Tool Wear Investigation in CNC Turning Operation

Yousuf Al Kindi, Murali R V, Salim R K

***Abstract*—** The aim of this attempt is to experimentally investigate the cutting tool wear rate and its correlation with the cutting speed values during a straight turning operation undertaken on a CNC Turning Centre. Work materials and cutting tool materials considered in this project are Stainless Steel (304) and Aluminium cylindrical rods of 30 mm diameter and 60 mm long, and Tungaloy carbide T9115 cutting tool (CVD coated grade for steel turning) used due to extremely stable tool life and amazing chipping resistance. A short study of the key variables that influence the cutting tool wear was done and cutting speed, feed rate and the depth of cut were among the factors that control the tool wear rate. However, major influence on the tool wear rate is due to the cutting speed variation. Therefore, in this study, cutting speed is considered and experiments are conducted at various cutting speed values for specific cutting length of the work piece. Machining time for straight turning operation of totally 10 work pieces with different cutting speed values is noted down and the weight reduction of cutting tool after cutting operation of each work piece is measured using a high-sensitive weighing balance. Along with these values and density value of the work material, Cutting Tool Wear rate is calculated and tabulated. The results reveal and re-affirm that an increase in cutting speed values results in increased cutting tool wear rate and reduced tool life values. Complete set of results and outcome of the investigative analysis help in determining the optimal values of the cutting speeds for the given cutting conditions and work materials. Furthermore, a microscopic analysis of the cutting tool regions is presented in order to provide an insight on the flank and crater wear phenomenon.

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I. INTRODUCTION

Cutting tools are subjected to an extremely severe rubbing process. They are in metal-to-metal contact between the chip and work piece, under high stress and temperature. The situation becomes severe due to the existence of extreme stress and temperature gradients near the surface of the tool. Tool wear is generally a gradual process due to regular operation. Tool wear can be compare with the wear of the tip of an ordinary pencil. According to Australian standard, the tool wear can be defined as the change of shape of the tool from its original shape, during cutting, resulting from the gradual loss of tool material.

Tool wear depends upon following parameters:
i. Tool and work piece material.
ii. Tool shape.
iii. Cutting Speed.
iv. Feed.
v. Depth of cut.
vi. Cutting fluid used.
vii. Machine Tool characteristics etc.

Main aims of the present study are to investigate on tool wear during turning operation done on a CNC machine, to study the cutting tool wear rate of different work – cutting tool combinations and finally present the analysis/comparison results to reflect the objectives stated in the abstract.

II. BACKGROUND STUDIES

Producing a welding machine than using an existing machine for welding and carrying out further tests poses a greater challenge and imparts a totally different altogether experience for students. In this work, a FW machine was built after selecting suitable parts, motors, work holding devices and designing base structure and electronic controller for process parameters control. While building the FW machine, several studies done in the past were referred and suitable design inputs and operational issues were considered. Summary of the inputs taken from the literature studies is given in the following sections.

The effect of material properties on surface roughness, material removal rate, and tool wear on a high speed CNC end milling process with various ferrous and nonferrous materials was demonstrated [1]. There are many challenges of material specific decision on the process parameters of spindle speed,

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feed rate, depth of cut, coolant rate, cutting tool material, and type of coating for the cutting tool for required quality and quantity of production is addressed. This paper described the effect of various parameters on the surface roughness characteristics of the precision machining part. Further it also suggested various experimental analysis of parameters in different compositions of input conditions which would be done in the industry on standardization of high speed CNC end milling processes. The results showed that there was more concentration around the band of 0.26–0.25 micron finish in the levels of spindle speed as in the range of 11000 to 12000 rpm at the feed rate of 600 to 650 m/min and between 0.66 mm and 0.87 mm of depth of cut. This result revealed that this technique produced good surface finish with higher depth of cut and feed rate and spindle speed more than the mid value.

Another case study was conducted [2] on strategies of measure concerning free-form surfaces which may be used during in-process measurements of a workpiece on a CNC milling machine. In addition, it shows some supplement to conventional strategy of measurements of free-form surfaces directly on CNC machine tools are propose, considering such variable factors as the real working length and real working radius of applied milling cutter as well as its wear. Results of experimental and numerical investigations are presented which show how tool wear and small changes of real working length and real working radius of applied milling cutter influence the shape and accuracy of machining a work piece containing some free-form surfaces. The investigations made in this work concerned the determination of the changes of real working length of applied tool and its real offset radius as well as tool wear in the process of machining of free-form surfaces. The obtained results of performed investigations show, that collected information from both numerical simulations and experimental investigations is helpful for establishing the measurement strategy of free-form surfaces.

An experimental investigation was carried out on machinability of Inconel 718 in conventional and alternative high pressure cooling conditions [3]. The experiments were designed according to Taguchi L18 orthogonal array based on three levels of cutting speed, feed rate and fluid pressure and two levels of depth of cut. The cutting forces and tool flank wear were measured, while turning Inconel 718 work pieces, using (Ti, Al) N+TiN coated CNMG0812 carbide cutting tools. In order to determine the importance of cutting parameters on tool flank wear and cutting forces, ANOVA (Analysis of variance) was employed. Moreover, with multi regression analysis, empirical equations that indicate relation between tool flank wear and cutting forces with machining parameters were defined. The experiment results have proven that the tool flank wear and cutting forces considerably decrease with the delivery of high pressure coolant to the cutting zone. Moreover, ANOVA results also indicated that high pressure cooling had a significant beneficial effect on cutting tool life. Regression modeling was also used to investigate the relationships between process parameters and machining responses. The most important of all result was the cutting tool wear, especially flank face wear, reduced with applying high pressure coolant to the tool-chip interface. This can be attributed to the fact that high pressure coolant provides better lubrication and cooling than conventional cooling [3].

Eventually, a series of experiments were conducted on Aluminium Al 6063 by high speed Stainless steel end mill cutter and tool wear was measured using tool maker's microscope [4]. The direct and interaction effect of the machining parameter with tool wear were analyzed, which helped to select process parameter in order to reduce tool wear which ensures quality of milling. The investigation presented a central composite rotatable second order response surface methodology to develop a mathematical model to predict tool wear in terms of helix angle, spindle speed, feed rate, axial and radial depth of cut. The result showed an increase in spindle speed and axial depth of cut reduced the cutting tool wear. The decrease in radial depth of cut reduced tool wear. In addition, the interactions between the process parameters were analyzed and strong interactions were observed between helix angle and axial depth of cut; spindle speed and feed rate; helix angle and feed rate; and spindle speed and radial depth of cut [4].

In the all the above research works, researchers used different combination of cutting tool – work materials to analyse the cutting tool wear rate. In the present attempt, Stainless Steel and Aluminium workpieces were selected and carbide tool (Tungaloy) is put to use in order to correlate the tool wear rate with the cutting speed values. All these experiments were conducted on a CNC Turning Center.

III. MATERIALS & METHODS

Computer Numerical Control (CNC) programming is prepared for the given dimensions of the cylindrical workpiece to complete the turning operation on the CNC Turning Center. Input parameters such as feed rate, depth of cut, spindle speed, are set in the programme and the experiments are carried out under dry cutting conditions. Lubrication is normally used in machining to prevent cutting at excessive high temperature. Basically, lower cutting temperature results in longer tool life of the cutting tool. But in the case of cutting tool inserts with

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TiN coating, the cutting tool insert will work better at high temperature. Dry cutting is better than wet cutting for TiN coating inserts under high speed cutting.

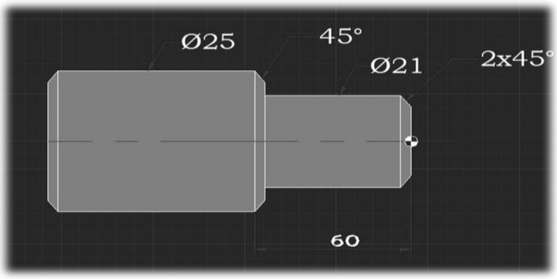

Figure 1 CAD Model of Component used
(All dimensions are in mm)

Table 1 Key Specifications of Tungaloy Cutting Tool

CUTTING TOOL SPECIFICATIONS	
ANSI Number	CNMG 432-TM
Brand Name	Tungaloy
Class	Turning
Code	CNMG 432-TM T9115
Grade	T9115
Hole Size	.203
Insert style	CNMG 432-TM
Insert Size	432
Material	Carbide
Radius	.031
Thickness	.187
Type	Turning Insert

Cutting tool (carbide insert) was taken from workshop and the work materials are purchased from Oman market. Literature studies have been referred to, for some of the calculations which were useful for the current project. Figure 1 illustrates the CAD model of the component used in the work and Table 1 presents the Key Specifications of Tungaloy Cutting Tool used in this attempt. Table 2 lists the chemical composition of each metal being turned using CNC machine. In fact, the work materials were taken from another student's project after the project was completed. This has reduced the cost incurred in this project. High sensitive chemical balance was used to find the difference in weight of the cutting tool before and after the turning operations.

TABLE 2 Chemical composition of materials used

Aluminum					
Al	Mn	Fe	Si	Cu	Zn
Balance	1.0 – 1.5	< 0.7	< 0.6	0.05 – 0.2	< 0.1

Stainless Steel							
C	Si	Mn	S	P	Cr	Ni	Fe
0.03	1	1.5	0.04	0.04	10.5	1	Balance

Scanning electron microscope was used to analyse the wear regions on the cutting tool before and after the operation. Flank and crater wear are the most important types of wear normally experienced with the cutting tool. Results from the microscopic analysis reveal that the flank wear in these experiments can be seen obviously when high speed turning process was conducted. Flank wear is caused by friction between the flank face of the tool and the machined surfaces. Flank wear is generally attributed to rubbing of the tool with work piece at the interface, causing abrasive wear at elevated operational temperatures [5].

IV. DESIGN OF EXPERIMENTS

The purpose of this project to study the tool wear rate of different tool materials used in CNC machine for the machining of various metals. The analysis of the results will be done with the help of tool wear software so that the optimum operating condition with enhanced tool life could be identified. The experimentation part of this project is planned to conduct at Caledonian college of engineering by making use of the various types of cutting tools and materials that are available in the mechanical workshop. The project focuses on the analysis of two materials which are stainless steel and aluminum. The collected samples have been taken from CNC laboratory. Cutting tools come in a range of sizes, materials, and geometry types on this experiment choose T9115 because it has highly effective cutting can be acquired and it has super performance at wet cutting condition due to excellent thermal crack resistance. The samples have been changed after the operation, so it should take the weight before and after each operation to apply the values in the equation below [5]:

$$\text{Tool Wear Rate} = \frac{Wi - Wf}{(t_m)(\rho)} \ (mm^3/min)$$

W_i= Initial Weight of the cutting tool insert (g)
W_f= Final Weight measured of the cutting tool insert (g)
ρ = Density of the cutting tool materials (g/mm^3)
t_m= Machining time in min

V. RESULTS AND DISCUSSION

There are totally 32 cylindrical workpieces for each category (SS and Al) that were used in this experiment. The cutting speed was varied from 102 m/min to 125 m/min. Time taken for each lot was recorded using a stop watch. Once the turning operation was completed for each lot, average machining time taken was worked out and final weight of the cutting tool was measured using a high-sensitive weighing balance.

Date: 10.12.2017	**Work Material:** Stainless Steel		**Machine Used :**Turning CNC Machine
Depth of Cut	1 mm	**Length & Diameter of Cylindrical Job**	60 mm long & ø 25 mm
Feed	1 mm/rev	**Density of Stainless Steel :** 7.9 g/cm³	**Initial Weight of Cutting Tool:** 8.598 g
Cutting Tool Material / Code	CNMG432TMT9115		

Job Nos	Cutting Speed 'Vc' (m/min)	Rotation Speed N (rpm)	Diameter of the Job (mm)		Time taken for each job (sec)	Total time taken (min)	Final Weight of cutting tool (g)	Tool Wear Rate $\frac{Wi-Wf}{(t_m)(\rho)}$ (mm³/min)
			Initial	Final				
1-4	102	1427	25	23	13.8 13.9 13.9 13.8	0.92	8.584	1.926252064
5-9	105	1464	25	23	13.5 13.6 13.5 13.4	0.9	8.581	2.390998594
9-12	108	1528	25	23	12.1 11.9 12 12	0.8	8.487	17.56329114
13-16	110	1592	25	23	11.4 11.5 11.5 11.6	0.76	8.482	19.32045303

Wi: Initial Weight of cutting insert in g; Wf: Final Weight of cutting insert in g; Tm: machining time in min; ρ= Density of the tool material in g/mm³

Figure 3 Tool Wear Rate Calculation for Stainless Rod

The results reveal that an increase in cutting speed decreases machining time and increases the cutting tool wear rate values. The microscopic images reveal that there is a wear region on the flank portion of the cutting tool and built up edge is formed because of the rubbing action of on-going chips. All these experiments were dry run without use of any lubrication. Relationships between the cutting speed values and cutting tool wear and Machining Time are shown in the figures 4,5 and 7,8 for Stainless Steel and Aluminium respectively.

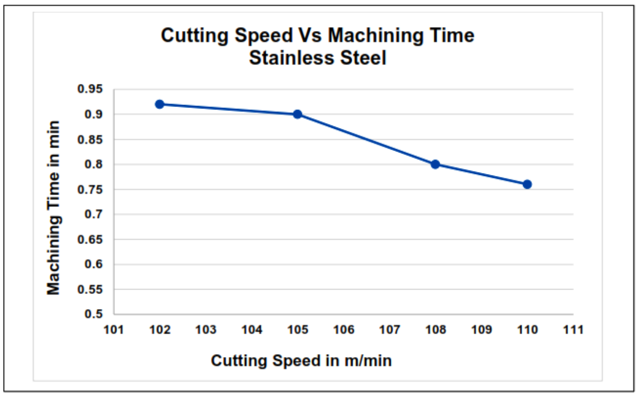

Figure 4 Cutting Speed Vs Machining Time (Stainless Steel)

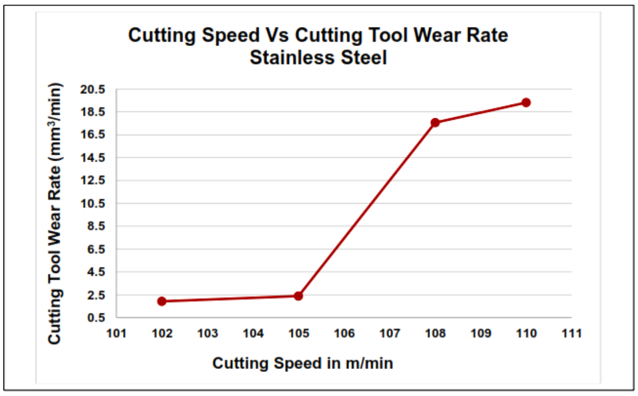

Figure 5 Cutting Speed Vs Cutting Tool Wear Rate (Stainless Steel)

Date: 10.12.2017	**Work Material:** Aluminium		**Machine Used :**Turning CNC Machine
Depth of Cut	1 mm	**Length & Diameter of Cylindrical Job**	60 mm long & ø 25 mm
Feed	0.7 mm/rev	**Density of Aluminium :** 2.7 g/cm³	**Initial Weight of Cutting Tool:** 8.651 g
Cutting Tool Material / Code	CNMG432TMT9115		

Job Nos	Cutting Speed 'Vc' (m/min)	Rotation Speed N (rpm)	Diameter of the Job (mm)		Time taken for each job (sec)	Total time taken (min)	Final Weight of cutting tool (g)	Tool Wear Rate $\frac{Wi-Wf}{(t_m)(\rho)}$ (mm³/min)
			Initial	Final				
1-4	102	1427	25	23	14 14 14 14	0.92	8.650	0.137589433
5-9	105	1464	25	23	13.5 13.4 13.6 13.5	0.9	8.592	8.298171589
9-12	108	1528	25	23	12.1 12 12 11.9	0.8	8.576	11.86708861
13-16	110	1592	25	23	11.5 11.5 11.5 11.5	0.76	8.574	12.82478348

Wi: Initial Weight of cutting insert in g; Wf: Final Weight of cutting insert in g; Tm: machining time in min; ρ= Density of the tool material in g/mm³

Figure 6 Tool Wear Rate Calculation for Stainless Rod

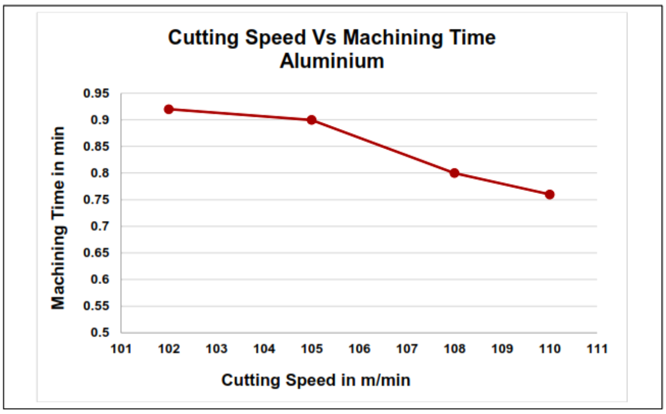

Figure 7 Cutting Speed Vs Machining Time (Aluminum)

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VI. CONCLUSION

The main objective of this project is to investigate the cutting tool wear rate and its variations with respect to the cutting speed values during a straight turning operation undertaken on a CNC Turning Centre. Work materials and cutting tool materials considered in this project are Stainless Steel (304) and Aluminum cylindrical rods of 30 mm diameter and 60 mm long, and Tungaloy carbide T9115 cutting tool (CVD coated grade for steel turning) used due to extremely stable tool life and amazing chipping resistance.

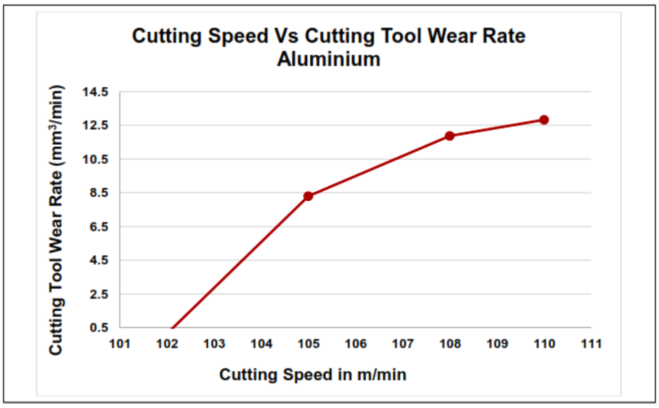

Figure 8 Stress – Cutting Speed Vs Machining Time (Aluminium)

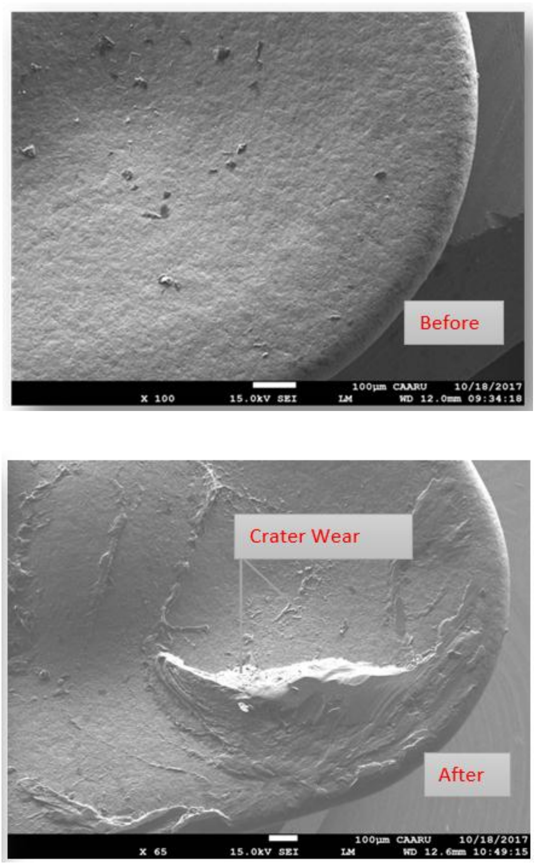

Figure 9 Results of the Microscopic Analysis before and after turning operations

Cutting parameters of a metal machining method such as cutting speed, feed rate and depth of cut have a significant influence on the cutting tool wear and tool life. Among these three factors, cutting speed got a major role on affecting the tool wear rate. Therefore, in this study, cutting speed is considered and experiments are conducted at various cutting speed values for specific cutting length of the work piece. Machining time for straight turning operation of totally 10 work pieces with different cutting speed values is noted down and the weight reduction of cutting tool after cutting operation of each work piece is measured using a high-sensitive weighing balance. Along with these values and density value of the work material, cutting tool wear rate is calculated and tabulated. The results reveal and re-affirm that an increase in cutting speed values results in increased cutting tool wear rate and reduced tool life values. Complete set of results and outcome of the investigative analysis help in determining the optimal values of the cutting speeds for the given cutting conditions and work materials. Furthermore, a microscopic analysis of the cutting tool regions is presented in order to provide an insight on the flank and crater wear phenomenon.

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