The Effects Of Cutting Conditions On Chip Area Ratio And Surface Roughness In Hard Turning Of AISI 52100 Steel

A. D. Bagawade[1], P. G. Ramdasi[2], R. S. Pawade[3] P. K. Bramhankar[3]

[1] *S.V.P.M.College of Engineering Malegaon(Bk.), Baramati*

[2]*Dept.of Mech.Engg.,Walchand College of Engineering,Sangli.*

[3]*Dept.of Mech.Engg., Dr.Babasaheb Ambedkar Technological University, Lonere, India*

Abstract

The aim of this research work is to evaluate the chip area ratio and surface roughness in hard turning of AISI 52100, (EN31) steel. This steel is hardened to 48~50 HR_C, machined by a PCBN tool insert MB 8025 of Mitsubishi. The results made it possible to study the influence of cutting variables i.e. cutting speed, feed rate and depth of cut on chip area ratio and surface roughness (Ra and Rz) values.

Keywords: *Hard Turning, saw-tooth chip, chip area ratio, surface roughness.*

1. Introduction

Hard turning is an emerging technology that can potentially replace many grinding operations due to improved productivity (increasing production efficiency), increased flexibility (increasing the range of material that can be machined), decreased capital expenses (saving in cost), and reduced environmental waste [1].In hard turning, ferrous metal parts that are hardened usually between 45-70 HRc are machined with the single point cutting tools. This has become possible with the availability of the new cutting tool materials cubic boron nitride (CBN) and ceramics. Since a large number of operations is required to produce the finished product.If some of the operations can be combined, or eliminated, or can be substituted by the new process so product cycle time can be reduced and productivity can be improved. The traditional method of machining hardened a material includes rough turning, heat treatment, and then grinding process. Hard turning eliminates the series of operations required to produce a component and there by reduces the cycle time resulting in productivity improvement [2-4].While most hard machining research thus far has focused on chip formation mechanisms and tool wear characterization. It is of great interest to study the effect of cutting conditions on chip morphology. It has been observed that the chip dimension changes as cutting conditions change [5].There is still no systematic study of chip morphology characterization in hard machining. The objective of this study aims to better define and further characterize different chip dimensions as functions of cutting conditions in hard turning. The paper first gives background for this study, experimental setup and design are then discussed, along with the experimental observations on the chip morphology. Finally, conclusions are presented. Such chip dimension knowledge will help better understand and model the hard machining process, making hard machining a viable technology.

Today, the development of very reliable machining processes is required to achieve higher material removal rates with high degrees of automation in manufacturing systems. One of the aspects notably affecting the efficiency of machining processes is the monitoring and control of the chip form. The normal variations of process conditions, due to the inherent variation of work material properties, thermal expansion, tool wear development, etc., can produce changes of the chip form or shape during a machining operation. Problems in surface finish, workpiece accuracy and tool life can be caused by even minor changes in chip forms.

Moreover, unacceptable chip shapes can cause injuries to operators and damage to cutting tools, workpieces and machines. All these negative effects can lead to additional costs due to scrap parts, lost machining time, and delays in part delivery. Efficient chip form monitoring and control is therefore needed to allow for the formation of chip shapes that can be easily and reliably evacuated from the working zone. This would contribute to the improvement of machining process reliability, the production of high quality machined surfaces, the increase of productivity, and the enhancement of operation safety and tools and machines protection [6].

2. Background

Chips produced in machining most metals and alloys can be generally classified into four distinct categories based on their geometric shapes: flow, wavy, saw-toothed and segmented and discontinuous [7].Flow type chip arises in machining of ductile materials and is classified by its uniform cross-section. Wavy chips occur when the shear angle oscillates widely causing fluctuations in cutting forces and chip thickness [8]. Discontinuous chip formation is common in machining brittle materials at low cutting speeds [9], and these chips are classified by their nearly identical and discontinuous segments that are entirely separated by their broken segments. Saw-toothed chips, a common name for segmented chips, are semi continuous and have zones of low shear strain (continuous portion) and high shear strain (discontinuous portion).

3. Experimental setup and Design

Hardened 52100 bearing steel with a hardness of 48~50 HRc was chosen for experimental studies because of its wide use in both automobile industry and research fields. The chemical composition analysis (according to the ISO 683-17 Standard) of the workpiece material is shown in Table 1. Turning operations were performed dry using a ACE design Jobber computer numerical control lathe. The Non coated PCBN cutting inserts (Mitsubishi, Japan) with a negative 5^0 rake angle and a 0.8 mm nose radius were used for turning experiments.

Table 1 Chemical composition of the work material

C	Cr	Mn	Si	S	P
0.92	1.06	0.51	0.22	0.039	0.040

The geometry and grade of insert is NP-CNMA120408G (Mitsubishi). Inserts are recommended for machining hardened steel and cast iron in finish operations. It is a highly recommended cutting tool material for hardened steel machining because it is suitable for high speed finishing of heat treated steel, sintered ferrous alloy and cast iron stability at elevated temperature, low affinity to iron so good surface finishes is possible. The tool holder used for clamping the insert is PCLNR 2525 M (Make-WIDIA). It has 95º approach angle and -6º back rake angle. Surface roughness was measured using Hobson surface tester. To characterize chip area ratio, steel chips were collected, mounted and clearly present the chip cross-section of interest. The experimental set-up is shown in Figure 1. Experimental designs were created to study and quantify chip morphology.

4. Experimental results and discussion

Chip morphology is characterized by its dimensional values in terms of width and thickness. The chip dimensional information for each design was measured and averaged, and only the mean values are presented here.

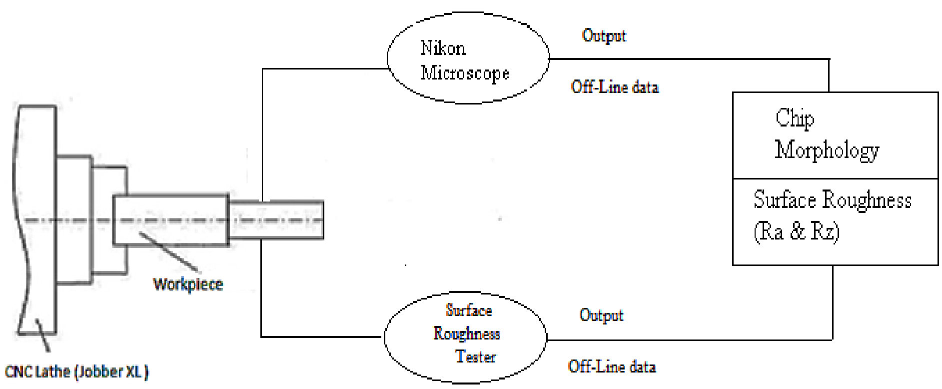
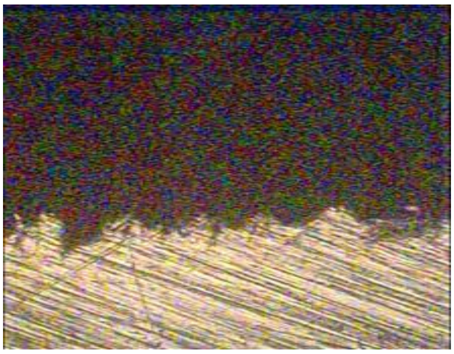
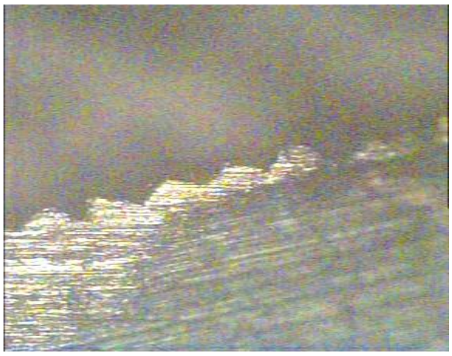


Figure 1 Experimental set up



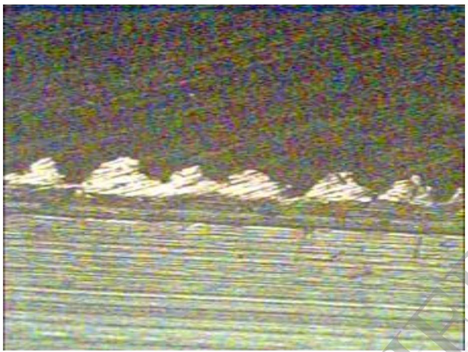
Expt. No.1, (a) V =100m/min, f =0.08mm/rev

a_p = 0.4mm, R_a = 0.43µm & R_z = 2.16µm



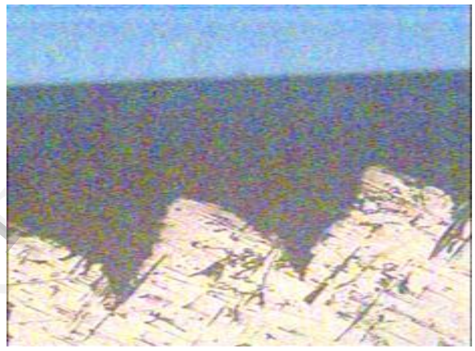
Expt. No.2, (b)V=160m/min, f = 0.08mm/rev

a_p = 0.4mm , R_a = 0.33µm & R_z = 1.7µm



Expt. No.4, (c) V=300m/min, f =.08mm/rev

a_p = 0.4mm &R_a =0.22 µm & R_z = 1.36 µm



Expt. No.9, (d)V=160m/min, f =0.4mm/rev

a_p = 0.4mm & R_a =3.86 µm & R_z = 8.86µm

Figure 2 Photographs of chip microstructure by Nikon Measuring Microscope

Figure 2 (a-d) shows a representative microscope picture of a collected chips. The design as shown in Table 2, aimed to research the effect of cutting conditions on surface roughness using new tools. Cutting conditions were varied to study the effect of cutting speed, feed, and depth of cut on chip morphology and surface roughness. Both surface roughness and chip morphology information were collected. Cutting conditions were selected based on recommendations for typical hard turning finishing processes and tool manufactures manuals [10]. Surface roughness is in relation to many properties of machine elements such as wear resistance, the capacity of fit and sealing.

Chip area ratio is given by the formula: Chip Area Ratio =

$$\frac{\text{Feed x Depth of cut}}{\text{Avg.Chip Thick.x Avg.chip width}}$$

$$= \frac{\text{Undeformed cross sect.area of chip}}{\text{Deformed cross sect. area of chip}} \quad \text{--- (1)}$$

The *Ra* theoretical arithmetic average surface roughness (µm) achievable based on tool geometry and feed rate is given approximately by the formula:

$Ra = 0.032\, f^2 / r$ ----- (2)

Where f = feed rate and r = tool nose radius (mm).It means that surface roughness increases with increasing feed rate and a large tool nose radius reduce surface roughness of the workpiece.

A Taylor Hobson Surtronic Duo portable surface profilometer, operated with Diamond cone sphere with 5µm nominal radius, 90º tip angle, was used to measure surface roughness of the machined EN31 Steel material. Surface roughness is a measure of the technological quality of a product and a factor that greatly influences functional characteristics and manufacturing cost of the component. There are various simple roughness amplitude parameters that are commonly specified to designate the surface finish. Out of those, two most common and significant parameters were considered in this experiment and measured to quantify the surface quality. These are average surface roughness (*Ra*), maximum peak roughness (*Rz*). Table 2 illustrates the experimental results of chip area ratio, *Ra* and *Rz* .

Table 2 Experimental results for Chip area ratio and Surface roughness

Expt. No.	Cutting speed ,*V* (m/min)	Feed Rate, *f* (mm/rev)	Depth of Cut, a_p (mm)	Chip Area Ratio	Surface roughness, *Ra* (µm)	Surface roughness, *Rz* (µm)
1	100	0.08	0.4	2.98	0.43	2.16
2	160	0.08	0.4	2.20	0.33	1.7
3	220	0.08	0.4	3.67	0.26	1.53
4	300	0.08	0.4	2.33	0.22	1.36
5	160	0.05	0.4	1.61	0.25	1.53
6	160	0.08	0.4	2.21	0.29	1.6
7	160	0.10	0.4	2.76	0.34	2.0
8	160	0.20	0.4	3.46	1.06	4.1
9	160	0.40	0.4	3.68	3.86	8.86
10	160	0.08	0.1	0.30	3.85	12.76
11	160	0.08	0.2	1.53	0.31	1.73
12	160	0.08	0.3	0.89	0.22	1.23
13	160	0.08	0.4	1.95	0.28	1.76
14	160	0.08	0.5	1.22	0.27	1.63

4.1 The Effect of cutting speed

The increase in cutting speed improves the machined surface quality. For the speed from 100 to 300 m/min. surface roughness *Ra* and *Rz* values falls between 0.43 to 0.22 µm and 2.16 to1.36. µm respectively.

4.2 The Effect of feed rate

In practice, the consequences of the influence of the feed rate on surface roughness are as follows: the increase in the feed rate from 0.08 to 0.40 mm/rev makes respectively increases the criteria of roughness *Ra* (0.25µm-3.86 µm) & *Rz* (1.53- 8.86 µm.).

The analysis of the effect of feed rate on surface roughness shows that this parameter has a very significant influence, because its increase generates helicoids grooves the result tool shape and helicoids movement tool-workpiece. These grooves are deeper and broader as the feed rate increases.

4.3 The Effect of depth of cut

Evolution of surface roughness according to the depth of cut shows that this parameter has a very weak effect compared to that of the feed rate. This is due to the increased length of contact between the tool and the workpiece.

5. Conclusion

In this experimental study, the effect of turning parameters such as cutting speed, feed rate, depth of cut on chip area ratio, surface roughness on machining characteristics of AISI 52100 bearing steel was investigated.

Summarizing the main features of the results, the following conclusions may be drawn. Most of the chips generated were saw-toothed which resulted in relatively high chip area ratio, greater than one.Chip area ratio increases with surface roughness in relation during cutting feed.For smaller feed and smaller theoretical roughness values, the measured roughness depenance was less sensitive than predicted by (eq.2).

It is to be concluded that the feed rate contributes largely to the evolution of surface roughness. Surface roughness is very sensitive to the variation of feed rate but was relatively insensitive to cutting speed, and depth of cut.

This study confirms that in dry hard turning of this steel and for all cutting conditions tested the roughness criteria found are close to those obtained in grinding.

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