Cutting zone temperature and Flank wear study in turning of AISI 4340 steel using different tool inserts

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Abstract— This paper is based on the study of cutting zone temperature and flank wear of AISI 4340 steel at different machining conditions. Uncoated and coated carbide tool inserts were used for investigation. Experiments are carried out on a high speed CNC turning machine under three speeds, three feeds and depth of cut has been kept constant. Flank wear was measured to study the wearing rate at different cutting conditions. Temperature was measured by using J type of thermocouple. It was observed that temperature and flank wear are the complex functions of speed, feed rate and type of tool.

Index Terms—CNC machining, cutting zone temperature, Flank wear, Coated and uncoated inserts.

1 Introduction

Turning is a process in which a tool removes material from the outer surface of a less resistant body, with the aid of relative movement and application of force. Major portion of the mechanical energy used to form the chip becomes heat, which generates high temperatures in the cutting region. Tool life, dimensional and form accuracy, surface integrity of the product gets adversely affected by high cutting temperature. This inherently characterizes the high speed machining. The effect of such high cutting temperature and its determined effects are generally reduced to minimal in industries by proper selection of parameters which are directly related to temperature generation[1].

AISI 4340 alloy steel is a heat treatable and low alloy steel containing chromium, nickel and molybdenum. It has high toughness and strength in the heat treated condition. AISI 4340 steel has its applications in power transmission gears, commercial and military aircrafts etc[2].

The basic cutting parameters which are defined in turning operations are cutting speed, feed rate and depth of cut. In metal cutting, tool wear is strongly influenced by the cutting parameters, cutting temperature, contact stresses, and relative sliding velocity at the interface. These process variables depend on tool and work piece materials, tool geometry and coatings, cutting conditions and use of coolant for the given application.

The cutting zone temperature of any material plays a vital role in all aspects of machinability and particularly for tool wear which relatively affects the tool life. The most important mode of wear in metal cutting is plastic deformation of tools, it is important to have the knowledge of high temperature strength of the tool material together with stresses acting on the tool and the temperature distributions inside the tool tip.

During machining, heat is generated in three deformation zones: primary deformation zone due to shearing action along
the shear plane, in which the workpiece material undergoes plastic deformation; the secondary deformation is as a result of deformation of chip and friction due to sliding of chip against the rake face of the tool: and the tertiary deformation zone due to the rubbing of workpiece surface and the tool flank[3].

The importance of knowledge of temperature measurement at the cutting point of the turning tool occurred due to the changes in the cutting condition is well known due to severe effects on the tool and work piece materials properties. The chip, tool and work piece help to remove this heat from the cutting zones.

A.V.N.L. Sharma et al. [4] performed a tool wear and surface finish investigation of hard turning using tool imaging. Here Genetic Algorithm and image processing models were developed to predict the surface roughness and tool wear. Work piece material was EN8 steel and tool material was HSS

Optimization by Taguchi method and inprocess monitoring of cutting parameters using Acoustic Emission for EN8 was done by Prof. Atul Dhale et al [5]. A technique Acoustic Emission was proposed as non-contact and indirect technique for in-process surface roughness assessment in turning. Three cutting parameters namely feed rate, depth of cut, cutting speed were optimized with consideration with surface.

The temperature in the cutting zone of any material plays a key role in practically all aspects of machinability and in particular for tool wear which inturn affects the tool life. The plastic deformation of tools is one of the most important wear modes in metal cutting. In the case of modelling plastic deformation, knowledge of high temperature strength of the tool material together with stresses acting on the tool and the temperature distributions inside the tool tip are of prime concern [6-8].

Heat during machining is generated in three deformation zones: the primary deformation zone due to shearing action along the shear plane, in which the workpiece material undergoes severe plastic deformation; the secondary deformation zone as a result of chip deformation and sliding friction of the chip against the tool rake face; and the tertiary deformation zone due to the rubbing effect of the workpiece surface against the tool flank [7].

Flank wear of the tool insert is one of the important factors, which depends on tool geometry and the cutting conditions. But more importantly the flank wear affects the surface roughness, tool life, cost of the machining process and many more.

In this paper, cutting zone temperature and flank wear of a tool during turning of AISI 4340 steel is presented. Thus obtained temperature values by using thermocouple and flank wear by using tool maker's microscope are plotted in relation with depth of cut, feed and speed.

EXPERIMENTAL SETUP AND PROCEDURE

The photograph of the experiments carried to measure the temperature is as shown in the Figure 1. The CNC turning machine in this case has the maximum swing over diameter as 450mm, maximum spindle speed of 4000rpm, maximum turning diameter of 140mm and maximum turning length of 200mm. The temperature was measured using J type of thermocouple which is mounted near tip of tool insert as shown in Figure 1. The thermocouple has range of 17°C to 1000°C.

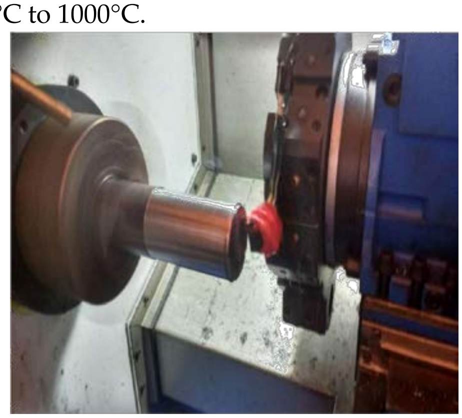

Fig.1. Temperature measurement in CNC turning

The tool inserts used for turning are shown in Figure 2. Two types of uncoated carbide tool inserts namely TTS and TTR and one type coated carbide tool insert K10 have been used in the study. These tool insets are used against AISI 4340 of 50mm diameter and 150 mm length.

Experiments are carried out for three speeds of 100, 150 and 200m/min, three feed of 0.1, 0.2 and 0.3 mm/rev by keeping depth of cut of 1.2 mm as shown in Table I. The temperature and flank wear are noted for every 30mm pass of 90mm effective turning length.

TABLE I.
CUTTING PARAMETERS

Cutting Speed (m/min)	100	150	200
Feed rate (mm/rev)	0.1	0.2	0.3
Depth of cut (mm)	1.2	1.2	1.2

Average temperature value and flank wear is taken for analysis. Thus totally 27 temperature values and 27 flank wear are obtained considering all conditions and tool inserts.

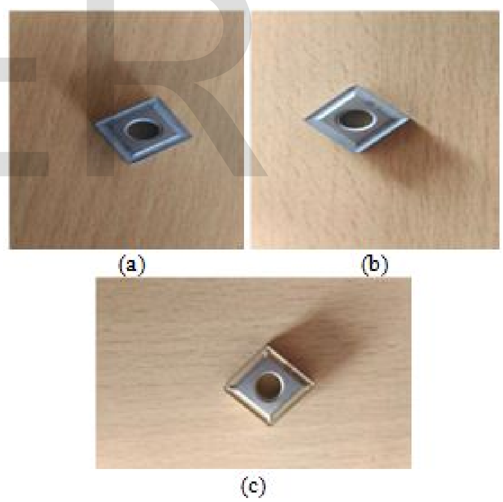

Fig.2. Tool inserts (a) TTR, (b) TTS, (c)K10P

RESULTS AND DISCUSSIONS

During machining material is removed in the form of chips of certain length and width. All such heat sources produce maximum temperature at chip-tool interface which influences the chip formation mode and measurement of temperature using direct contact method. The experiments were conducted in dry condition with three different speeds, feed rate and a constant depth of cut. The values of flank wear and cutting zone temperature for different conditions are listed in Tables II and III respectively.

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TABLE II.
FLANK WEAR FOR DIFFERENT INSERTS

Spee (m/min)	Feed (mm/rev)	TTR (mm)	TTS (mm)	K10P (mm)
100	0.1	0.16	0.17	0.13
100	0.2	0.23	0.14	0.12
100	0.3	0.23	0.16	0.12
150	0.1	0.24	0.14	0.12
150	0.2	0.27	0.15	0.11
150	0.3	0.24	0.16	0.12
200	0.1	0.23	0.19	0.10
200	0.2	0.26	0.15	0.09
200	0.3	0.25	0.14	0.09

TABLE III.
CUTTING ZONE TEMPERATURE FOR DIFFERENT INSERTS

Spee (m/min)	Feed (mm/rev)	TTR (□C)	TTS (□C)	K10P (□C)
100	0.1	87	71	121
100	0.2	76	67	103
100	0.3	86	79	67
150	0.1	110	84	126
150	0.2	89	74	112
150	0.3	91	80	73
200	0.1	114	95	136
200	0.2	107	152	118
200	0.3	92	100	81

Using these values variation of flank wear for constant speed has been plotted for all three types of tool inserts.

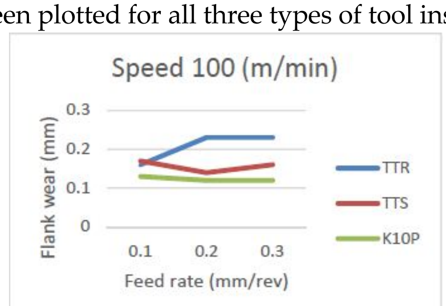

Fig.3. Flank wear comparison at 100 m/min

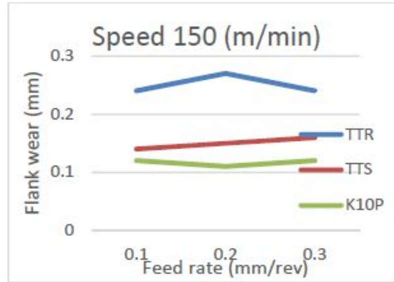

Fig.4. Flank wear comparison at 150 m/min

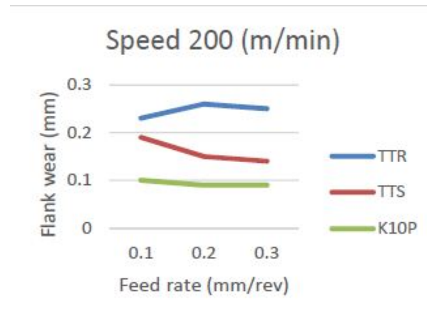

Fig.5. Flank wear comparison at 200 m/min

Above plots show that the flank wear behavior is little varied for different speeds. We can observe that flank wear is minimum at lower feed rate, for 100 m/min and 150 m/min speed. For 200 m/min, flank wear is lower at higher feed rate.

Similarly, the flank wear variations for constant feed rates are also plotted (Figure 6 to Figure 8).

Fig.6. Flank wear comparison at 0.1 mm/rev

Fig.7. Flank wear comparison at 0.2 mm/rev

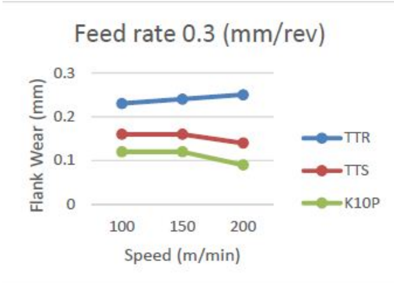

Fig.8. Flank wear comparison at 0.3 mm/rev

From above plots we can notice that flank wear is the complex function of speed and feed rates. As per above graphs, flank wear was less in tool K10P than other two uncoated inserts.

Figure 9 to figure 11 are based on temperature of tool inserts with respect to the speed.

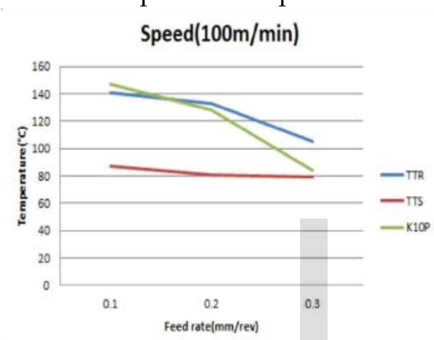

Fig.9. Cutting zone temperature comparison at 100 m/min

At constant speed, temperature has reached minimum value at maximum feed rate at 0.3 mm/rev.

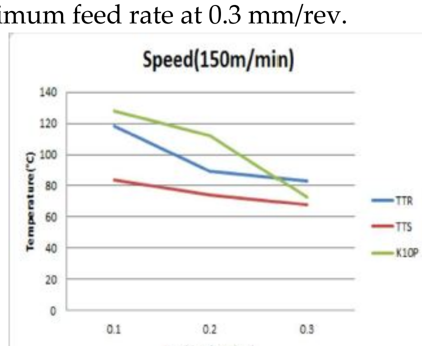

Fig.10. Cutting zone temperature comparison at 150 m/min

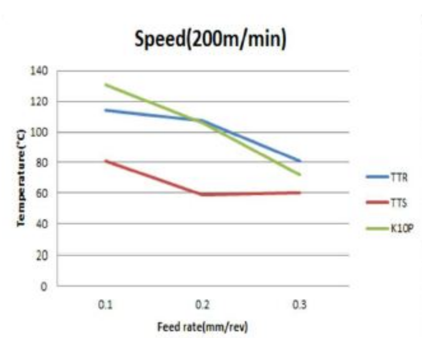

Fig.11. Cutting zone temperature comparison at 200 m/min

Similarly, for the constant feed rate temperature variations are given in Figure 12-figure 14.

Fig.12. Cutting zone temperature comparison at 0.1 mm/rev

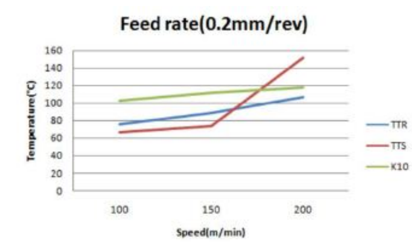

Fig.13. Cutting zone temperature comparison at 0.2 mm/rev

From above plots we can say that speed and feed rates together have a compound effect on flank wear and cutting zone temperature. Also it was observed from the experiment that coated type of tool insert K10P showed the minimum flank wear and uncoated carbide TTS have minimum working temperature.

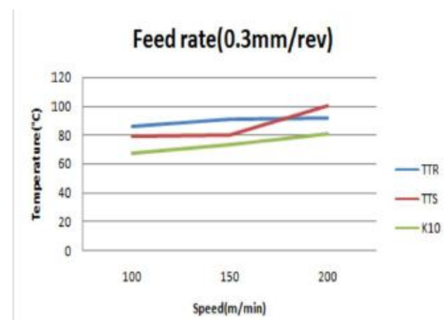

Fig.14. Cutting zone temperature comparison at 0.3 mm/rev

CONCLUSION

The turning experiments were carried out in dry condition using three different types of tool inserts; two uncoated and one coated type. The flank wear was measured after the experiments, using tool maker's microscope and the temperature was measured using thermocouple. The behavior of flank wear and temperature was plotted for constant speeds and constant feed rates. The following conclusions were made:

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- Cutting speed and feed rates together have a compound effect on the flank wear and temperature.
- From the plots, we can observe that the behavior of flank wear changes non-linearly, in the sense the behavior is different at lower and higher cutting conditions.
- Coated tool has the better tool life compared to other two types of tool inserts used in this experiment.
- Uncoated insert TTS showed better tendency in terms of lesser temperature rise.
- Temperature value reduced for increased feed rate and reduced speed.

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