Analysis of Tool Wear in Hard Turning AISI 4340

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Abstract- *Turning is a major machining process used in manufacturing various components like drive shafts, cam shafts, axles, connecting rods etc. The accuracy of the component produced is often affected by wear of the cutting tool. As the wear increases, the accuracy of the part decreases. Tool wear reduces the performance of the machining process and which rise to tool replacement. The material EN 19 is widely used in aerospace, automotive, steam turbines and nuclear industry applications. AISI 4340 is the alternate material proposed. The appropriate tool insert was selected based on the material. The turning of AISI 4340 was carried out using selected Cubic Boron Nitride (CBN) and Polycrystalline Cubic Boron Nitride (PCBN). In this project the turning operation was carried out on AISI 4340 and Cubic boron nitride, Polycrystalline cubic boron nitride tool wear was predicted using weight loss method and Scanning Electron Microscope (SEM). Tool insert wear rate was analyzed and the minimum wear rate was achieved in Cubic Boron Nitride tool insert compared to Polycrystalline Cubic Boron Nitride.*

Keywords- Cubic boron nitride, Polycrystalline cubic boron nitride, scanning electron microscope, tool wear, weight loss method, AISI 4340.

I. INTRODUCTION

Turning is a machining process in which a cutting tool, typically a non-rotary tool bit, describes a helix tool path by moving more or less linearly while the work piece rotates. The tool's axes of movement may be literally a straight line, or they may be along some set of curves or angles, but they are essentially linear (in the non-mathematical sense). Usually the term "turning" is reserved for the generation of external surfaces by this cutting action, whereas this same essential cutting action when applied to internal surfaces (that is, holes, of one kind or another) is called "boring". Thus, the phrase "turning and boring" categorizes the larger family of (essentially similar) processes. The cutting of faces on the work piece (that is, surfaces perpendicular to its rotating axis), whether with a turning or boring tool, is called "facing", and may be lumped into either category as a subset. Turning can be done manually, in a traditional form of lathe, which frequently requires continuous supervision by the operator, or by using an automated lathe which does not. Today the most common type of such automation is computer numerical control, better known as CNC. (CNC is also commonly used with many other types of machining besides turning).

When turning, a piece of relatively rigid material (such as wood, metal, plastic, or stone) is rotated and a cutting tool is traversed along 1, 2, or 3 axes of motion to produce precise diameters and depths. Turning can be either on the outside of the cylinder or on the inside (also known as boring) to produce tubular components to various geometries. Although now quite rare, early lathes could even be used to produce complex geometric figures, even the platonic solids; although since the advent of CNC it has become unusual to use non-computerized tool path control for this purpose.

In this paper process capability study is performed for turning operation, keeping in mind the end goal to check the process performance within specific limits. Three process input like spindle speed, feed and depth of cut has been chosen for process capability study in plain turning operation following Taguchi's L27 orthogonal array. This study deals with an investigation of turning process parameters on steel. Experiments have been conducted using factorial design, to study the effect of machining parameters such as cutting speed, feed rate, depth of cut, tool nose radius and lubricant on surface roughness while turning En-31 steel. The Results have been analyzed by the variance technique and the F-test, showing thereby that the cutting speed, feed rate, depth of cut, tool nose radius and lubricants have significant effect on measured surface roughness during turning steel [1-2]

Machined surface integrity during orthogonal turning titanium alloy TB6 was systematically researched. The effects of cutting parameters and process system vibration on the machined surface roughness and defects were studied. The result showed that it was not the cutting speed, but feed rate obviously significant impact on the surface roughness, residual stress and micro hardness. The current research involves the performance analysis in turning incoloy 800 in dry, minimum quantity lubrication(MQL) and the flooded lubrication condition Grey relational method is used to ameliorate the cutting process restriction (feed, depth of cut and cutting speed) ,in order to have minimum roughness of surface and tool wear [3-4]

The cutting parameters chosen for this investigation are cutting speed, feed rate, and radial depth of cut were used as input parameters in order to predict tool wear. The experiment was designed by using full factorial33 in which 27 samples were run in a Fanuc 0i TC CNC lathe. Taguchi technique and multiple regression is used to optimize the machining parameters for minimum surface roughness. The result showed that nose radius is more influence than feed, depth of cut, cutting speed. This paper investigate the performance of wiper insert in hard turning of oil hardened steel. Influence of process parameters such as speed, feed, depth of cut and nose radius (for wiper and conventional inserts) on surface roughness is analyzed using analysis of variance (ANOVA) and analysis of means (AOM) plots. From the analysis, it can be clearly seen that wiper inserts produce a very good machined surface compared to conventional inserts [5-7].

In this research work, an attempt has been made to investigate the effect of liquid nitrogen when it is applied to the rake surface, and the main and auxiliary flank surfaces through holes made in the cutting tool insert during the turning of the Ti–6Al–4V alloy. The cryogenic results of the cutting temperature, cutting forces, surface roughness and tool wear of the modified cutting tool insert have been compared with those of wet machining. This article depicts the optimization of the three prominent turning process parameters, cutting speed, feed rate and depth of cut. The influence of various input parameters of the turning process and their impact on determining the process capability were studied by adopting Taguchi approach. Scanning Electron Microscopy (SEM) with Energy Dispersive Spectroscopy (EDS) approach has been utilized to compare the results of both tools. The obtained width of flank wear was noticed to be below than 0.3 mm for both tools [8-10].

The objective was to investigate the influence of machining parameters including peak current, pulse-on time, gap voltage, spindle speed and flushing pressure on performance characteristics at reverse polarity. Taguchi-grey relational approach based on multi objective optimization has been used to optimize material removal and surface roughness simultaneously. The wear of inserts surface, cutting forces, and surface roughness were studied to optimize PVD-coated carbide inserts. Surface topography, residual stresses, micro hardness, and microstructure were analyzed to characterize the surfaces layer under different turning parameters. Surface integrity and fatigue life tests of c-TiAl alloy were conducted under turning and turning-polishing processes [11-12].

II. OBJECTIVES

To analyze the tool wear in two different tool inserts using weight loss method and Scanning Electron Microscope (SEM). To optimize the machining parameters (speed, depth of cut, feed) using Taguchi technique.

III.PROBLEM DEFINITION

AISI 4340 have high toughness, good fatigue strength and high strength than EN-19 due to the Ni and Chrome alloying additions. Hence for the AISI 4340 is used as a new proposal material for EN 19 alloy steel. The application of AISI 4340 alloy steel Axles, axle components, arbores, shafts, wheels, pinions and pinion shafts.
In hard turning of AISI 4340, the tool wear and surface roughness is most affected due to high hardness of the workpiece material. The optimum selection of parameters reduces the tool wear and surface roughness.

MATERIAL PROPERTY AND CHEMICAL COMPOSITION OF AISI 4340 ALLOY STEEL

AISI 4340 alloy steel rods having diameter 50 mm and length 200 mm were used as workpiece material. The workpiece material selected was AISI 4340 alloy steel because it is used in various applications like steel axles, axle components, arbores, shafts, wheels, pinions and pinion shafts. Which requires turning as a main operation.

Fig 1. AISI 4340 alloy steel

Table 1. Chemical composition of AISI 4340 alloy steel

C%	Mn%	P%	S%	Si%	Ni%	Cr%	Mo%
0.38	0.6-0.8	0.035	0.04	0.15-0.3	1.65-2.0	0.7-0.9	0.2-0.3

Table 2. Mechanical properties of AISI 4340 alloy steel

Properties	Metric
Tensile strength	745 MPa
Yield strength	470 MPa
Bulk modulus	140 GPa
Shear modulus	80 GPa
Elastic modulus	190-210 GPa
Poisson's ratio	0.27-0.3
Reduction of area	50%
Hardness, Brinell	217

TOOL INSERT

Cubic Boron Nitride (CBN)

Cubic boron nitride (CBN or c-BN) is widely used as an abrasive. Its usefulness arises from its insolubility in iron, nickel and related alloys at high temperatures, whereas diamond is soluble in these metals to give carbides. When in contact with oxygen at high temperatures, BN forms a passivation layer of boron oxide. Boron nitride binds well with metals, due to formation of interlayer of metal borides or nitrides. Materials with cubic boron nitride crystals are often used in the tool bits of cutting tools. For grinding applications, softer binders, e.g. resin, porous ceramics, and soft metals, are used. Ceramic binders can be used as well. Commercial products are known under names "Borazon" (by Diamond Innovations), and "Elbor" or "Cubonite" (by Russian vendors). Contrary to diamond, large CBN pellets can be produced in a simple process (called sintering) of annealing CBN powders in nitrogen flow at temperatures slightly below the BN decomposition temperature. This ability of c-BN and h-BN powders to fuse allows cheap production of large BN parts. Similar to diamond, the combination in CBN of highest thermal conductivity and electrical resistivity is ideal for heat spreaders.

As cubic boron nitride consists of light atoms and is very robust chemically and mechanically, it is one of the popular materials for X-ray membranes: low mass results in small X-ray absorption and good mechanical properties allow usage of thin membranes, thus further reducing the absorption.

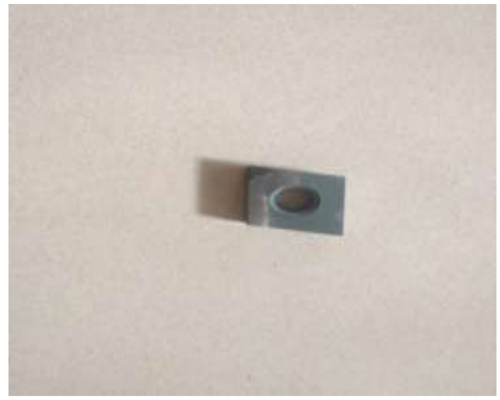

Fig 2. Cubic Boron Nitride (CBN) tool

Polycrystalline Cubic Boron Nitride (PCBN)

Polycrystalline Cubic Boron Nitride (PCBN) is solids that are composed of many crystallites of varying size and orientation. Crystallites are also referred to as grains. Small or even microscopic crystals and forms during the cooling. Polycrystalline CBN (PCBN) abrasives are therefore used for machining steel, whereas diamond abrasives are preferred for aluminum alloys, ceramics, and stone. It has good hot hardness that can be used at high cutting speed. It also exhibits good toughness and thermal shock resistance.

Fig 3. Polycrystalline Cubic Boron Nitride (PCBN) tool

DESIGN OF EXPERIMENT

The turning experiments were conducted for Cubic boron nitride and polycrystalline cubic boron nitride based on the machining time. The machining time was divided into three equal parts for experimentation. The experiments were conducted based on the machining time given in the following table 3.

Table 3. Experimental details

Cutting tool	Machining time (min)		
	1	2	3
Cubic Boron Nitride(CBN)	1.5	3	4.5
Polycrystalline Cubic Boron Nitride(PCBN)	1.5	3	4.5

Table 4. Cutting parameters

Speed	Feed	Depth of cut
1400 rpm	0.05 mm/rev	0.5 mm

The cutting conditions are selected based on the material and tool insert. On fixing this cutting condition as a constant, the turning operation was carried out on AISI 4340 alloy steel using both Cubic Boron Nitride (CBN) and polycrystalline cubic boron nitride (PCBN).

Fig 4 Turning of AISI 4340 alloy steel

The experiments were conducted on the AISI 4340 alloy steel using above condition and the wear is measured using weight loss method and wear behavior was studied Scanning Electron Microscope (SEM).

IV. RESULT AND DISCUSSIONS

The tool wear was measured using tool weight loss. The following table shows the initial and final tool weight for various set. The experiments were conducted in CNC turning center using Cubic Boron Nitride (CBN) and Polycrystalline Cubic Boron nitride (PCBN) and their wear values are given below:

Table 5. Results of Polycrystalline Cubic Boron Nitride tool (PCBN)

Experiment	Machining time (min)	Initial weight (grams)	Final weight (grams)	Weight loss (grams)
1	1.5	9.5679	9.5614	0.0065
2	3	9.5614	9.5578	0.0036
3	4.5	9.5578	9.5510	0.0027

The table 5 shows that the initial weight (grams), final weight (grams) and weight loss of Polycrystalline Cubic Boron Nitride (PCBN) of various set of experiment.

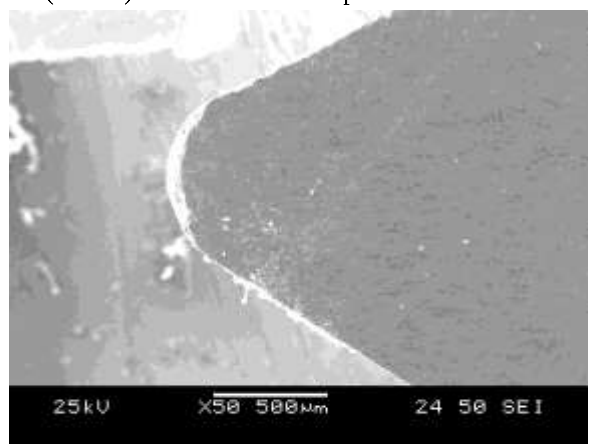

Fig 5 SEM image of Polycrystalline Cubic Boron Nitride (PCBN) tool

The fig 5 shows that the wear behavior of Polycrystalline Cubic Boron Nitride (PCBN). This image was taken using Scanning Electron Microscope (SEM).

Table 6. Results of Cubic Boron Nitride tool

Experiment	Machining time (min)	Initial weight (grams)	Final weight (grams)	Weight loss (grams)
1	1.5	9.6024	9.6014	0.0010
2	3	9.6014	9.6006	0.0008
3	4.5	9.6006	9.5997	0.0009

The table 6 shows that the initial weight (grams), final weight (grams) and weight loss of Cubic Boron Nitride (PCBN) of various set of experiment.

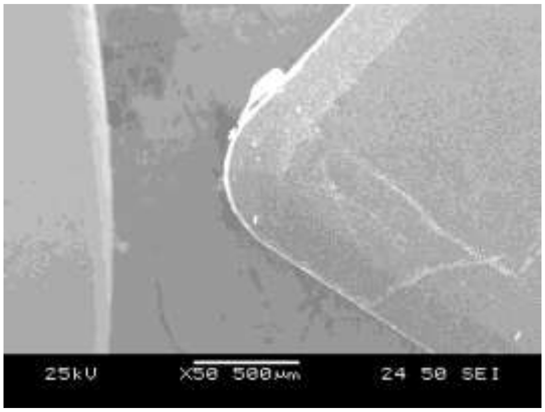

Fig 6 SEM image of Cubic Boron Nitride (CBN) tool

The fig 6 shows that the wear behavior of Cubic Boron Nitride (CBN). This image was taken using Scanning Electron Microscope (SEM). The fig 5 and 6 shows the wear of both Polycrystalline Cubic Boron Nitride (PCBN) and Cubic Boron Nitride (CBN). From the SEM image the minimum wear was achieved in Cubic Boron Nitride (CBN) tool compared to Polycrystalline Cubic Boron Nitride (PCBN).

Comparative Studies of Cubic Boron Nitride (CBN) and Polycrystalline Cubic Boron Nitride

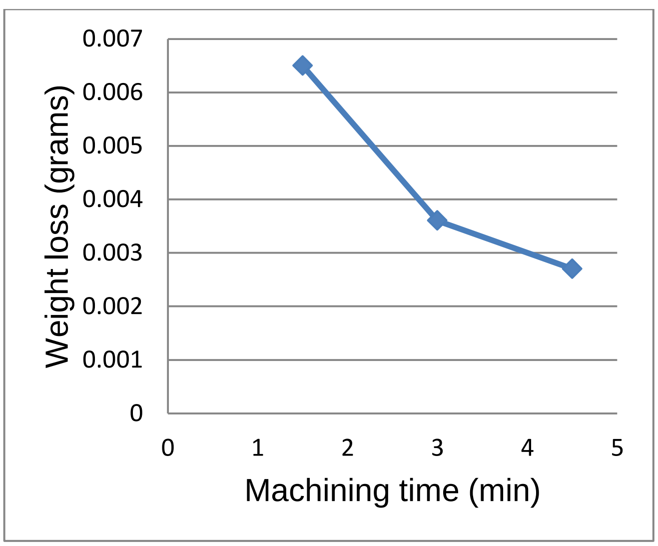

Fig 7. Weight loss of Polycrystalline Cubic Boron Nitride tool

The fig 7 shows that the weight loss of Polycrystalline Cubic Boron Nitride (PCBN) and maximum weight loss was occurred at first trail and decreases further.

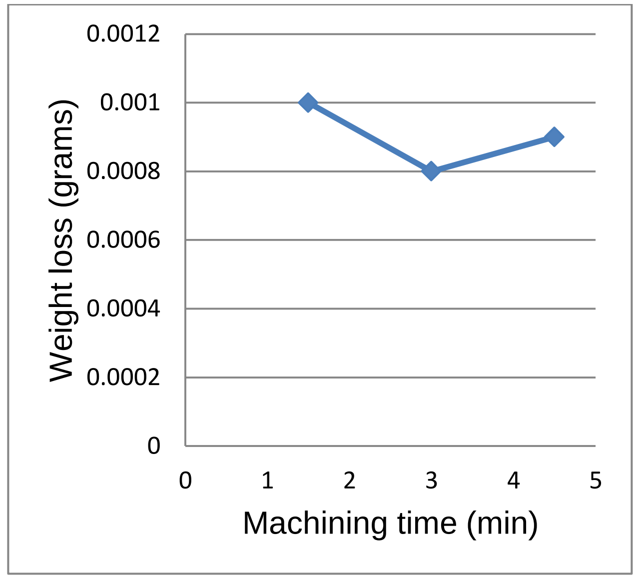

Fig 8. Weight loss of Cubic Boron Nitride tool

Fig 8 shows the weight loss of Weight Cubic Boron Nitride (CBN) and maximum weight loss was occurred at first trail then decreases and remains constant. The fig 8.3 and 8.4 shows the difference in weight loss of Cubic Boron Nitride (CBN) and Polycrystalline Cubic Boron Nitride (PCBN) tool insert.

V. CONCLUSIONS

In this project work the wear rate was investigated experimentally using weight loss method and wear behaviour was studied using Scanning Electron Microscope (SEM). The above study shows that polycrystalline cubic boron nitride has the weight loss from 0.0027 to 0.0065 (g) and cubic boron nitride has weight loss the ranging from 0.0008 to 0.0010 (g). Hence the minimum wear rate was achieved in cubic boron nitride tool insert compared to Polycrystalline cubic boron nitride.

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