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THE INFLUENCE OF CUTTING PARAMETERS ON CUTTING FORCE AND SURFACE ROUGHNESS OBTAINED BY DRY TURNING OF AISI-52100

S. Padhi, R. K. Mohanty, S. K. Pattnaik, M. Behera and S. K. Sarangi
Department of Mechanical Engineering,
Veer Surendra Sai University of Technology Burla,
Sambalpur-768018, India

ABSTRACT

Often, hard turning substitutes as an economical alternative to machining bearing steel. In this research, the investigation has been carried out to know impact of cutting parameters upon cutting forces and surface roughness. Five different advanced cutting tools are utilized having same nose radius. The tools are WC (tungsten carbide) tool SPGN type, PVD (Physical Vapor Deposited) TiN coated WC tool, WC + Ti (C, N) + Al_2O_3 *multicoated tool, Ceramic (*Al_2O_3*) tool and CBN (Cubic Boron Nitride) tool. Under the conditions of constant depth of cut as 0.2mm with various cutting speeds (106, 136, 166 m/min) and feeds (0.06, 0.09, 0.12 mm/rev.) discussions have been made about the cutting forces, tool wear and surface roughness. The results found out from experiments showed that WC tool produced less cutting force among all tools. On the other hand CBN is producing very good surface finish with negligible tool wear. At higher speed (166 m/min) CBN produced less cutting force with better surface finish.*

Key words: Force Measurement, Hard Turning, Surface Roughness, Tool Wear.

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1. INTRODUCTION

In the current world hardened steel machining is having greater requirement particularly in industry and science research fields. Normally CBN tool is recommended to machine hardened steel. The limitation is that the CBN tool inserts cost 10 times more than the cemented carbide tools [1], ceramic tools and different coated tools. So a comparison should be done with these tools so that a cutting tool with a better result at all aspects could be chosen. Dry machining is always preferable as compared to the wet machining and MQL techniques [2-4]. The wet machining requires extra attachments for circulating cutting fluid, its filtration and replacement which will increase the machining cost as well as the maintenance cost [5]. The grinding has been found to be comparatively costlier, so hard turning would be a better alternative [6]. The CBN tools showed both crater and flank wears. The process of abrasion due to material available with harder material is main cause of flank wear [7, 8]. The crater wear is produced because of friction present between the tool rake surface and the chip. Again the flank wear greatly affects the machined part quality (finish, geometric accuracy, integrity of surface) [9]. Influence of cutting parameter on hard turning has great impact during machining [10].

The cutting force of the tool material should be minimized because the cutting force directly affects the life of both cutting and machine tool. More force of cut produces more vibration, noise and stress on the tool used to cut which straightly varies finish. Because the cutting force is directly correlated with parameters as feed, speed, depth of cut and performance of cutting like accuracy of surface, tool wear, cutting temperature, tool damage and vibration [11]. The cutting force is comparatively low for high speed machining, because with increase in speed the cutting force decreases so the energy consumption also reduces.

From the literature following facts can be noticed. Many researchers investigated the impacts of different parameters of cuttingupon cutting force using either single or two cutting tools. Some proposed for machining with diamond tools which may increase the production cost as diamond tools are much more costly. This study attempts to show the influence of cutting parameters upon cutting force and surface roughness. Five numbers of different advanced cutting tools were utilized for proper investigation. The tool wear mechanism are also studied to check the tool life.

2. EXPERIMENTAL DETAILS

2.1. Workpiece Material

A bearing steel of diameter 150 mm and length 420 mm AISI 52100(100Cr6) was used as the work material. The machining is carried out by precision Gottwaldov Capstan lathe. The composition of workpiece was [C(0.99%),Cr(1.4%),Ni (1.4%),Mn(0.39%), Si(0.16%)] and balance percentage as Fe.

2.2. Cutting Tool

Five types of cutting tool used to machine hardened steel are; Tungsten Carbide tool (WC), TiN coated Tungsten Carbide tool (WC+TiN), Multicoated tool [WC+Ti(N,C)+Al_2O_3], Ceramic tool (Al_2O_3), CBN tool.The specifications are shown in the Table 1.

Table 1 Specification of Tool with Tool Holder

Cuttingtool Number	Material of Cutting tool	Designation	Tool Holder
1.	Cemented Carbide	SNGA120408 PR 4035	PSBNR 2020 K12
2	Cemented Carbide + PVD TiN	SNGA120408 PR 4035	PSBNR 2020 K12
3.	Cemented Carbide + CVD MT-Ti(C,N) + TiN+Al_2O_3	SNMG 120408 PR 4235	PSBNR 2020 K12
4	Ceramic Al_2O_3 tool insert + PVD TiN Coating	SNGA 120408T01525 6050	CSRNR 2525M 12-4
5.	CBN + PVD TiN Coating	SNGA 120408 SO1030A 7025	CSRNR 2525M 12-4

2.3. XRD plot of Cutting Tool

- Characterization of the cutting tools

XRD is one of the best ways to properly identify the cutting insert material. So before machining it is very much essential to characterize the tool materials. The XRD used for the analysis wasModel: Shimadzu, XRD – 7000L, Japan; Scanning speed:5000/min,Scanning radius: 200-275 mm, Scanning mode: θ-2θ (independent), Minimum step angel: 0.00010.

Sharp peaks of WC can be seen at various planes like 001, 100, 111 and 102 shown in Fig.1. The XRD result of TiN coated WC tool is shown in Fig.2 and TiN appears at different planes of 111, 200, 300 and 222 respectively. The TiC present at different planes and peaks are shown in fig.3, planes are 111, 200, 300 and 222 respectively. The ceramic tool (Al_2O_3) is having only one element within it and it appears at various planes of 111, 201, 009 and 119 which are shown in fig.4. The XRD result of cubic boron nitride (CBN) tool is shown in fig.5 and is available in 110, 111, 211 and 300 planes respectively.

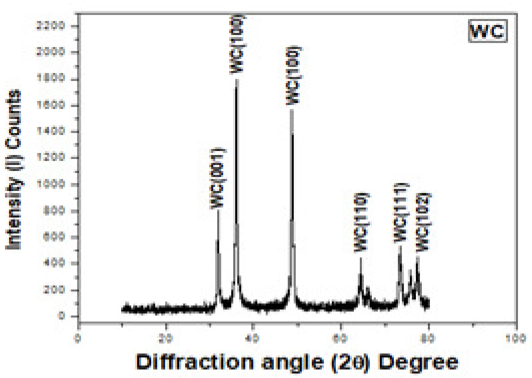

Fig.1 XRD image of Tungsten Carbide Tool (WC)

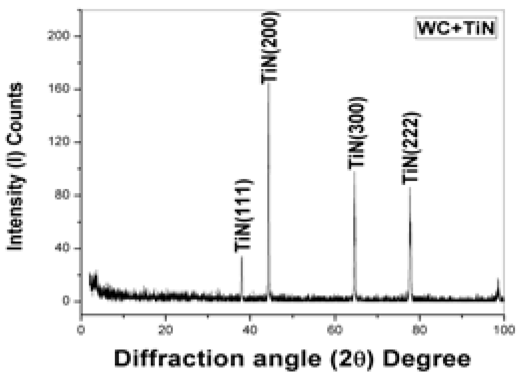

Fig.2 XRD image of TiN Coated Tungsten Carbide Tool (WC+TiN)

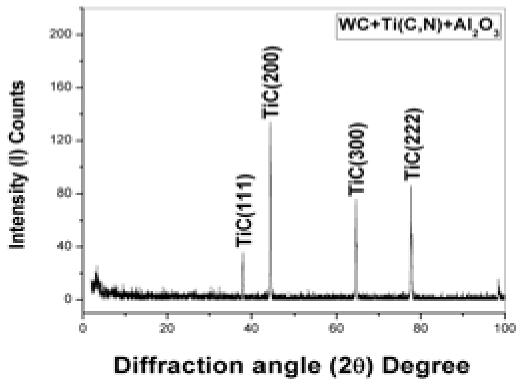

Fig.3 XRD image of Multicoated Tool (WC+Ti (N, C) +Al_2O_3)

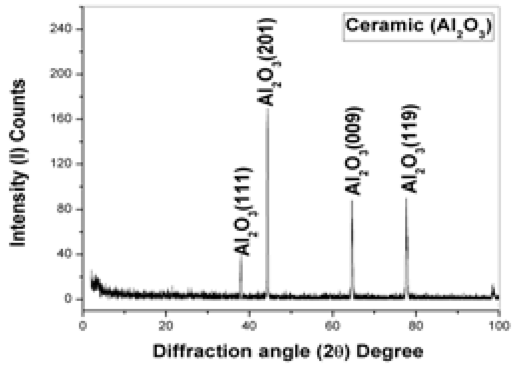

Fig.4 XRD image of Ceramic Tool Al_2O_3

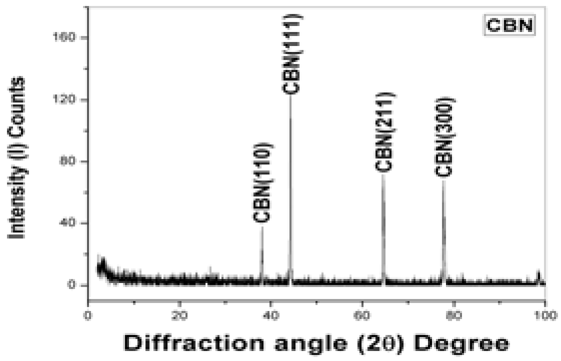

Fig. 5 XRD image of CBN ToolMachine tool:

The Gottwaldov semiautomatic capstan lathe machine (Czechoslovakia, zps) is used for the experiment. This is equipped with centre height 230mm, Swing over cross slide: 255 mm, the speed of the spindle varies from 28 to 1400 rpm and a 7kW with 5 HP motor drive was used for the test togetmore rigidity in machine system. Work material was placed in between head stock (three jaws) and tail stock. To avoid any accident and better accuracy for the experiment, run out measure on head stock side was 10 μm and tail stock side was 20 μm with bed length as 800 mm (max.).

2.4. Cutting Conditions:

For this experiment the cutting condition is taken as dry along with constant depth of cut. The values of three variable cutting parameters are shown in the table 2.

Table 2 Cutting parameters and their levels

Factor	Low level	Centre level	High level	Unit
A: Speed (v)	106	136	166	m/min
B: Feed rate (f)	0.06	0.09	0.12	mm/rev
C:Depth of cut (d)	0.2	0.2	0.2	mm

2.5. Cutting force measurement:

The Kistler piezoelectric force dynamometer (9257B) and eight-channel charge amplifier (5070A) are used to measure cutting forces for turning operation with the machining duration of 30-35 seconds. The Data-acquisition hardware NI ENET- 9163 gets data from dynamometer. Then it stores the data in the computer with the help of LABVIEW-2015 software.

2.6. Surface roughness measurement

Now a day's diamond stylus instrument is used for analysing the machined surface smoothness or roughness. The surface for analysis is being traversed by the stylus. The transducers convert the stylus motion into horizontal and vertical tracks. The surface roughness were measured using Tylor Hobson talysurf (sutronic S-128) having cut-off length as 0.8 mm. The average surface roughness (Ra) was taken after the machining.

2.7. Tool wear

The tool wear was analysed using Scanning Electron Microscope (SEM; Model SU3500; Hitachi made) attached with Energy Dispersive X-ray Spectroscopy (EDS). The crater wear at the rake surface and the flank wear at the flank of the cutting tools were studied.

3. RESULT AND DISCUSSION

3.1. Cutting force

- The cutting forces are shown in fig.6-8 having a constant feed with variable velocities

The fig.6-8 clearly show that the cutting force provided by the WC tool were comparatively less among all cutting tools, because the WC tool is having lesser nose radius (0.4mm) whereas other tools are having larger nose radius (0.8mm). It is a well-known phenomenon that for smaller nose radius, the cutting force also decreases. However, among all cutting tools having same nose radius the CBN tool produced the best result even at various speeds. At higher speed (166m/min) it produced less cutting force than WC tool, whereas multi coated tool produced higher cutting force. A similar type of result was observed and WC tool insert produced better result at lower speed. In case of CBN tool the cutting force reduced when the speed increased, in this experiment also the multi coated tool produced more cutting force among all. In fig.8 at lower speed (106 m/mm), the cutting force produced by the WC tool was very less (near about 20 N). With larger feed rate (0.12 mm/rev) the CBN tool produced a constant cutting force independent of speed. At this larger feed (0.12 mm/rev) the multi coated insert produced lesser cutting force from its previous results.

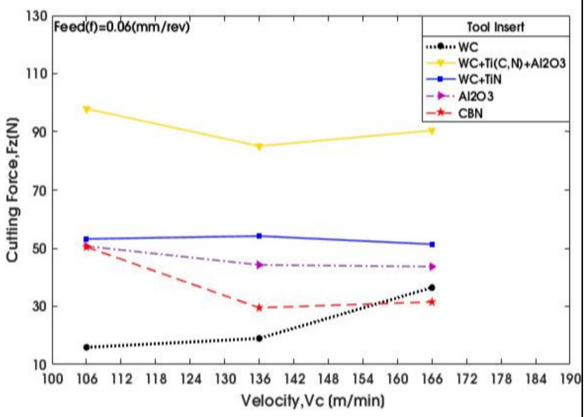

Fig.6 Cutting force vs. Velocity at constant Feed (0.06 mm/rev), speed (106, 136, 166 m/min)

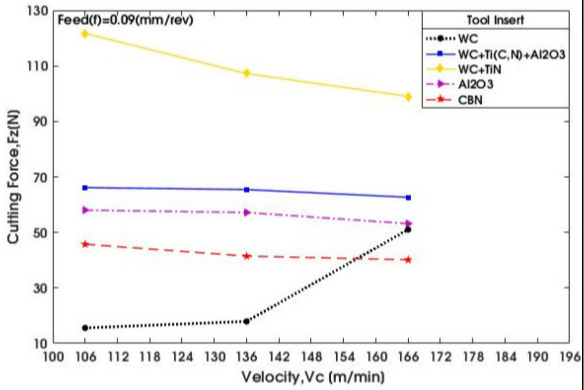

Fig.7 Cutting force vs. Velocity at constant Feed (0.09 mm/rev), speed (106, 136, 166 m/min)

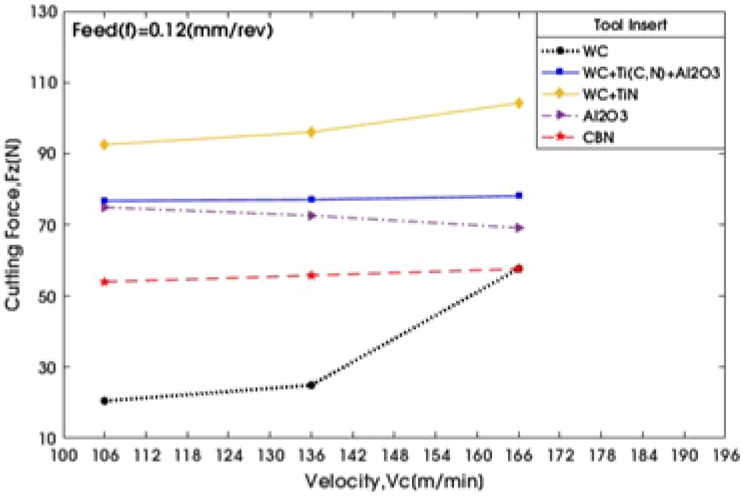

Fig.8 Cutting force vs. Velocity at constant Feed (0.12 mm/rev), speed (106, 136, 166 m/min)

- The cutting forces are shown in Fig.9-11 at constant speed and various feed rates

The cutting forces produced by the cutting tool at various speeds are shown in Fig. 9-11.

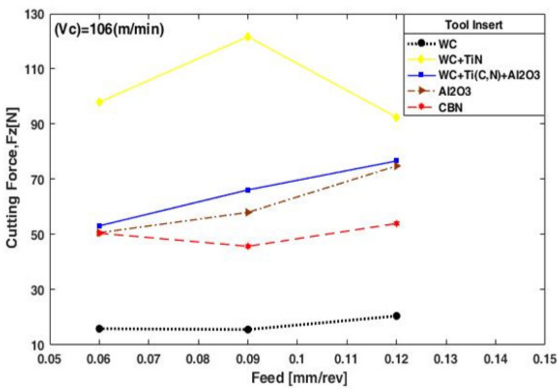

Fig.9 Cutting force vs. Feed at constant Speed (106 m/min), Feed (0.06, 0.09, 0.12 mm/rev)

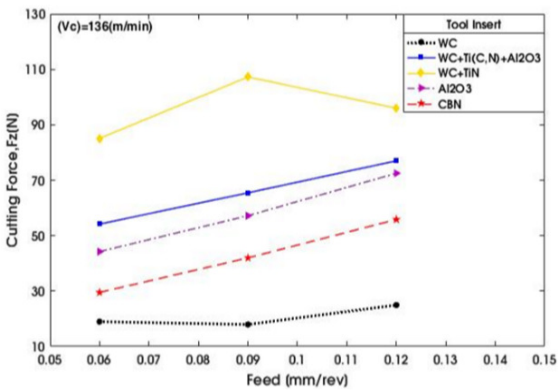

Fig.10 Cutting force vs. Feed at constant Speed (136 m/min), Feed (0.06, 0.09, 0.12 mm/rev)

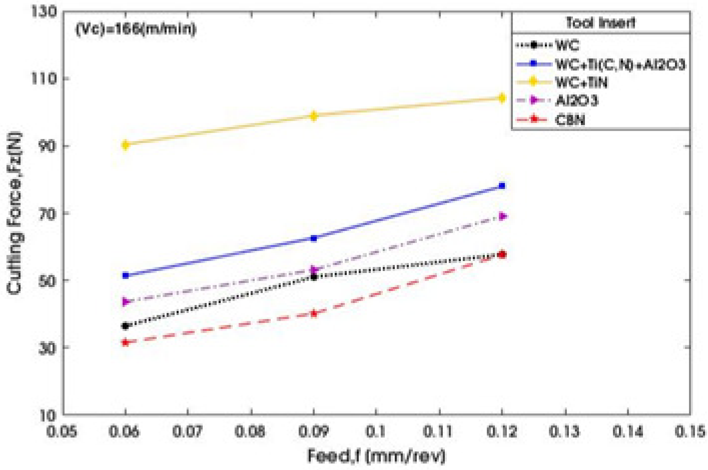

Fig.11 Cutting force vs. Feed at constant Speed (166 m/min), Feed (0.06, 0.09, 0.12 mm/rev)

Similar scenario can be observed like previous fig. 6-8, the WC tool produced lower cutting force among all cutting tools at lower and medium speed as shown in fig. 9 and 10 respectively. But at higher speed (166 m/min), the CBN tool produced less cutting force than WC and other cutting tools which can be noticed from fig.11. Whereas, the TiN coated WC tool produced more cutting force at all cutting speed, but average cutting forces were produced by multi-coated and ceramics tool.

3.2. Surface roughness

- The surface roughness at constant feed and speed are shown in fig.12-14.

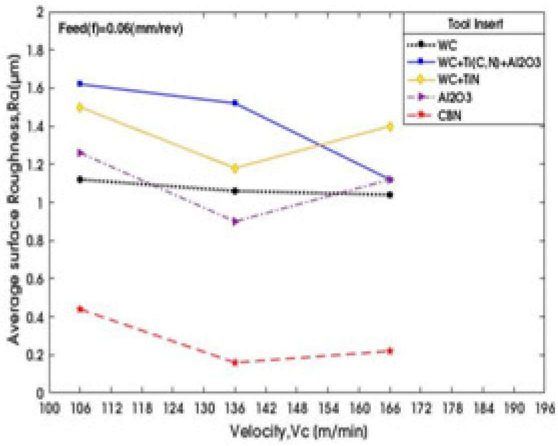

Fig.12 Surface Roughness vs. Velocity at constant Feed (0.06 mm/rev), speed (106, 136, 166 m/min)

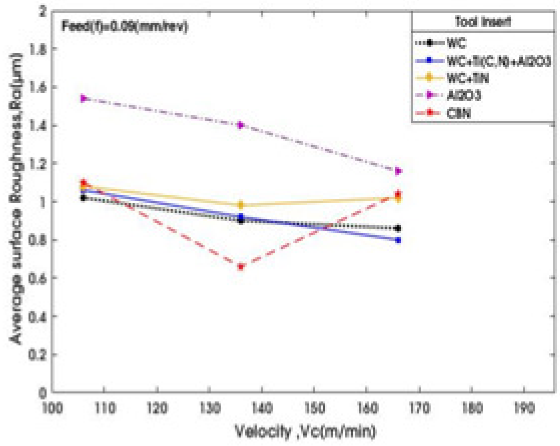

Fig.13 Surface Roughness vs. Velocity at constant Feed (0.09 mm/rev), speed (106, 136, 166 m/min)

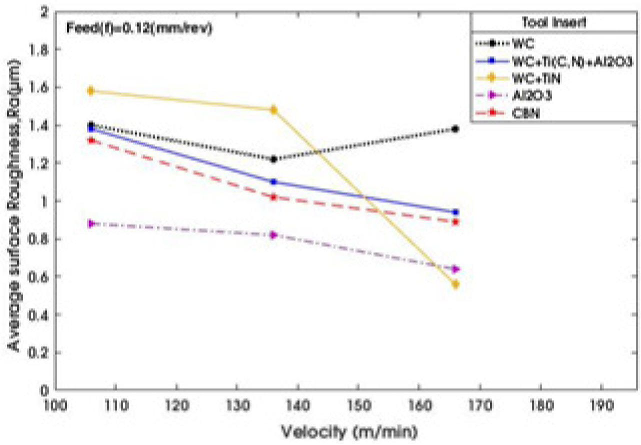

Fig.14 Surface Roughness vs. Velocity at constant Feed (0.12 mm/rev), speed (106, 136, 166 m/min)

The CBN tool produces minimum surface roughness as expected, because it is well known that higher surface finish can be obtained with a larger nose radius (0.8 mm). Except WC tool, other tools are having same nose radius. But the extreme hardness and linear grain sizeof CBN helps in better machining. The WC cutting tool produced a constant surface finish, whereas the ceramics tool (Al_2O_3) produced a lower surface finish at medium speed (136 m/min) but it produced best surface finishwith higher speed. The multi coated tool produced a better surface finish at medium and higher feed rate which are 0.09 mm/rev. and 0.12 mm/rev. respectively. The TiN coated WC tool produced lesser surface roughness at medium feed rate (0.09 mm/rev) whereas at lower and higher feed rate (0.06mm/rev, 0.12mm\rev) surface roughness increased. In all three cases the WC tool produced an average surface finish shown in fig.12-14.

Fig.15-17 Shows that CBN tool produced a better surface finish at low feed rate and it gradually decreased when the feed rate increased. Whereas in case of ceramics tool the surface roughness decreased at higher feed rate and the surface roughness more at medium feed rate (0.09 mm/rev.). In case of WC cutting tool average surface roughness was achieved at low and medium feed rate and surface roughness increased at higher feed rates (0.12 mm/rev.). But in case of the multicoated tool the surface roughness was the lesser at medium feed rate and the roughness value was more at lower and higher feed rate. Similar type resultwas observed in case of TiN coated WC cutting tool where roughness was the lesser at medium feed rate (0.09 mm/rev) and higher at low and high feed rate.

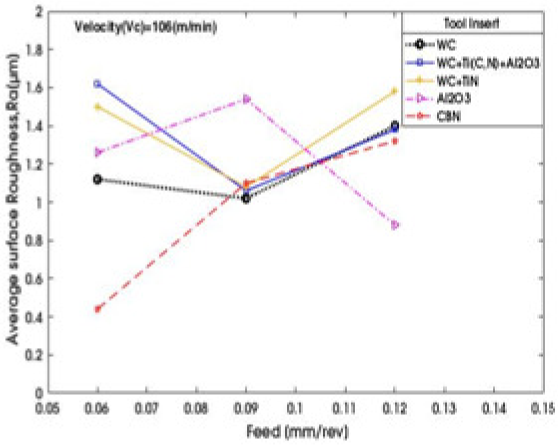

Fig.15 Surface Roughness vs. Feed at constant Speed (106 m/min), Feed (0.06, 0.09, 0.12 mm/rev)

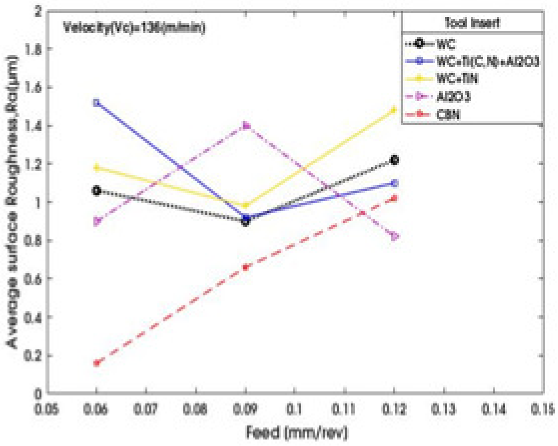

Fig.16 Surface Roughness vs. Feed at constant Speed (136 m/min), Feed (0.06, 0.09, 0.12 mm/rev)

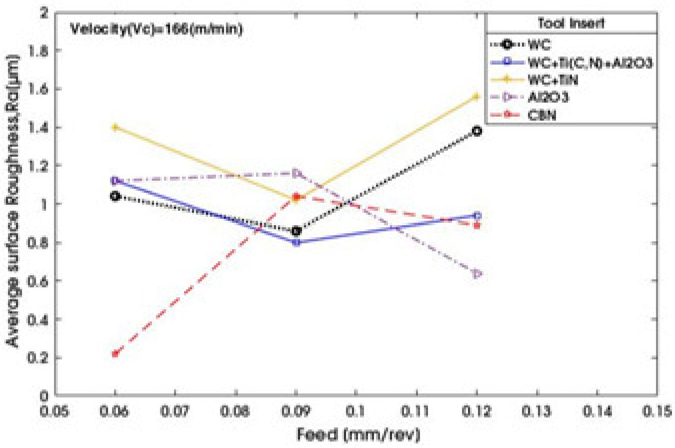

Fig.17 Surface Roughness vs. Feed at constant Speed (166 m/min), Feed (0.06, 0.09, 0.12 mm/rev)

3.3. Tool wear

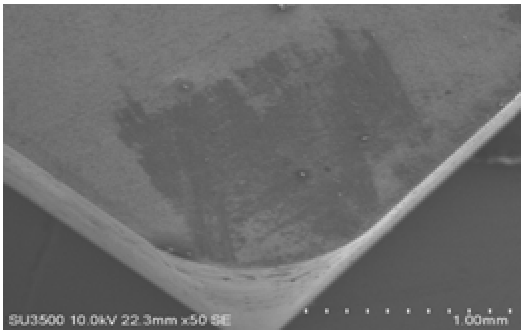

Fig.18 SEM image of WC

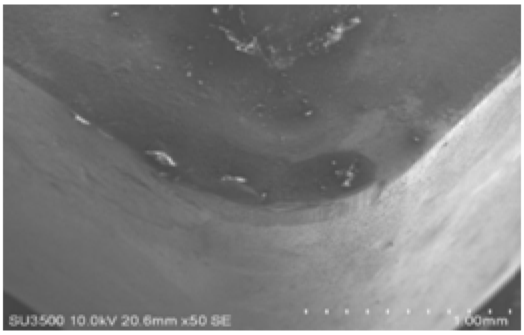

Fig.19 SEM image of WC+TiN

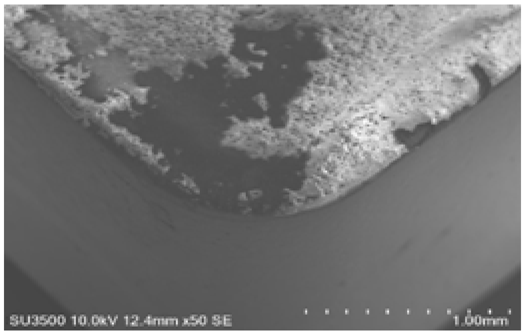

Fig.20 SEM image of WC+Ti (C, N) +Al_2O_3

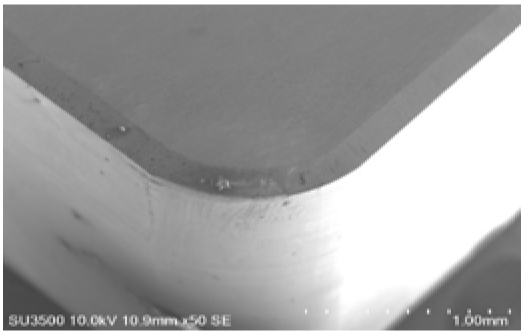

Fig.21 SEM image of Al_2O_3

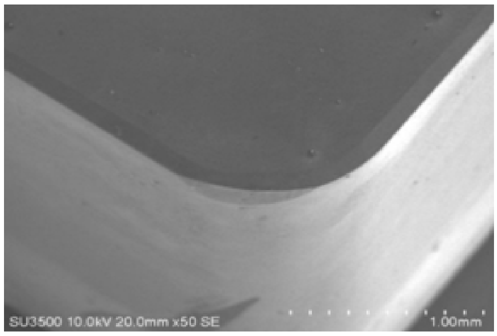

Fig.22 SEM image of CBN

In machining tool wear is directly related to the tool life and production cost. It is one of the important region of the tool failure. The SEM images of all five tools were shown in fig.18-22 are captured in such a manner that the rake face and the flank of the tool is clearly visible. It is observed that there was a crater wear formed on the rake surface of the tool due to the friction between the chip and the tool. So it may not be a good tool for machining steel where for TiN coated WC tool there is no crater wear formed because it's having a chip breaker on its surface which breaks the continuous chips produced during machining of the ductile materials. Preferablythe discontinuous type chip allows to avoid the crater wear. Some coating is chipped out at the nose of the tool due to friction between workpiece and tool but there is no flank wear. Ceramic tool (Al_2O_3) is a very good tool material for machining harder materials. It has a negative rake angle which is preferable for the larger tool life and tool strength. There is almost negligible tool wear which can be noticed from the figure. Similarly CBN is also a very good material for hard turning. Almost no tool wear was occurred during machining which makes it a best cutting tool for machining of hard material.

4. CONCLUSION

Hard turning of bearing steel (AISI 52100) was carried with five advanced cutting tools under various cutting parameters. The cutting force, surface roughness and tool wear were analysed. From that the following conclusions are made.

- From cutting force point of view, WC SPUN produced comparatively less cutting force compared to other cutting tool, because it's having a lower nose radius. But its main disadvantage is that it has lesser tool life.
- After WC tool CBN produced lesser cutting force, but at high speed (166 m/min) it produces an even lesser force than the WC tool.
- CBN tool produced better surface finish at all cutting conditions except at high feed rate (0.12 mm/rev). Whereas, ceramic tool produced minimum roughness at higher feed rate so it also can be concluded that after CBN ceramics tool will be a better alternative.
- From tool wear point of view, both CBN and Ceramic tool were having longer tool life.

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