EXPERIMENTAL INVESTIGATION ON THE CHIP MORPHOLOGY DURING THE MACHINING OF AISI 4140 HARDENED STEEL BY USING CBN TOOL INSERT

[1]VICKEY NANDAL, [2]VISHAL SINGH

[1]Centre for Materials Science and Engineering, NIT Hamirpur, [2]Centre for Materials Science and Engineering, NIT hamirpur

Abstract - In machining of AISI 4140 (410 HV) steel, the formation of Continuous and saw tooth chips takes place at relatively low cutting speeds and different feed rate has been examined. All cutting tests were performed by using Cubic boron nitride (CBN) tool inserts on specific cutting speeds from 75 m/min to 150 m/min.The saw- tooth chip produced in this investigation was a result of interrelated mechanisms such as adiabatic shear, localized shear in the forms of cracks. The chip forms collected were observed using SEM and were measured in terms of their form, surface roughness of workpiece after all experiments, thickness and micro hardness of chips.This study investigated that both cutting speed and feed rate are found to have an influence on the chip thickness.

Keywords: Chip morphology, Cutting condition,Hard turning, Saw-toothed chip, Chip thickness.

I. INTRODUCTION

Cutting is a pervasive activity in daily life, science and technology [1, 2]. Finishing &machining of hardened steels offers many economical and technical advantages over conventional grinding such as shorter setup/tool change times and less negative environmental implications. Thus it has obtained increasing awareness in many industrial applications[3,4,5]. As the demand growing for enhancing production efficiency has stretched a high development of machining technology, which has many advantages such as high removal rates of material, low cutting forces, leading to excellent dimensional accuracy and surface finishing quality [6,7].However, higher cutting speed usually provide the emergence of serrated chip flow, which leads to decrease in tool life, degradation of the surface finish and less accuracy in the machined part [8]. The formation of saw-toothed or segmented chips, which are of great research interest, is generally considered the result of a highly nonlinear and dynamic plastic deformation process that has been shown to adversely affect cutting forces, machine deflection and vibration, tool wear, and surface finish [9, 10]. While most of the researchers have 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 tools wear and cutting conditions change [11]. Chips obtained in machining metals and alloys can be generally classified into four different categories on the basis of geometric shapes: flow, saw-toothed/segmented, wavy, serrated and discontinuous [12].It is noticed that different approaches have also been developed to characterize chips in machining other non-metallic engineering materials. Chips obtained from machining advanced materials such as ceramics and hybrid composites might be quite different in physical nature than those observed in metal machining. For example, Shih et al. [13] investigated a classification seven types of chips obtained in machining non-metallic elastomers under different cutting environment.

G.sutter et al. [14] investigated the significant reduction of cutting forces developed with increases in cutting speed and feed.However, systematic study of chip morphology characterization in hard machining is still undetermined. The main aim of this study is to better define and further characterize different chip dimensions as functions of cutting conditions in hard machining. First the paper gives tool and workpiece material for this study. Then experimental setup and design are discussed, alongwith the experimental observations on the chip morphology. Furthermore, chip thickness, chip micro hardness, roughness and SEM imaged of chips is given. Finally, conclusions and recommendations for the future research are presented. Such chip morphology knowledge will help for better understand.

Notation

v	cutting speed (m/min)	f	feed (mm/rev)
d	depth of cut (mm)	R_a	average surface roughness
AISI	American iron and steel institute	HV	Vickers hardness
CBN	cubic boron nitride	HRC	Rockwell hardness
SEM	Scanning electron microscope	CNC	computerized numerical control

II. TOOL AND WORKPIECE MATERIAL

A. WORKPIECE MATERIAL

Hardened AISI 4140 steel (cylindrical bar) with a hardness of 410 HV (42 HRC) was chosen for this experimental studies because of its extreme use in research and industry fields. It is also known as chromium molybdenum steel. AISI 4140 steel influenced a choice for this study because it has excellent machinability and dimensional stability in hardened state, good combination of high surface hardness and toughness after quenching and tempering.

B. CUTTING TOOL MATERIAL

A Rhomboid shaped carbon boron nitride (CBN) tool was used for the machining test. The tool insert (CCMT09) and has a tool nose radius of 0.4mm.

The cutting tool has following geometry;

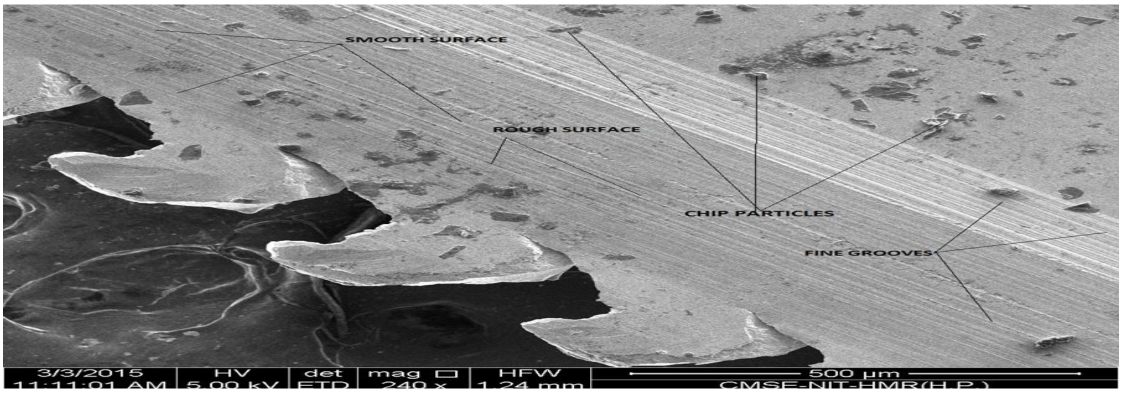
- Dry cutting
- Cutting speed: from 75m/min to 150m/min
- Depth of cut = 0.5 mm
- Feed rate: f = 0.05 to 0.14 mm/rev
- Tool geometry: Side rake angle = -5^o
  Back rake angle (α) = -5^o
  Side rake angle (SCEA) = -5^o
  Approach angle = 90^o
  Nose radius = 0.4 mm

III. EXPERIMENTAL SETUP AND DESIGN

The significant work piece length 100mm and diameter 36mm was selected for this experimental work. The AISI 4140 workpiece was machined on the faces obtain a perfect shaped facial area. The vibrations and impact of forces resulting from the material removal were basically minimized by center drilled the workpiece at both ends to enable support between centers. The CBN cutting tool was mounted and securely held in position and aligned with the work piece at both X & Z coordinates being reference for the machine set up. Operations were performed by using Sprit 16 TC (CNC) turning center lathe with variable spindle speed and feed tool. During turning average cutting forces were obtained by using a turning (TeLC with DKM 2010 software) dynamometer where the force fluctuation due to the saw-toothed chip formation was not taken into account.

A scanning electron microscope (SEM) was used to characterize saw-toothed chip and continuous chips cross-sections. The specimens of chips were prepared for microscopic examination. Figure 1(a) shows a SEM picture which were collected from the experiment after that it is etched with a 2% Nital solution for 10 to 15 second. To characterize chip morphology analysis, steel chips of different cutting speed and feed were collected for further investigation.

a



b

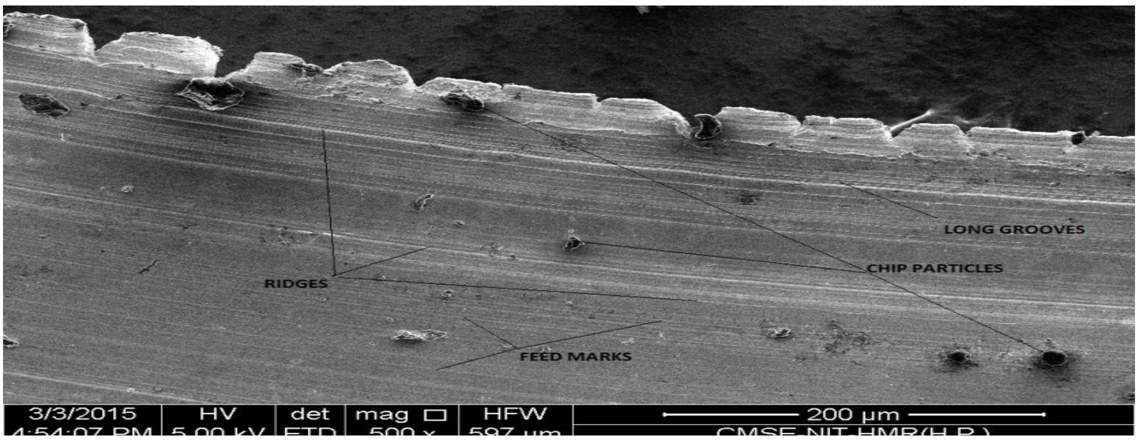


Figure 1. SEM pictures of the surface quality observed during turning of AISI 4140 hardened steel: (a) v = 75 m/min, *f* = 0.11mm/rev; and (b) v = 125 m/min, *f* = 0.14mm/rev.

IV. RESULTS AND DISCUSSION

Fig. 1 shows different types of chips obtained at different cutting speed conditions. Fig1 (a) shows the microscopic (SEM) images of the best and poor surface finish quality obtained when AISI 4140 hardened steel was machined by using CBN tool insert under different cutting conditions. These showing phenomenon were observed at experimental where v = 75 m/min, f = 0.11mm/rev and v = 125m/min, f = 0.14mm/rev. Which indicates the actual topography of the chip bottom surface in terms of fine grooves, feed marks by tool insert and ridges, adhere chip particles, smooth and rough surface. The best improved surface finish is distinctly shown in fig 1 for decreased feed. This investigation is attributed to reduction in cutting force which reduces the stress and frictional force at tool-work interface and, the plastic deformation of surface which was machined becomes less significant that causes a good improvement in surface finish, as reported by Zou et al. [15].In fig1(a) the surface shows that feed marks are not visible at low feed rate .On the other side, feed marks are very clearly observable at higher feed rate (0.14mm/rev).

As shown in fig 1(b) Due to plastic deformation of machined surface, the ridges and grooves were noticeable. Formation of hard and strong ridge was recognized in between the feed mark region and feed marks. According to Zhou et al. [16] the ridges developed at the feed marks are because of damaged cutting edge in the perception of tool wear.In this investigation it is observed that different types of chips from bottom section and top section which is formed at different cutting speed and feed rate. Basically, the chip forms were helical types despite having been obtained at different cutting condition. Numerous combination of feed rate and cutting speed and had been investigated.

The mostly chips produced in different tests were basically continuous chis and was possibly influenced by the stress, strain and temperature gradient. Rao [17] ascribed ideal condition that influence the continuous chips during machining of metal which contains sharp edge, small chip thickness, high cutting speed, ductile cutting materials & friction is less between the chip tool interface through effective lubricationsContinuous types of chips are basically very useful chips because the work surface finish attained is usually smooth and effective. It helps in having long tool life and lower power consumption. However, from this study it is concluded that at higher cutting speed, the surface finish was also better and that surface finish increases as the cutting speed increases from 75 m/min to 150 m/min as shown in fig.2.

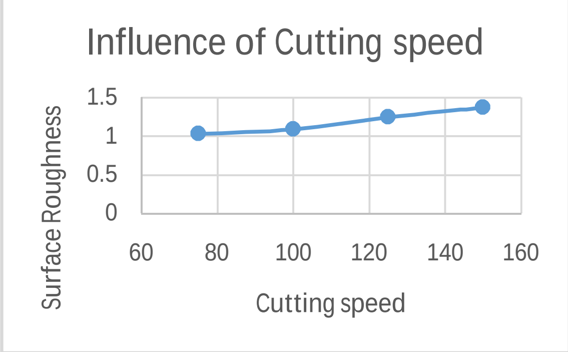


Fig. 2.Surface roughness (R_a) propagation with cutting speed.

V. CHIP MICROLOGY ANALYSIS

It was examined that there was no consequent effect in the shape of the chip at lower cutting speed. However, jagged saw teeth edges shapes were analysed at lower feed rate than higher feed rate. The saw tooth edge chip form was suddenly influenced at cutting speed 75 m/min and feed 0.11mm/rev and it tends to reduces with increase in feed rate from 0.11mm/rev to 0.14mm/rev.

It can be clearly observedthat the influence of feedwhere the chip is increasingly curled. The cause of this result was thermoplastic instability in the shear zone. In this investigation, few trends were examined in the thickness of the workpiece where thickness of chips was influenced by cutting speed and feed rate. At cutting speed 100 m/min and feed rate 0.11mm/rev, the thickness of chip was observed up to 0.24mm which was measured by using Mitutoyo Digital Vernier Caliper.

The thickness of chips decreases as feed rate was increased from 0.11mm/rev to 0.14mm/rev where thickness observed 0.24mm to 0.17mm respectively. Hence large chip reading was noted at large cutting speed which also decreases as cutting speed drops. It is also observed that by increasing cutting speed and feed rate, the transition from non-saw tooth chip formation to saw tooth chip formation takes place. Therefore, either feed or cutting speed could influence the formation of saw tooth shape chips from a non-saw tooth shape chips. The SEM images of all the chips which showing the chips transition with increasing feed and cutting speed. It means that it takes more saw tooth types of shape due to cyclic cracking by creating very intensive shear bands. Finally, by increasing feed during turning the temperature increases which cause thermal softening, microstructural deformation and heat generation.

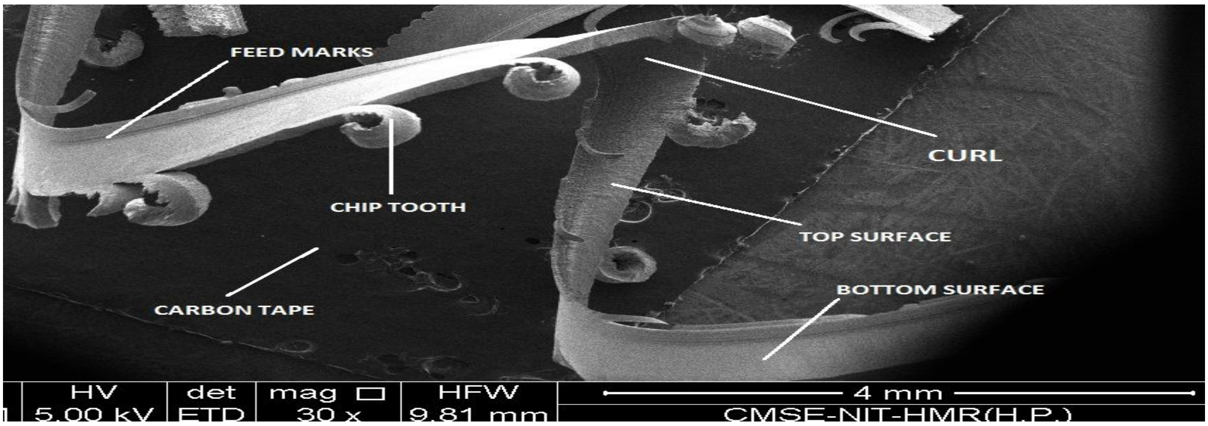


Fig. 3. SEM observation of chip morphology at v = 75 m/min, *f* = 0.14mm/rev.

MICROHARDNESS OF THE CHIPS

Micro hardness of chips wereperformed by using Vickers micro hardness tester. Ten indentation were done on chips of single experiment in which mean value was considered. Micro hardness reading were in the range of 640 – 700 HV (56 – 58 HRC). The micro hardness values obtained were basically more than the hardness obtained on the work piece material. Y.B.Guo [18] investigated that the hardness variation off the turned surface to extremely small grain size and high dislocation density as well as re-quenched martensite.

CONCLUSION

The hard turning has been executed successfully on AISI 4140 steel using CBN tool inserts under dry environment. Then chip morphology analysis has been done. From the experimental investigation to draw the following conclusions:

(1) From all the cutting conditions continuous chips were obtained wherein saw tooth shaped was caused by both the cutting speed and different feed rate.
(2) Fig 2 shows, the surface roughness is principally affected by the cutting speed. As increase in cutting speed leads to better surface finish.
(3) The SEM images of the chips explain the formation of saw tooth kind of chips due to the cyclic crack propagation and also shear pattern are seen with most of the chips. It is also investigated that, decreasing the feed tends to higher chip thickness.
(4) The higher feed rate (0.11-0.14mm/rev) favours the formation of saw tooth on the chip edges hence the degradation of surface quality occurs.
(5) The experiment also concludes that the chip thickness tends to reduce the cutting speed decreases. Generally, this study investigated that both cutting speed and feed rate are found to have an influence on the chip thickness.
(6) This experimental investigation helped in explaining the chip morphology and its relationship with cutting conditions, which will give valuable knowledge to researches and manufacturers in proper selection of cutting parameters.

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