiments consuming less energy [8] and also the performance of a newly developed CNT-reinforced alumina tool insert [9].

Yanda et al. [10] found out the effect of cutting conditions in dry environment on material removal rate, surface roughness and tool life while turning ductile cast iron rods using TiN coated cutting tool, while Mondal et al. [11] explored machinability during turning a hard material. Ramanujam et al. [12] selected optimal machining parameters in Al-15%SiCp metal matrix composites. Selvaraj and Chandarmohan [13] reported the influence of basic cutting parameters on surface roughness of austenitic stainless steel rods during dry turning with the use of TiC and TiCN coated tungsten carbide cutting tool. Sahoo et al. [14] developed mathematical models and did parametric optimization for surface roughness in turning D2 steel using TiN coated carbide insert. Velibor and Milos [15] employed Taguchi robust parameter design for modeling and optimization of surface roughness in dry single-point turning of cold rolled alloy steel using TiN-coated tungsten carbide inserts, when Kazancoglu et al. [16] investigated turning process for evaluating an optimal parametric combination to require quite low cutting forces, and to yield quite low surface roughness with maximum material removal rate (MRR) using a combination of a Grey relational analysis (GRA) and the Taguchi method. Verma et al. [17] also derived through Taguchi method optimal cutting condition to obtain appreciably low surface roughness in turning ASTM A242 Type-1 alloy steel. The effect of cutting parameters and workpiece hardness on surface roughness and cutting force components in hard turning of AISI H11 steel was investigated by Aouici et al. [18] using cubic boron nitride. Yadav et al. [19] evaluated the relation between the change in hardness of EN 8 workpiece during turning with varying machining parameters. The same workpiece material was also machined by Vikas and Vinayak [20] to find out appropriate machining parameters. Biswas and Mandal [21], in an investigation, modeled turning process parameters to reduce frequency of tool vibration and tool wear rate substantially. Models were further optimized using Genetic Algorithm. EN-31 steel workpiece and carbide insert were used by them.

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Two types of coated carbide inserts with two different nose radii of 1.2 mm and 1.6 mm are used in the present work under two cutting velocity and four feed to explore machinability of AISI 4340 steel during turning in dry condition. Type of chip formation, cutting forces required, etc. are noted during the experiment. The aim is to recommend suitable parametric combination corresponding to good machinability.

2 Experimental Details

Turning tests are performed on a Mysore Kirloskar Ltd., Bangalore made centre lathe (model: Turnmaster, TM-35; main motor power: 2.2 kW) to turn AISI 4340 steel rod. Composition of AISI 4340 steel is given in Table 1. Its hardness is 25 HRC. For measuring chip thickness, Mitutoyo, Japan make point-edge micrometer is used. Chip reduction coefficient (CRC) is found out with chip thickness and uncut chip thickness. Tool holder (R174.3- 2020-12) used is made by Sandvik Asia Ltd., India having tool signature, -6°, -6°, 6°, 6°, 15°, 75° and two nose radii of 1.2 mm and 1.6 mm. Sandvik Asia Ltd., India made carbide tool inserts are used having specification: SNMG 120412-PF and SNMG 120416-PR. Photographs of these two inserts are shown in Fig. 1. Experimental detail is shown in Table 2.

Fig. 1. Photograph of inserts used

Table 1 Chemical composition of AISI 4340 steel used

C 0.14%	Si 0.56%	Mn 1.29%	P 0.036%	S 0.036%	Cr 1.101%	Ni 0.087%	Al 0.037%
Co 0.017%	Cu 0.137%	Nb 0.005%	V 0.011%	W 0.085%	Pb 0.013%	Sn 0.01%	As 0.053%

Table 2 Experimental Condition

Experiment set	Cutting velocity, V_c (m/min)	Feed, f (mm/rev)	Depth of cut, t (mm)	Nose radius, r (mm)	Environment
1	93, 147	0.112, 0.09, 0.071, 0.05	1	1.2	Dry
2				1.6	

3 Results and Discussion

In this investigation, values of chip reduction coefficient (CRC) are calculated, and types of chip formed and formation of built-up edge are observed. Main cutting force and horizontal cutting force components are noted. Results obtained from experiments performed as detailed in Table 2 are presented, and discussion on them are detailed corresponding to the two sets of experiments.

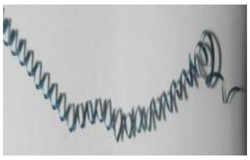
3.1 Observation and discussion on results of experiment set 1

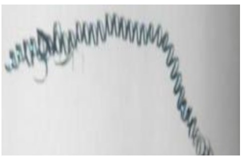
Experiment set 1 is performed on AISI 4340 rod using TiC coated carbide tool insert of 1.2 mm nose radius. Results obtained from experiment set 1 are shown in Table 3, and Figs. 2-4. No built-up edge is found in this set of experiment. CRC varies from 1.19– 2.29. Mostly chips are coiled type continuous and a few chips are irregular or ribbon type continuous.

Table 3 Experimental data in turning AISI 4340 steel with 1.2 mm nose radius in experiment set 1

Sl. No.	Diameter, mm	Spindle speed, N (RPM)	Cutting velocity, V_c (m/min)	Feed, f(mm/rev)	Depth of cut , t (mm)	Built-up edge observed	Chip reduction Coefficient , ζ	Types of chip observed
1	66	450	93	0.112	1	No	1.48	Open coil continuous, blue colour
2				0.09		No	2.29	Open coil continuous, blue colour
3				0.071		No	1.97	Open coil continuous, blue colour
4				0.05		No	1.87	Open coil continuous, blue colour
5		710	147	0.112		No	1.29	Ribbon type continuous, blue colour
6				0.09		No	1.19	Open coil continuous, blue colour
7				0.071		No	1.32	Open coil continuous, blue colour
8				0.05		No	1.66	Ribbon type continuous, blue colour

Variation of main cutting force and horizontal cutting force with feed are plotted in Fig. 3 and Fig. 4 respectively. Main force component (P_z) has its range from 55.3 N to 122.2 N. At 147 m/min cutting velocity, Vc and 0.05 mm/rev feed, low cutting force is observed that is desired. At this condition, flat ribbon type chips are formed indicating favourable machinability condition. Force increases with increase in feed on the whole, but sometimes, rate of increase in force is less. Also, higher Vc shows lesser force components that may be due to thermal softening effect.


At V_c = 93 m/min, f= 0.112 mm/rev, t = 1 mm


At V_c = 93 m/min, f= 0.09 mm/rev, t = 1 mm


At V_c = 93 m/min, f= 0.071 mm/rev, t = 1 mm


At V_c = 93 m/min, f= 0.05 mm/rev, t = 1 mm


At V_c = 147 m/min, f= 0.112 mm/rev, t = 1 mm


At V_c = 147 m/min, f= 0.09 mm/rev, t = 1 mm


At V_c = 147 m/min, f= 0.071 mm/rev, t = 1 mm


At V_c = 147 m/min, f= 0.05 mm/rev, t = 1 mm

Fig. 2. Photographs of observed chips in experiment set 1 with 1.2 mm nose radius

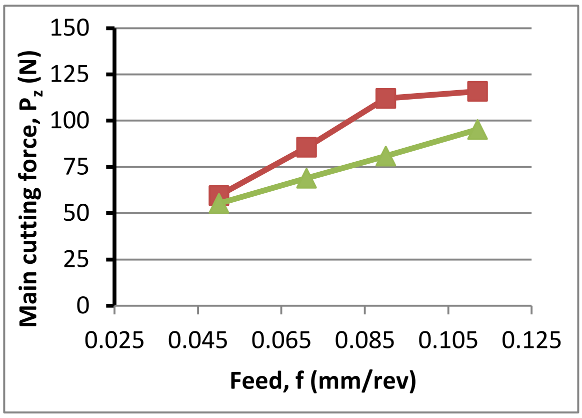


Fig. 3. Plot of variation of main cutting force with feed in experiment set 1(red line is for 93 m/min Vc, green line is for Vc= 147 m/min)

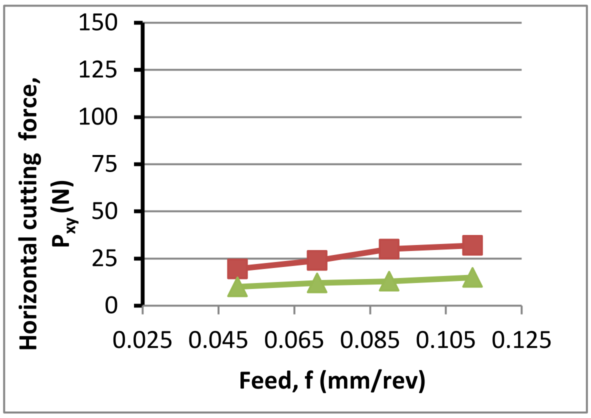


Fig. 4. Plot of variation of horizontal cutting force with feed in experiment set 1 (red line is for 93 m/min Vc, green line is for Vc= 147 m/min)

3.2 Observation and discussion on results of experiment set 2

Experiment set 2 is performed with TiC coated carbide tool insert of 1.6 mm nose radius. Results obtained from experiment set 2 are shown in Table 4. This table includes CRC values ranging from 1.32 to 2.08. Types of chips observed are listed in Table 5 and their photographs are shown in Fig. 5. It is observed that mostly chips are coiled type continuous and only one or two chips are ribbon to irregular type continuous. Coil type chips require more force for its curling, and hence, the increased force values. No built-up edge is found in this set of experiment as observed in experiment set 1 also.

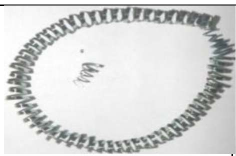
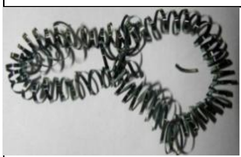
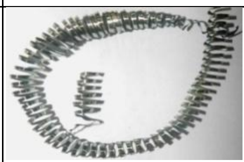
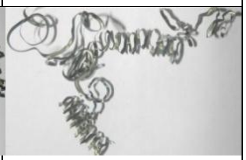
			
At V_c = 93 m/min, f= 0.112 mm/rev, t = 1 mm	At V_c = 93 m/min, f= 0.09 mm/rev, t = 1 mm	At V_c = 93 m/min, f= 0.071 mm/rev, t = 1 mm	At V_c = 93 m/min, f= 0.05 mm/rev, t = 1 mm
			
At V_c = 147 m/min, f= 0.112 mm/rev, t = 1 mm	At V_c = 147 m/min, f= 0.09 mm/rev, t = 1 mm	At V_c = 147 m/min, f= 0.071 mm/rev, t = 1 mm	At V_c = 147 m/min, f= 0.05 mm/rev, t = 1 mm

Fig. 5. Photographs of observed chips for experiment set 2 with 1.6 mm nose radius

Variation in main and horizontal cutting forces with feed at two cutting velocity are shown in Fig. 6 and Fig. 7 respectively. Main cutting force shows an increasing trend with an increase in feed at both the two cutting velocities. This trend is all but natural as increase in feed results in increased shear area that needs more shear force for deformation of enhanced shear area. However, this clear trend is not that prominent in case of horizontal cutting force (Fig. 7). Range of P_z force is from 55.3 N to 115.8 N. At 147m/min Vc and 0.05 mm/rev feed, low cutting force is observed that is desired. At this experiment set 2, clear effect of cutting velocity on force components is not visible. However, it is seen by comparing the force results of 1.2mm and 1.6mm nose radius inserts that increase in nose radius tends to require more forces as a natural phenomenon.

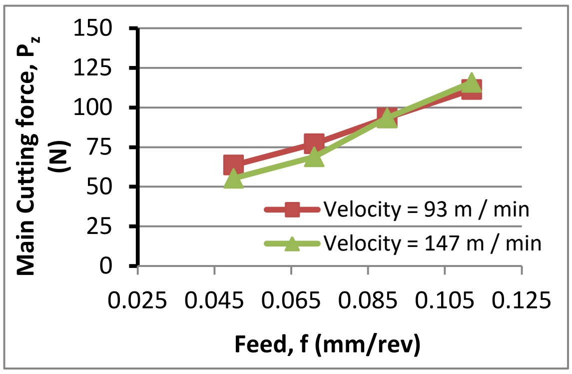


Fig. 6. Plot of variation of main cutting force with feed in experiment set 2

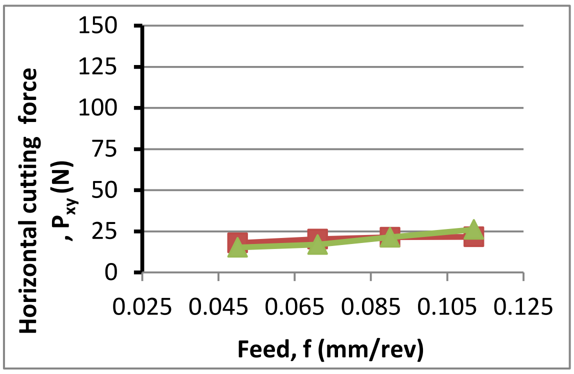


Fig. 7. Plot of variation of horizontal cutting force with feed in experiment set 2

Table 4 Experimental data obtained with 1.6 mm nose radius in experiment Set 2

Sl. No.	Diameter, mm	Spindle speed, N (RPM)	Cutting velocity, V_c (m/min)	Feed , f(mm/rev)	Depth of cut , t (mm)	Built-up edge observed	Chip reduction Coefficient , ζ	Types of chip observed
1	66	450	93	0.112	1	No	1.38	Open coil continuous, blue colour
2				0.09		No	1.49	Open coil continuous, blue colour
3				0.071		No	1.61	Open coil continuous, blue colour
4				0.05		No	2.08	Open coil continuous and some ribbon type, blue colour
5		710	147	0.112		No	1.48	Open coil continuous, blue colour
6				0.09		No	1.49	Open coil continuous, blue colour
7				0.071		No	1.32	Open coil continuous, blue colour
8				0.05		No	1.66	Ribbon type continuous, blue colour,

4 Conclusions

Following are conclusions drawn from the results obtained from the experiments performed.

1. Fairly good machinability is obtained with the two inserts at all the machining conditions chosen.

2. Favourable chip formation that is generation of flat continuous chips is obtained with 1.2mm nose radius at a cutting velocity of 147m/min at a feed of 0.05mm/rev. At this condition, cutting forces are on the whole less compared to other conditions. Hence, this condition may be recommended to yield good machinability.

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