Machinability Characteristics of Hard SCM 440 Alloy Steel using CBN and PCBN Tools by Turning Process

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Abstract

Hard turning of alloy steels are gaining momentum using super hard tools like Cubic Boron Nitride (CBN) and Polycrystalline Cubic Born Nitride (PCBN) cutting tools in many automobile and aerospace industries. The super hard cutting tools have longer tool life and replacement of tools takes long time. The production of components per cutting edge is more. Machinability of hard and difficult to cut materials by using these tools is producing good surface roughness, less tool wear, dimensional accuracy and form etc. The material used in this experiment was SCM alloy steel with hardness between 45 to 55 HRC is ideal to get low tool wear, low surface roughness. The effect of turning by parameters on the cutting force, specific cutting pressure, tool wear and surface roughness criteria were investigated during the experimentation. The surface roughness was measured by using Mitutoyo SJ 400 surface roughness tester and effect of turning parameters was examined through Scanning Electron Microscope (SEM). The research work findings will also provide useful economic turning solution by CBN and PCBN tools, which are otherwise usually machined by ceramic inserts. The present approach and tests results will be helpful for understanding the machinability of hard SCM 440 alloy steel by manufacturing engineers. The cutting velocity used in the range of 100 to 200 m/min in multiples of 25 m/min with feed rates of 0.10, 0.20 and 0.30 mm/rev and constant depth of cut of 1.00 mm.

***Keywords**: Machinability, Surface roughness, Tool wear, Specific cutting pressure*

1 Introduction

Development of new materials and manufacturing technologies influence manufacturers in adopting new methods of product production and production strategies. It is necessary to select the optimum parameters for each specific manufacturability criteria and machining operations [1-2]. Hard turning of materials is latest and fast moving technology which is being applied by most manufacturing industries to reduce the processing time to produce more parts per cutting edge and thus less cost of manufacturing. Machinability of a material is generally defined in terms of three factors: forces and power consumption, tool wear and surface finish and integrity [1]. A material with good machinability is the one requiring low poor consumption, low tool wear and producing a good surface finish with no surface damage [3]. Machinability helps to achieve less tool wear and few replacements of cutting tools. Less wear contribute to the quality final product in terms of surface roughness, dimensional accuracies and form error etc [4]. The hard machining of materials takes place with hardness ranging from 45 to 55 HRC and sometimes up to 65 HRC. Machining is a finishing process with specified dimensions, tolerances and surface roughness, the type of surface that a machining operation generates and its characteristics are of great importance in manufacturing [5]. The operating parameters of the machining factors by considering the machinability criteria the production rates and excellent output such as low cutting forces, surface finish, tool life, power consumption and dimensional accuracies can be obtained with conventional machining methods if the unique characteristics of this material are taken into account [6]. Machinability was much affected by chip thickness ratio, shear angle; surface integrity and chips are of prime importance.

2 Experimental works

The turning experiment was carried on NC lathe Harrison 400 using CBN and PCBN tools. The cutting forces were measured using Kistler type 9265 B dynamometer with multi-channel amplifier type - 5019 A and data acquisition system and all forces were measured on line. The turning was carried for 150 mm length and maximum length of 750 mm. The cutting parameters are 100, 125, 150, 175 and 200 m/min with feed rate of 0.10, 0.20 and 0.30 mm/rev with constant depth of cut of 1.00 mm. The tools used were CBN and PCBN inserts. There were three cutting edges in each insert and 15 cutting edges were available for turning. For every 150 mm length of turning, surface roughness, flank wear, crater wear were measured using Mitutoyo SJ 400 tester, Joel 6380 LA scanning electron microscope (SEM) respectively.

The CBN tool was manufactured by M/s Mitsubishi and PCBN tool by M/s Kennametal. The tool holder used was MTJNR2020KL16N. The tool signature are, rake angle -6°, side rake -6° and end clearance angle of 27° with nose radius of 0.80 mm for both inserts. The work material used was hard SCM 440 alloy steel. The size of the material was 50 mm diameter and 300 mm length. The work material was induction hardened and hardness of 45 to 55 HRC was maintained. The chemical composition, mechanical properties and operating parameters are shown in the Tables 1, 2 and 3 respectively.

Table1: Chemical composition of work piece materials

Material	C	Mn.	Si.	Cr	Mo	P	S
SCM 440	0.35-0.43	0.75-1.00	--	0.80-0.75	0.15/0.25	- -	- -

Table2: Mechanical properties of work piece materials

Material	Tensile strength (MPa)	Yield strength (MPa)	% of Elongation
SCM 440	664	556	--

Table3: Operating parameters

Sl.No.	Parameters	Range
1	Cutting velocity	100 -200 m/min
2	Feed	0.10, 0.20 & 0.30 mm/rev
3	Depth of cut	1.00 constant in mm

3 Results and discussions

3.1 *Surface roughness*

Surface roughness of the turned work material mainly depends on the cutting conditions. Surface quality plays vital role in functioning and fatigue life of the product. Figures 2 and 3 show the influence of cutting velocity on surface roughness during dry turning of SCM 440 alloy steel. The surface roughness is relatively low at high cutting velocity and high at low cutting velocity for both 150 mm and 750 mm length of turning. The quality surface roughness by CBN tool is better than PCBN tool. It was observed that high value of surface roughness was due to hard carbide particle present in the matrix in the material. The surface roughness increased with increase in feed rates by both tools. When the tool completes 750 mm length of turning, flank wear formed and was responsible for increase in the surface roughness. The cutting velocity between 150 to 175 m/min gives optimum roughness because after 175 m/min cutting velocity the trend is increasing due to rapid tool wear rate.

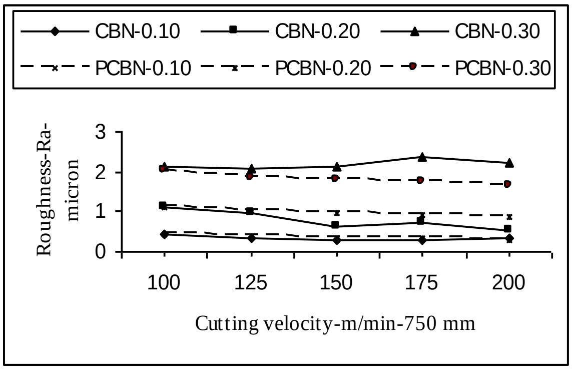


Figure 1: Variations in roughness by CBN and PCBN tools after 150 mm length of turning

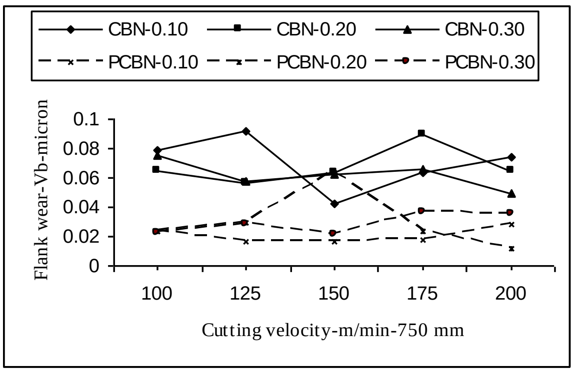


Figure 2: Variations in roughness by CBN and PCBN tools after 750 mm length of turning

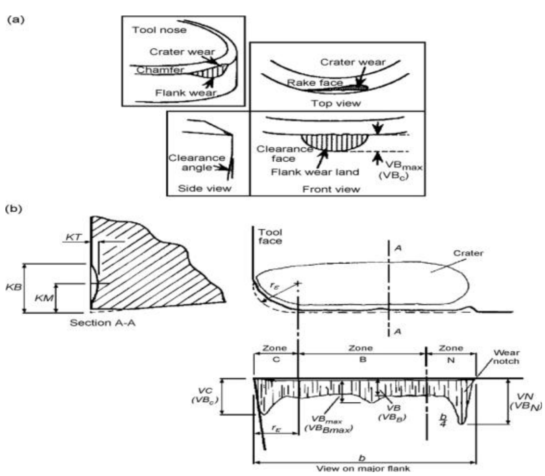


Figure 3: Various wears in single point tool [8, 9]

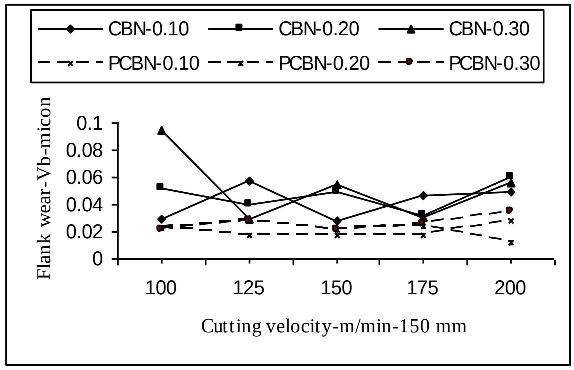


Figure 4: Variations in flank wear by CBN & PCBN tool after 150 mm length of turning

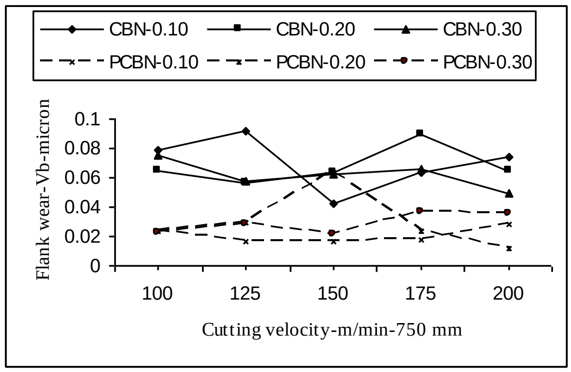


Figure 5: Variations in flank wear by CBN & PCBN tool after 750 mm.

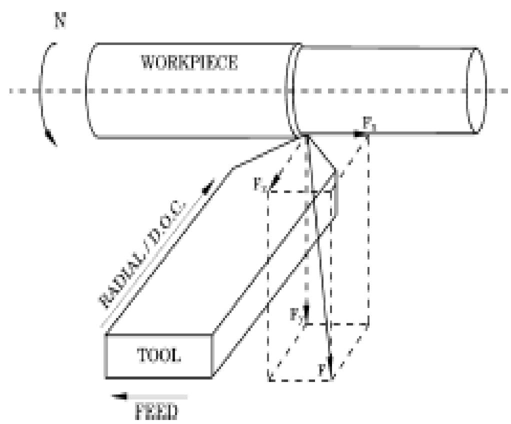


Figure 6: Forces acting on single point tool [10]

3.2 *Flank wear*

Tool wear mechanisms are generally influenced by three phenomenon: namely thermal softening, diffusion and notching at the depth of cut and trailing edge. Nickel base super alloys have a tendency to work harden and retain the major part of their strength during machining [7]. Flank wear has a strong influence on the surface finish, integrity and dimensional accuracy of the machined part while crater wear affects process reliability. Flank wear and other wears is depend very much on the cutting condition, tool geometry, hardness of material and others. Figure 3 shows the various tool wear which are formed on a single point tool. The tool life criteria used in this study is flank wear of 0.30 mm as per ISO standard. The variations of flank wear caused by cutting velocities and feed rate for a constant depth of cut are shown in the Figure 4 and 5. The temperature generated shared by three areas - work material, tool edge and chip. The heat at cutting tip was most affected and softens the cutting edges. The volume of the work material is more than cutting tool edge and tool edge makes quick softening. This tool edge is much affected by plastic deformation. Therefore, the extent of flank wear and cutting edge deformation increased with cutting velocity. The flank wear formed by CBN tool is much more than PCBN tool. The cutting velocity of 150 to 175 m/min gives optimum result and gives a uniform wear. At this value, the wear rate was more rapid which results in short tool life. The crater wear formed at chamfer edge of the tool which is not preferred. The crater wear at chamfered edge weaken the tool and stress at cutting edge chip off. This would increase the cutting force due to more effort required to plastic deform the material. Figures 11 and 12 show the flank wear and crater wear formed by CBN and PCBN tool. The crater wear at cutting velocity of 200 m/min with feed rate of 0.30 mm/rev has scored the rake face of the tool. The scoring has occurred due to thermal softening of the cutting edge and shown in the Figure 11 (d). The crater wear also formed at chamfer cutting edge while using PCBN tool and shown in the Figure 12 (a & b). The Figure 13 shows the analysis by EDS process on the diffusion of materials. Due to high temperature at tool tip, diffusion of work material deposited on the rake face of the tool.

3.3 *Cutting forces*

In turning, three force components exists i.e. cutting force F_Y acts along the direction of cutting velocity which is tangential to turned surface. This is a major component of cutting forces. The forces acting on a single point tool is shown in the Figure 6. The feed force F_X acts along the direction of tool travel or feed direction and radial force F_Z acts normal to the turned surface. Cutting force and feed force plays major role in determining the machinability of any material. Therefore cutting force and feed force were taken into consideration to determine the machinability. Cutting force is an important parameter that decides the power requirements of a machine tool. It also influences tool wear. The cutting forces increases with increased in feed rates due to less time required to plastically deform the work material. Generally as the cutting velocity increases, the force decreased. In this research, as the cutting velocity reduced or almost constant at low feed rate by CBN tool and cutting velocity with high feed rates increased the forces by CBN tool due to fact that coefficient of friction between the tool and the work material compared to high cutting velocity and low feed rates. The PCBN tool able to deform the material much easier than CBN tool due to its strength of the tool and decrease the cutting forces at all feed rates. At the end of 750 mm length of turning, flank wear was more and this makes cutting difficult to cut and increased the forces. However, the PCBN tool produced low cutting force. Figures 7 and 8 show the cutting forces for 150 mm and 750 mm length of cutting respectively. The variation in feed forces was due to flank wear and crater wear while turning 750 mm length.

3.4 *Specific cutting pressure (β)*

The specific cutting pressure is also chosen as another process indicator to determine the machinability of materials. The specific cutting pressure is usually influenced by parameters like cutting speed, feed rate, and depth of cut, material, and variation in the cutting forces. The specific cutting pressure is largely on area of the chip removed (product of depth of cut and feed rate). The quality of the machine surface is significantly influenced by cutting wedge, cutting force and specific cutting pressure which are indirectly affect the quality.

The specific cutting pressure $\beta = F_Y / A = F_Y /$ feed rate and depth of cut ($N\ mm^{-2}$) where F_Y is the cutting force (Newton), A is the area of the cutting edge, f is the feed rate (mm/rev) and d is the depth of cut (mm). In general, the specific cutting pressure (β) varied due to change on the cutting speed, feed rate and depth of cut. As the feed rate increased with cutting speed, the β increased. Figure 9 & 10 shows the graphical representation of specific cutting pressure β against cutting velocity for both tools.

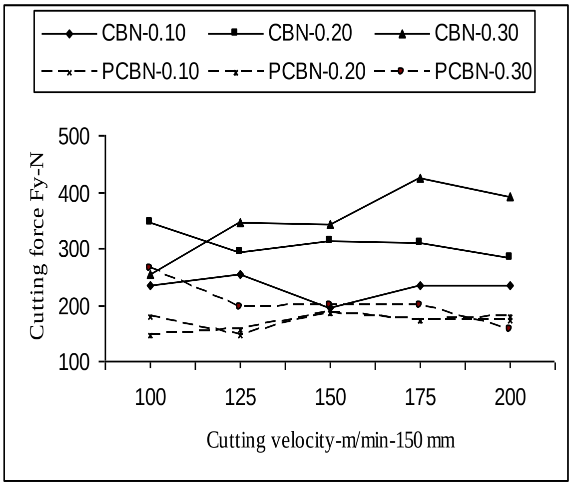


Figure 7: Variance on cutting force by CBN & PCBN tool after 150 mm length of turning

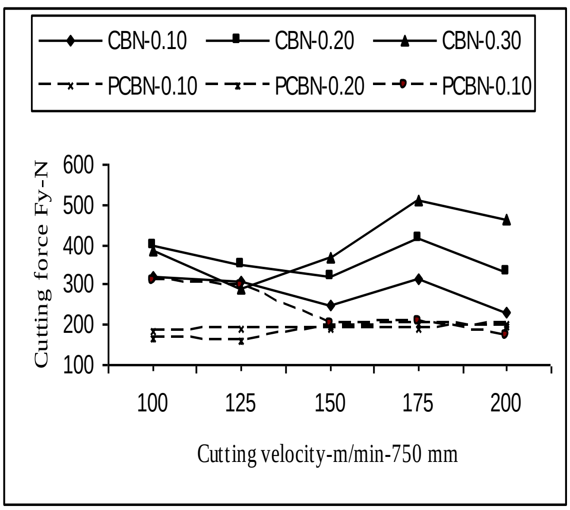


Figure 8: Variance on cutting force by CBN & PCBN tool after 750 mm length of turning

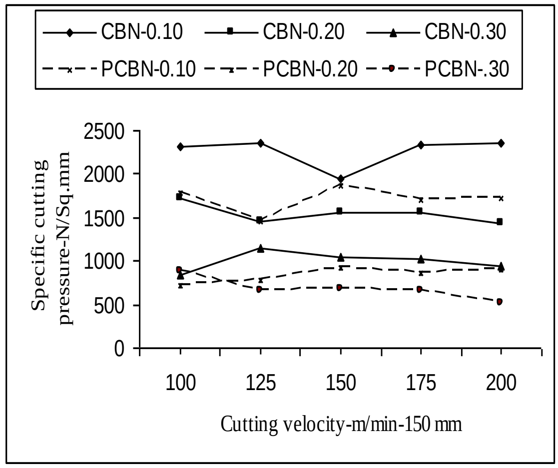


Figure 9: Variations on cutting pressure by CBN & PCBN tool after 150 mm length of turning

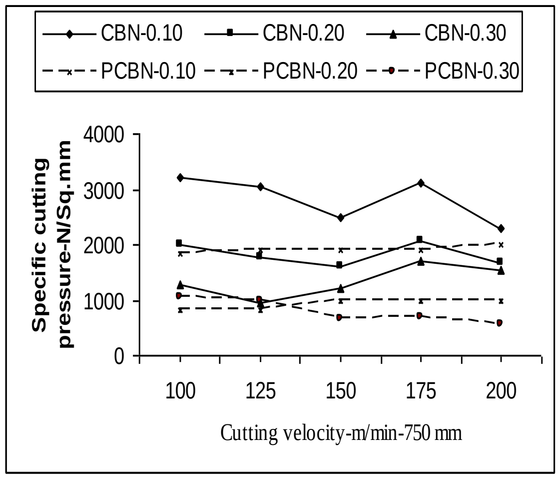
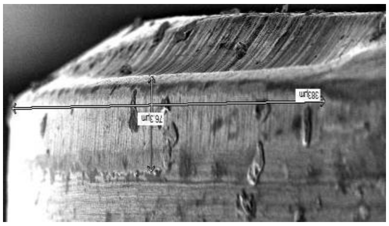
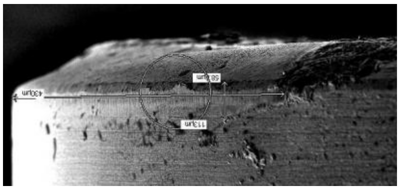


Figure 10: Variations on cutting pressure by CBN & PCBN tool after 750 mm length of cutting

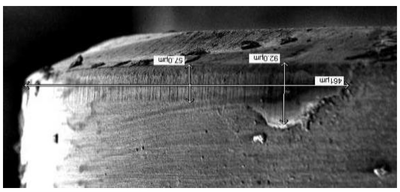
The specific cutting pressure is a function of cutting force and this decreased as the cutting speed increased for a given feed rate and depth of cut. At low feed rates, the material is subjected to low strain rate. The reduction or maintaining the same level of β was due to shear strength and temperature of the work material. Under no tool wear conditions, the specific cutting pressure should decrease but if there are abnormal variations in the tool wear, the forces also varied which lead to variations in the β. The specific cutting pressure of CBN tool was more than PCBN tool.



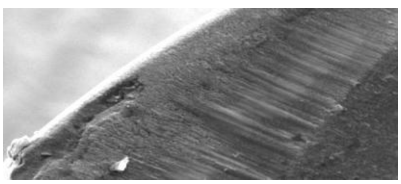
(a)



(b)

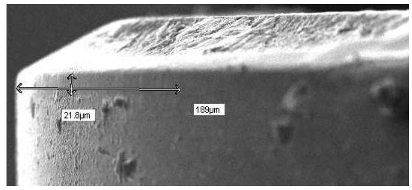


(c)

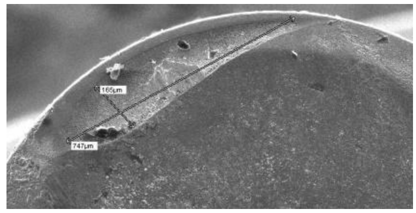


(d)

Figure 11: SEM images on CBN tool - (a). 200-0.10-750, (b). 125-0.30-750, (c). 125-0.20-750, (d).200-0.30-750.



(a)



(b)

Figure 12: (a). Velocity 200-feed rate 0.10- length 600 mm–flank wear and crater wear by PCBN tool.

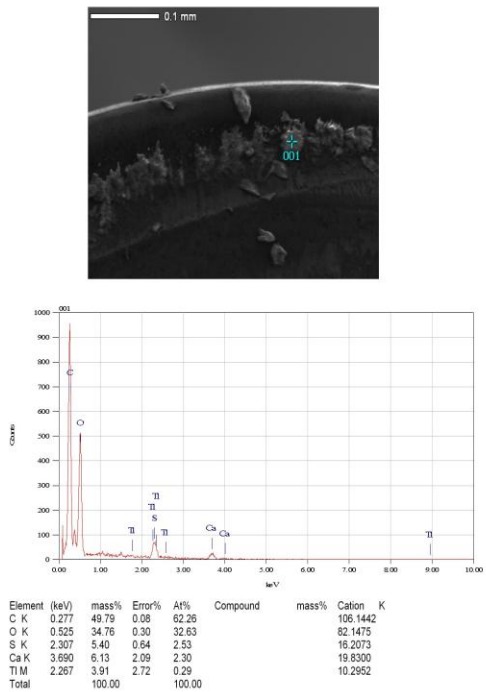


Figure 13: EDS analyses at 200 m/min at feed rate of 0.10 mm showing diffusion of work material.

4 Conclusions

Based on the performance and test results, of the various set of experiments performed to analyze the influence of cutting parameters on the machinability characteristics of SCM 440 alloy steel, the following conclusions are drawn:

1. The cutting force magnitude is high than feed force. Decrease in both cutting force and feed force is due to decrease in contact area and drop in the shear strength, which was increase in the temperature at high cutting velocity. The forces are near linear between 150 to 175 m/min at feed rate between 0.10 and 0.20 mm/rev. The cutting force produced by PCBN tool was lower than CBN tool.
2. Specific cutting pressure β can be referred as one of the important process parameter to know the status of the cutting edge. The β variation can be attributed to the instability of the cutting edge.
3. The main type of wear is abrasion and less by abrasion. At certain cutting velocity, diffusion of work material was noticed on the rake face of the tool. The crater wear formed in the chamfered edge which is detrimental to failure of the cutting edge.
4. The optimum parameter found between 150 to 175 m/min with feed rate between 0.10 to 0.20 mm/rev for roughness and tool wear.

   In order to find machinability of cutting tools, the CBN performed good on surface roughness and PCBN tool found good in resisting tool wear.

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