

Experimental Analysis and Modeling of Tool Wear and Surface Roughness in Hard Turning under Minimum Quantity Lubricant Environment

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Abstract

This paper presents an on-going comparative study of tool wear and surface roughness for varying cutting parameters under dry and Minimum Quantity Lubrication (MQL) environment while turning hardened medium carbon steel (hard turning) by coated carbide insert. A mathematical model was also developed to determine the surface roughness in terms of machining time and cutting tool wear function in terms of the four independent variables: the cutting depth (d), the cutting feed (f), the cutting speed (V_c) and the cutting duration (t). The results indicated that the application of MQL technique significantly helps to obtain better performance in compare to dry condition.

Keywords

Hard turning, Minimum Quantity Lubrication, Tool wear, Surface roughness.

1. Introduction

Machining of pre-hardened steel materials, known as hard turning, is gaining more and more attention recently because it offers numerous advantages over traditional grinding in some applications. For hard turning process it is very important to know the cutting tool wear function. Tool wear which leads to tool failure is an integral part in all machining processes. High speed machining uses high cutting speed and feed rate and ultimately generates high cutting temperature which not only reduces tool life but also impairs the product quality. The most important surface quality requirement in hard turning is surface roughness. Although there are many economic advantages of replacing grinding with hard turning, tool wear remains a major obstacle. Therefore, it is important to address the factors affecting surface quality and tool wear mechanism in hard turning [2-8]. For continuous hard turning the maximum tool wear land width (VB_{max}) shows a near linear increase with cutting distance after initial rapid wear [9].

Advances in cutting tool technology have led to the introduction of coated and uncoated carbide, ceramic, CBN/PCBN and PCD tools with adequate hot hardness and toughness to withstand elevated temperatures generated at high-speed conditions. Cutting parameters (cutting speed and feed rate), hardness of workpiece material, and cutting tool material (including tool edge type) are important to understand wear mechanisms of advanced cutting tools. Also, machining techniques, such as ramping (or taper turning), high-pressure coolant (HPC) delivery system, minimum quantity lubrication (MQL) system hot machining and cryogenic machining have been developed in recent years. The concept of minimum quantity lubrication is based on the principle of less lubrication with dry surface after the machining process. MQL fluid selection is one of the most critical decisions. The most common fluids are vegetable oil, ester oil or a synthetic equivalent because of their superior lubrication and high pressure performance [10]. In this research work straight run cutting oil (VG 68) is supplied because it was previously studied that cutting oil performs better than other cutting fluids [11].

This paper presents the results of an experimental study of hard turning of a hollow shaft made of medium carbon steel hardened to 56~57 HRC. The goal was to obtain a similar or better surface finish as in case of grinding. A

statistical analysis of the surface roughness with machining time using non-linear curve fit technique is also presented here. In addition to this a mathematical model is also developed to determine the cutting tool wear function in terms of the four independent variables: the cutting depth (d), the cutting feed (f), the cutting speed (V_c), the cutting duration (t) for turning the hardened medium carbon steel, with respect to the specific working conditions.

2. Experimental Set-up

This experimental study was conducted on a powerful rigid lathe machine (7.5 KW). Figure 1 shows the photographic view of the experimental set-up with the MQL applicator. The coolant used was straight run cutting oil (VG 68) at a flow rate of 60 ml/hr. the oil pressure was set at 20 bar and the air pressure was 15 bar. The workpiece material is medium carbon steel (Outer dia 120mm, inner dia 40mm and length 250mm) hardened to 56~57 HRC. The cutting tool used was coated tungsten carbide tool (SNMG TN 4000 WIDIA) having tool geometry of $-6^\circ, -6^\circ, 6^\circ, 15^\circ, 75^\circ, 0.8$ mm. The insert has been clamped in a PSBNR 2525 M12 type tool holder.

The rapid growth of wears on main and auxiliary flanks was studied at regular intervals for all trials. The machining was interrupted for this purpose. An inverted metallurgical microscope (Olympus: model MG) fitted with a micrometer of least count $1\text{ }\mu\text{m}$ was used to measure the flank wears. The surface roughness of the machined surface after each cut was measured by a Talysurf (Surtronic 3⁺) using a sampling length of 0.8mm.



(a) MQL applicator



(b) Surface roughness measuring technique



(b) Nozzle position

Figure 1. Photographic view of the experimental set-up

3. Results and Discussion

During the machining trials, mainly the growth of average principal flank wear and average auxiliary flank wear have been monitored. Figure 2 shows the variation of average principal flank wear depending on the machining time for different speed and feed conditions under both dry and MQL environment. The wear land length increases with the increase in cutting speed and feed rate. It has been observed that the rate of growth of VB increases from $8.45 \sim 32\text{ }\mu\text{m/min}$ irrespective of feed with the increase of speed under MQL condition. It has been also noticed that the effect of feed increment is not so dominant for tool wear. Tool wear increases from $8.45 \sim 12.15\text{ }\mu\text{m/min}$ while $V_c=170\text{ m/min}$ and $25 \sim 32\text{ }\mu\text{m/min}$ while $V_c=235\text{ m/min}$. But if we compare this with dry environment it has been found that rate of growth of VB increases from $68.88 \sim 155\text{ }\mu\text{m/min}$ with the increase of speed, which is much higher

than that of MQL. The gradual growth of VB, observed under MQL environment indicates steady machining without any premature tool failure thus reducing rate of tool wear. Such reduction in tool wear might have been possible for retardation of abrasion and notching by retaining tool hardness, decrease or prevention of adhesion and diffusion type thermally sensitive wear at the flanks and reduction of built-up edge formation which accelerates wear at the cutting edges by chipping and flaking. It has been noticed from the graph that the insert fails catastrophically while machining under dry condition. The tool sustains only 4.5 minutes at $V_c=170$ m/min and 2.5 minutes at $V_c=235$ m/min.

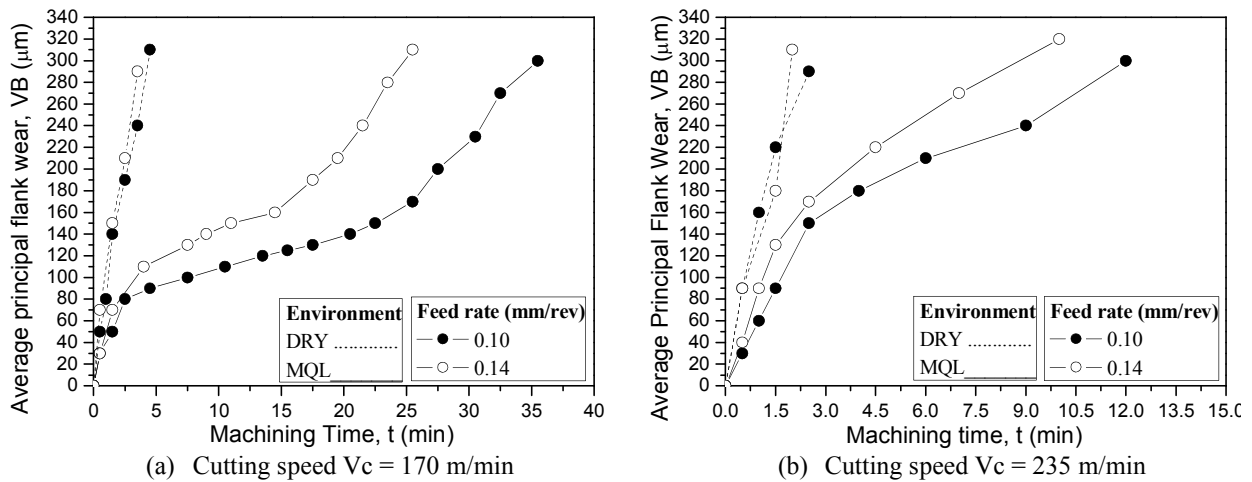


Figure 2. Growth of average principal flank wears with machining time under different environments

Another important tool wear criteria is average auxiliary flank wear, VS, which governs the surface finish on the job as well as dimensional accuracy. The growth of VS has been depicted in Figure 3 for different speed feed conditions under both the environments. The nature of growth of VS matches with that of VB expectedly. It is noticed from the graphs that the application of MQL has reduced VS in comparison to dry environment, which is expected to provide better surface finish and dimensional accuracy. It has been observed that the rate of growth of VS increases from $5.63\sim 31\mu\text{m}/\text{min}$ and $60\sim 140\mu\text{m}/\text{min}$ irrespective of feed with the increase of speed under MQL and dry condition respectively.

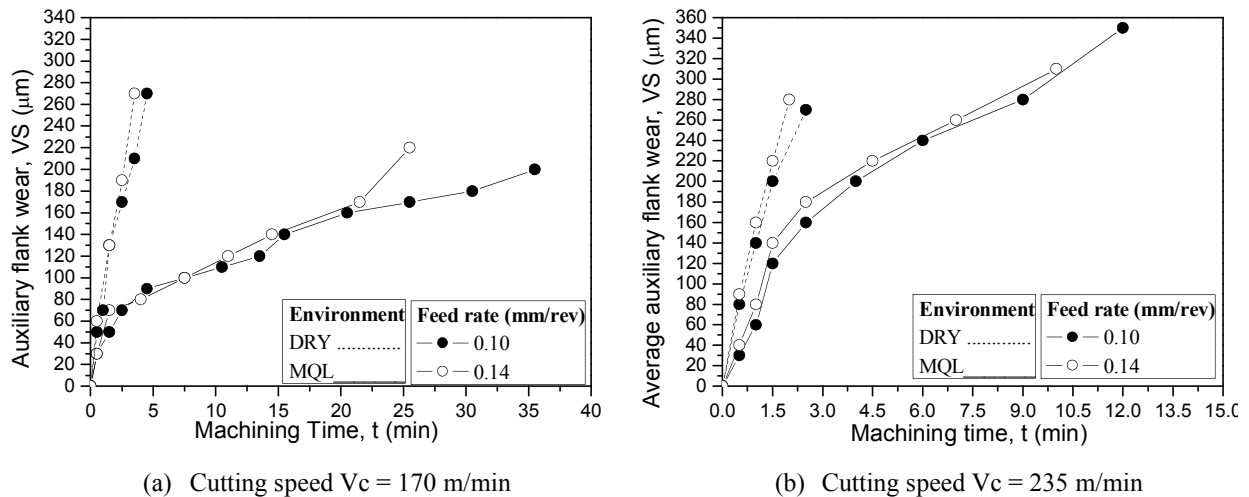


Figure 3. Growth of average auxiliary flank wears with machining time under different environments

Tool wear functions is computed from empirical expressions in the form:

$$VB = C v^x f^y d^z t^m \quad (1)$$

Where v is the cutting speed (m/min), f is the feed (mm/rev), d is the depth of cut (mm), t is the machining time (min) and C , x , y , z and m are coefficients experimentally obtained.

To estimate the C constant and the x , y , z , m polytropic exponents, the equation (1) has been linearized, by using logarithm [12]:

$$\log VB = \log C + x \log v + y \log f + z \log d + m \log t \quad (2)$$

Empirical model was experimentally obtained for tool wear under MQL, resulting in

$$VB = 5.725 \times 10^{-3} v^{0.72} f^{0.3076} d^{1.126} t^{0.2137} \text{ (mm)} \quad (3)$$

Figure 4 shows the variation in surface roughness with machining time under both dry and MQL environments. As MQL reduced average auxiliary flank wear and notch wear on auxiliary cutting edge, surface roughness also grew very slowly under MQL conditions. It appears from Fig.4 that surface roughness grows quite fast under dry machining due to more intensive temperature and stresses at the tool-tips, MQL appeared to be effective in reducing surface roughness.

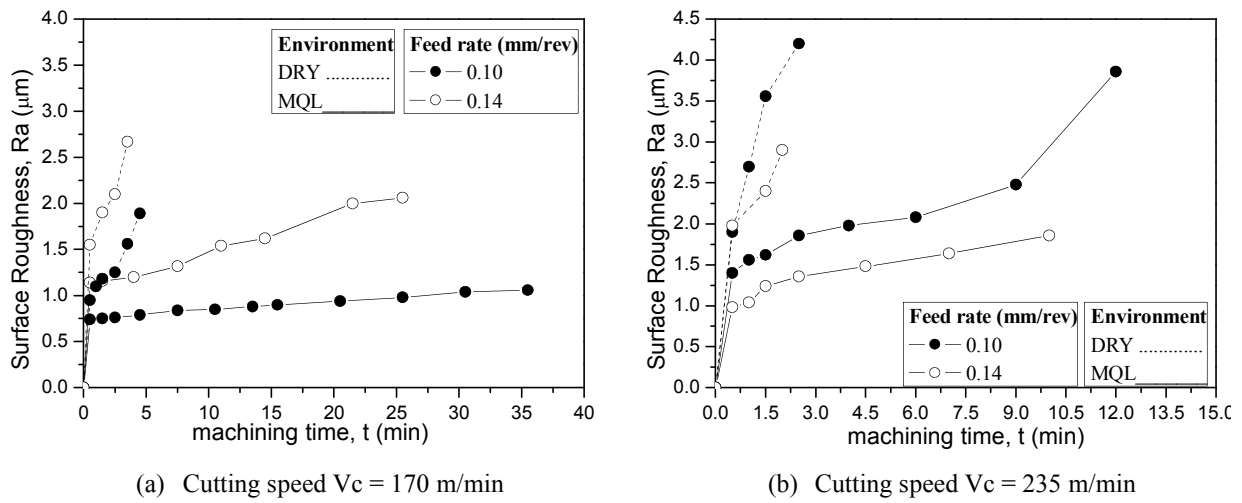


Figure 4. Growth of surface roughness with machining time under different environments

As time evolves roughness increases. This phenomenon can be expressed by the following exponential relationship:

$$Ra = K t^\alpha \quad (4)$$

Where, co-efficient K and exponent m depends on the process parameters combination, hardness ratio of work material to tool material. These are calculated from experimental values and are shown in Table 1. The experimental values have been calculated with the accuracy of approximately 90%.

Table 1: Values of roughness co-efficient and exponent of time at different speed feed combinations under both the environments.

	$v = 170$ m/min				$v = 235$ m/min			
	$f = 0.1$		$f = 0.14$		$f = 0.1$		$f = 0.14$	
	K	α	K	α	K	α	K	α
Dry	1.09642	.28405	1.79008	0.25252	2.73265	0.50724	2.31863	0.24749
MQL	0.72578	0.08739	1.11274	0.15283	1.51742	0.26057	1.1033	0.21322

4. Conclusion

- Application of minimum quantity lubricant (MQL) jet not only can reduce cutting fluid requirement but also substantial technological benefits as has been observed in machining hardened medium carbon steel by coated carbide insert (SNMG-TN 4000).

- The most noteworthy contribution of application of MQL jet over dry environment in hard turning by coated carbide insert undertaken is the high reduction in flank wear, which would permit either remarkable improvement in tool life or enhancement of productivity allowing higher cutting velocity and feed.
- It has been observed that the rate of growth of VB increases from $8.45 \sim 32 \mu\text{m}/\text{min}$ irrespective of feed with the increase of speed under MQL condition. But if we compare this with dry environment it has been found that rate of growth of VB increases from $68.88 \sim 155 \mu\text{m}/\text{min}$ with the increase of speed, which is much higher than that of MQL.
- It has been also noticed that the effect of feed increment is not so dominant for tool wear. Tool wear increases from $8.45 \sim 12.15 \mu\text{m}/\text{min}$ while $V_c = 170 \text{m}/\text{min}$ and $25 \sim 32 \mu\text{m}/\text{min}$ while $V_c = 235 \text{m}/\text{min}$.
- It is noticed from the graphs that the application of MQL has reduced VS in comparison to dry environment which is expected to provide better surface finish and dimensional accuracy. It has been observed that the rate of growth of VS increases from $5.63 \sim 31 \mu\text{m}/\text{min}$ and $60 \sim 140 \mu\text{m}/\text{min}$ irrespective of feed with the increase of speed under MQL and dry condition respectively.
- The surface finish obtained with the use of MQL is better than that obtained in the case of dry machining because MQL reduced auxiliary flank wear that is responsible for surface roughness, also reduced or eliminated the formation or possibility of formation of built-up edge due to reduction in flank temperature

Acknowledgement

The authors would like to acknowledge the financial support provided by Directorate of Advisory Extension and Research Services, BUET, and technical support provided by Department of Industrial and Production Engineering and Department of Materials & Metallurgical Engineering, BUET, Dhaka, Bangladesh.

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