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Study of the surface integrity and heat measurement of hard turning of hard chrome coated EN24 substrate

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Abstract

The principal aim of this paper is to hard turn the hard chrome plated EN24 substrate using TiAlN coated PcBN inserts. The variables used for the experimentations are the spindle speed, feed, depth of cut, nose radius and cutting edge angle. EN24 substrate was coated with hexavalent chrome to a thickness of 170 µm. The surface hardness before and after hard turning of hard chrome plated surfaces were studied. The temperature developed on the insert, workpiece and chips were studied in the present investigation. An experiment was carried out to determine the maximum heat development on the insert. The experimental results revealed that the maximum heat was observed at 2mm from the cutting edge on the top diagonal. The images obtained from the confocal microscope and scanning electron microscope discovered the nature of fracture of the chips from the work surfaces.

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Keywords: Hard turning; heat measurement; surface roughness; chips.

1. Introduction to Machining and Hard Turning

Metal cutting is the process of producing a finished part by shearing a layer of material from the workpiece with the help of relative movement of cutting tool. One such solution the researchers proposed was the hard turning which

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can be considered as the alternate to the grinding. Vitor Augusto, et.al.,(2011) have stated that the hard turning is a simple turning operation which operates on the harder material having hardness above 45 HRc. The hard turning machines are normal CNC lathes with more rigid fixtures for workpiece mounting. High quality hard turning applications do require a properly configured machine tool and the appropriate tooling. Gaurav, et.al.,(2012) have mentioned that the Poly Cubic Boron Nitride (PcBN), ceramic and PCD are generally used as the tool materials for the hard turning operation. But for very less depth of cut ceramic tool materials cannot be used as this insert cannot penetrate into workpiece. PcBN with different coatings are generally practiced for most of the applications as mentioned by Gerard, et.al., (2000), Bermingham et.al., (2011), Nalbant, et.al,(2007) and Augusto, et.al., (2011).

1.1. Chrome Coating

The increased demand for hard surface applications has resulted in the development of coated materials with hard substances. One such coated material is chrome plating. The chrome plating is a method of electroplating a thin layer of chromium onto the base substrate. The thickness of chrome plating depends on the applications. The very thin coating is normally called as the decorative coating. Other type of chrome plating is the hard chrome, also recognized as the industrial chrome or engineered chrome according to ASM handbook on surface engineering (1995).

Nomenclature

v	cutting Speed, rpm
f	feed rate, mm/rev
d	depth of cut, µm
OA	orthogonal array
T	temperature, ^{0}C
V	voltage, V
r_ε	nose radius, mm
K_r	maximum principal cutting edge angle, degree

2. Experimentation

The present investigation is a novel attempt and this is focused on turning studies of hard chrome plated surface as mentioned by Mohandas, et.al.,(2013). EN24 was selected as the base substrate to coat hard chrome plating. Base substrate was selected with a dimension of 50mm diameter and 70mm length. The machining was carried out to a length of 50mm. The hard chrome coating was performed to a thickness of 170µm using electroplating technique. The Vicker's test was conducted to determine the hardness of the coated specimen. The hardness of this coating was of the order of 742 HV1 which is equivalent to 62HRc. TiAlN coated PcBN tool material was selected to machine the hard chrome plated surfaces. Figure 1 shows the hard turning of hard chrome plated surfaces.The specifications of the TiAlN coated PcBN inserts used in the experimentation were shown in Table 1. The cutting edge angles selected were 55^0 and 80^0 and the nose radii of 0.4mm and 0.8mm.

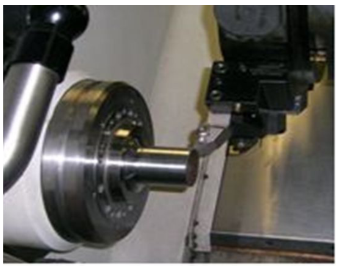


Fig. 1 Hard turning of hard chrome plated surfaces.

Table 1 Inserts Specifications of TiAlN coated PcBN

Sl. No.	Insert	Cutting edge angle	Nose radius (mm)
1.	CNGA 120404	80^0	0.4
2.	CNGA 120408	80^0	0.8
3.	DNGA 150404	55^0	0.4
4.	DNGA 150408	55^0	0.8

A series of experiments were conducted on Harding make Quest 8/51 special purpose precision hard turning CNC Lathe. The dry cutting condition was adapted during machining. The study on the tool wear, surface roughness, feed rates, spindle speed and depth of cut were carried out. The cutting parameters selected were listed in table 2.

Table 2 Cutting Parameters with levels

Cutting Parameters	Level 1	Level 2	Level 3
Spindle Speed, *v* (rpm)	300	400	500
Feed Rate,*f* (mm/rev)	0.04	0.06	0.08
Depth of Cut, *d* (µm)	40	80	120

The cutting conditions like speed and feed rate were selected based on the PcBN tool material specifications. The experimentation was decided based on Taguchi's Gray Relational Analysis [10]. L_9 orthogonal arrays were used in the experiments. Table 3 illustrates the experimentation based on the Grey Relational Analysis.

Table 3 Levels and Factors of Experimentation (L9 OA)

Trail No.	Speed (rpm)	Feed (mm/rev)	DOC (µm)
1	300	0.04	40
2	300	0.06	80
3	300	0.08	120
4	400	0.04	120
5	400	0.06	40
6	400	0.08	80
7	500	0.04	80
8	500	0.06	120
9	500	0.08	40

2.1. Microhardness measurement

The hardness of the workpiece was measured on the coating before and after machining. Clemex made CMT.HD was used for measuring the hardness. In general, the hardness measurements are carried out with Vickers or Knoop diamond indenters using the average indented diagonal. Due to the fact that hardness may vary considerably within a short distance, loads below 1N are employed in microhardness test. In the present investigation, the load of 300gm was applied.

2.2. Cutting Temperature measurement

The major concern of the hard turning of hard chrome plated surface was to reduce the temperature development during the finishing of hard chrome plated surfaces. As the grinding of chrome plated surfaces produces enormous heat, it was indeed necessary to measure the heat developed in turning operation to suggest the alternate method. In this regard, attempts were made to measure the heat developed on the inserts and the workpiece.

The contact type temperature measurement technique was adopted during the experimentation. As the chip produced was discontinuous in nature, the top face of insert was not in constant contact with the chip. The K-type thermocouple was used to measure the temperature of the inserts. Figure 2 shows the picture of the super drilled PcBN insert.

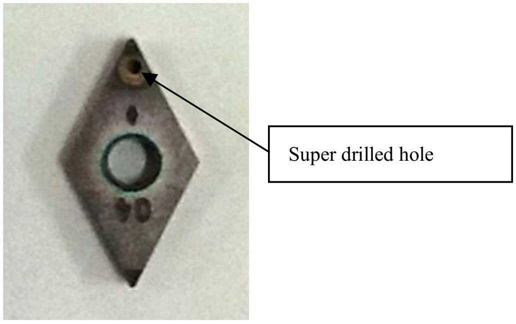


Fig. 2 Picture of super drilled PcBN insert.

The K-type thermocouple was embedded into the super drilled cutting insert. The thermocouple was insulated with inconel sheathed heating cable. When compared with different types of thermocouple, it was observed that the K-type thermocouple has a linear relationship between the voltage displayed and the temperature converted.

2.3. Installation of Infra Red Pyrometer

The Infra-Red Pyrometer (IR pyrometer), TPT-300V, was used in the experimentation to measure the workpiece temperature. The output of the pyrometer was in the form of voltage (V) which was converted to temperature (T ^{0}C) using Equation 1.

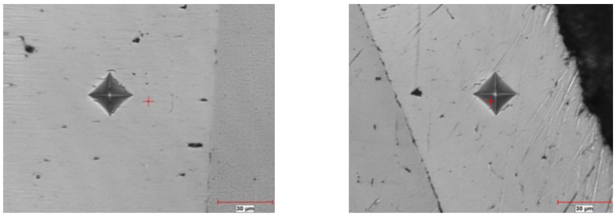
$$T\ (^{0}C) = 65.2018 - 13.04\ V \quad (1)$$

The temperature measured by the IR pyrometer was calibrated by Bow–type thermocouple. The bow type thermocouple was held against the rotating workpiece to measure the temperature of the workpiece. The temperature measured by the bow type thermocouple was equal to the temperature measured by the IR pyrometer. The pyrometer was held at a distance of 3mm from the workpiece. A fixture was designed to mount the pyrometer on the turret of the hard turning machine.

3. Results and Discussions

3.1. Microhardness

The indentations obtained for un-machined and machined samples are shown the Figure 3, whereas the microhardness reading for both the un-machined and machined surfaces on three different samples are shown in Table 4.



(a) (b)

Fig. 3 Micro Hardness of: (a) unmachined sample @400X; (b) machined sample @400X.

Table 4 Micro-hardness measurement readings

Sl. No.	Hardness before machining (Hv)	Hardness after machining (Hv)
1.	858	796.58
2.	865.31	811.13
3.	873.50	789.45

Table 4 demonstrated a decrease in hardness after hard turning the workpiece surfaces. This decrease is due to the removal of the upper layer of the coating which is hard because of the reaction with the environment. There was less than 10% reduction in hardness after completion of the hard turning. These results indicated that there were very less microscopic transformations observed as the change in hardness before and after hard turning was minimal. The hardness observed after hard chrome plating was verified by the literature report.

3.2. Maximum heat location on the insert

Experiments were designed to find out the location of maximum temperature developed during hard turning on the surface of the tools. The holes were made on the various places of the different inserts. Table 5 shows the tool temperatures recorded at various locations on insert.

Table 5 Tool temperatures noted at various locations on insert

Tool Side	Temperature (°C)	Tool Number
Right top Face (2mm) on the right diagonal cutting edge	120	B1
Right Cutting Edge	140	B2
Left Cutting Edge	100	B3
Top Face Center (4mm) from the cutting edge	110	B4
Left Top Face (2mm) on the left diagonal cutting edge	160	B5
Top Face just after coating from cutting edge (2mm)	230	B6

This experiment helped in deciding the location of the drilled hole where the maximum temperature was recorded. The holes were drilled on the top face of the insert at 2mm from cutting edge to a diameter of 1.5mm. The diameter of the hole was drilled to ensure that the thermocouple sheath fitted into the hole. The comparative study of the temperature developed on the various locations of the inserts is shown in Figure 4.

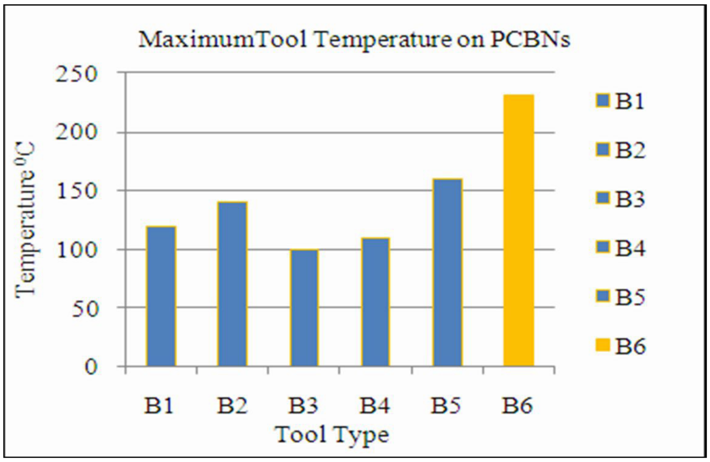


Fig. 4 Comparative study of the temperature developed on the various locations.

3.2.1 Measurement of temperature on tool and workpiece

The experiments were carried out using Taguchi's design of experiment to record the temperatures developed on the inserts and on the workpiece. The K-type thermocouple was used to record the temperature on the cutting inserts and the IR pyrometer was used to measure the temperature on the workpiece. These temperatures for all the different types of inserts were recorded and shown as a comparative study in Figure 5.

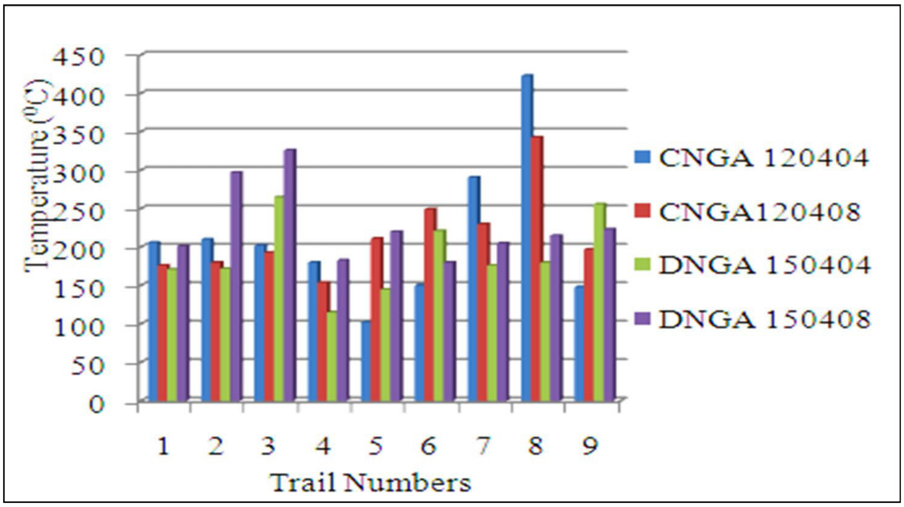


Fig. 5 Comparison of the insert temperature developed with different inserts.

It was clear from these temperature measurements that the temperature developed during CNGA (80^0 cutting angle) was comparatively lesser than the DNGA (55^0 cutting angle). The nose radius also influenced the temperature development on the insert. The results evidenced that with a smaller nose radius, minimum temperature was observed on the inserts.

3.2.2 Verification of heat developed

The heat developed during hard turning of hard chrome plated surfaces was verified using the Infra Red (IR) camera. The cutting conditions selected to compare the temperature developed using IR camera was spindle speed of 300rpm, feed of 0.06mm/rev and the depth of cut of 80µm with DNGA 150408 insert. The IR images confirmed that the temperature on the insert was comparable with the temperature recorded during the experimentation. The image of the IR camera is shown in Figure 6. The variation of 5.37% was observed for a cutting length of 10mm. This variation was due to the conditions assumed in IR camera to predict the cutting temperature such as emissivity, thermal conductivity of the material. The point's *sp2* and *sp3* were the temperatures of the chips observed.

Fig. 6 Temperature distributions observed under IR camera.

It was clearly observed from Figure 6 that the chip was carrying a heat of 80^0C, which was negligible when compared to the heat on the cutting inserts. Greenwood (1981) had reported that the hard chrome deposit has a very low surface energy which has resulted in very low coefficient of friction of 0.2. Therefore the chrome plating exhibits the lesser heat during the hard turning of the surfaces.

3.3 Chip Morphology

The study of the chips during turning of materials play a significant role in the surface finish achieved in the machining process. The samples of the chips produced through hard turning of hard chrome plated surface were collected to study the behavior. The chips were initially observed under the confocal microscope to analyze the chip structure. The structure of the chip observed through confocal microscope during hard turning is shown in Figure 7.

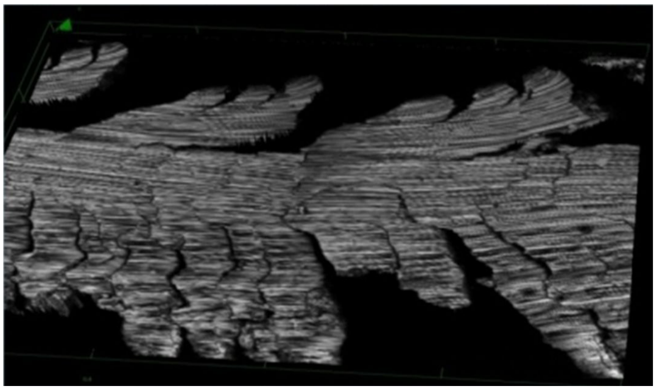


Fig. 7 Image of the chip collected during hard turning observed under confocal microscope at 100X.

To study the nature of fracture of the chip, the higher magnification was required. The major limitations of the confocal microscope being 100X and beyond which the images cannot be magnified. Due to this reason, these chips were observed under Scanning Electron Microscope (SEM) to study the chip morphology. Figure 8 is the SEM image of the chip collected during hard turning of hard chrome plated surfaces.

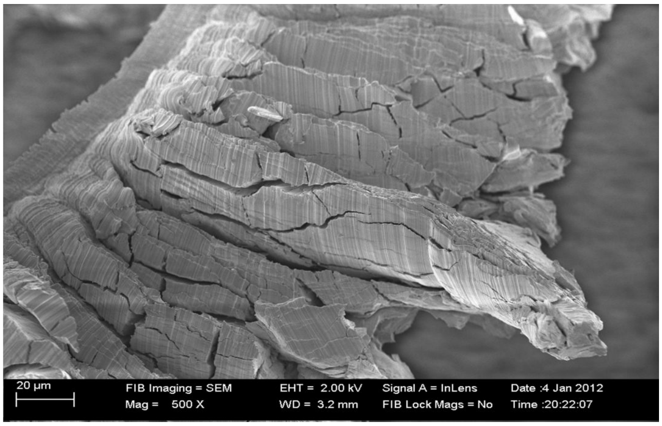


Fig. 8 SEM image of the chip collected during hard turning of hard chrome plated surfaces at 500X.

The SEM images revealed the nature of fracture of the chips from the workpiece. There was a brittle kind of fracture observed at a magnification of 500X. Similar types of fractures were observed in all the different cutting conditions. These results demonstrated that the chrome plated surface was separated from the workpiece as soon as the metal cutting started. This could be one of the reasons for getting comparatively lesser temperature during finish turning of the chrome plated surfaces. The SEM images are shown in the Figure 9 and 10. The pictures clearly pointed out that the characteristic of the chip generated from the hard turning of hard chrome plated surfaces is of saw-tooth type. The average length of the chips observed was in the order of 1mm and the average width of 100 - 150μm.

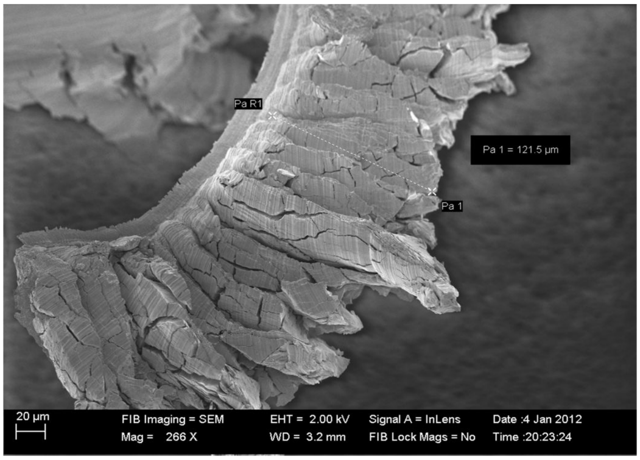


Fig. 9 The average width measurement of the chip at 266X.

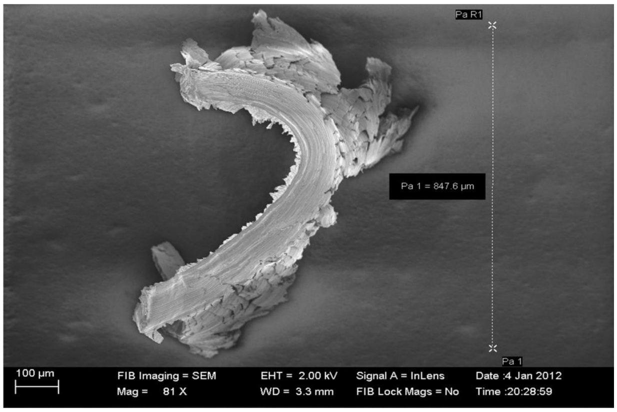


Fig. 10 The average width measurement of the chip at 81X.

3.3 Principal Cutting Edge Angle

The depth of cut of the finish turning is very less when compared to the nose radius of the inserts selected. In these experiments, the depth of cut selected were 40µm, 80µm and 120µm against the tool nose radii of 0.4mm and 0.8mm. In such situations, the nose radius governs the cutting action. These phenomenon results in change in principal cutting edge angle with change in nose radius and the depth of cut.

Lalwani, et.al., (2008) have shown the calculation of maximum principal cutting edge angle, K_r as Equation 2.

$$K_r = \cos^{-1} [(r_\varepsilon - d) / r_\varepsilon] \tag{2}$$

Table 6 illustrated the variation of the maximum cutting edge angle with the change in nose radius and depth of cut. The values obtained from Equation 2 showed the influence of the shape of the inserts and the nose radius on the finish turning. As there was change in the shape of the inserts from 55^0 to 80^0 and the nose radii from 0.4mm to 0.8mm, the principal cutting edge angle also changed considerably. It was very clear from Table 6 that the lesser depth of cut and minimum nose radius has resulted in smaller principal cutting edge angle.

Table 6Variation of maximum cutting edge angle with nose radius and the depth of cut

Sl. No.	Cutting Insert	Depth of cut (µm)	Nose radius (mm)	Maximum Principal Cutting Edge angle
1.	CNGA/DNGA 0408	40	0.8	20.22^0
2.	CNGA/DNGA 0408	80	0.8	28.71^0
3.	CNGA/DNGA 0408	120	0.8	35.32^0
4.	CNGA/DNGA 0404	40	0.4	28.71^0
5.	CNGA/DNGA 0404	80	0.4	40.97^0
6.	CNGA/DNGA 0404	120	0.4	50.64^0

4. Conclusions

The important finding of the present investigations is that the engineered chrome plated surfaces having hardness 60 HRc and above can be hard turned successfully. The following conclusions were drawn from the results of the hard turning of hard chrome plated surfaces.

- The tool temperature produced during machining has very less effect on the surface characteristics of the hard chrome plating. The tool wear was rapid and that has the major role in producing lower surface finish in hard turning of hard chrome.
- The tool temperatures produced during hard machining is due to the shearing action of the tool on the workpiece surface. As the chrome plated surfaces exhibited lowered co-efficient of friction, these temperatures were comparatively lesser than the other hard turning of different steel materials.
- The SEM images revealed that the nature of fracture was brittle. This could be one of the reasons for exhibiting comparatively low temperatures during hard turning of hard chrome plated surfaces.

The hard turning process is fast compared to grinding. Because hard turning is carried out in dry condition, the process can be considered as an environment friendly. The surface obtained from the hard turning is at far with that of grinding with controlled cutting conditions. Plethora of applications is available to apply the above findings. These results will open up a new era in machining of hard chrome plated surfaces.

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