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Hard Turning under Minimum Quantity Lubrication: Modeling of Cutting Force and Surface Roughness

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ABSTRACT

The aim of the present work is to develop a model which can predict the cutting force and surface roughness during hard turning of AISI 52100 alloy steel (62 HRC) under minimum quantity lubrication using PVD-coated nanocrystalline TiSiN-TiAlN coated carbide tool. Experiments were carried out varying the cutting speed, feed and depth of cut in the wide range of cutting conditions to investigate the effect of cutting parameters on the responses studied in the present investigation. The predicted cutting force and surface roughness values obtained at various cutting conditions were validated with the experimental results. The correlation coefficient found to close to 0.9, which showed that the developed models are reliable and could be used effectively for predicting the cutting forces and surface roughness for the given tool and work material pair and within the domain of the cutting parameters.

Keywords – Cutting force, Hard turning, Minimum quantity lubrication (MQL), Modeling, Surface roughness

1. INTRODUCTION

The increasing trend toward maximizing productivity with a reasonable accuracy has generated the need for developing reliable predictive models of all manufacturing processes. In the machining area, predictive models, which are capable of predicting quantitatively the influence of the magnitude of one or more input parameters on the magnitude of one or more output parameters, are of special importance in view of to find ways of optimizing the processes quickly and realistically. Also, realistic predictions of process results, such as, tool life, surface finish/integrity of the component being machined and forces on the tool and/or workpiece could be reliably predicted with the developed models. Moreover, predictive models would be helpful to obtain new knowledge of process steps and process design and to derive capabilities of process monitoring and control from this. With this view, nowadays, the ability to predict/simulate and evaluate the cutting performance is embedded in the road map for cutting technology [1-2].

Nowadays, with environment consciousness enhanced laws and regulations consummated, green cutting using minimum quantity lubrication (MQL) has become important tendency of machining. Most of researchers have made great effort to compare dry cutting, wet cutting and cutting with MQL. Dhar et al. [3] reported that MQL-assisted machining results in lower cutting temperature and cutting force, favorable chip–tool interaction, reduced tool wear, surface roughness, and dimensional deviation during turning of AISI-1040 steel. Chinchanikar and Choudhury [4] performed hard turning of AISI 4340 steel (54-57 HRC) under dry and MQL condition using new generation coated carbide tools. They observed improvement in tool life of almost 20-25% under MQL, especially with nanocrystalline AlTiCrN coated carbide tools due to better cooling and lubricating effects. However, this effect was more prominent at higher cutting speed of 150 m/min.

Chinchanikar et al. [5] experimental analysis during hard turning of AISI 52100 steel using PVD-coated nanolaminated TiSiN-TiAlN carbide tool under dry, with water-based and coconut oil-based cutting fluids concluded that hard turning under dry condition produced lower values of surface roughness. However, they observed lower values of surface roughness using coconut oil at higher cutting speeds. They observed that surface roughness gets affected mostly by feed and increased when cutting speed exceeds 150-160 m/min irrespective of the cooling mediums used. However, this effect was seen more prominent when turning under dry cutting conditions.

Varadarajan et al. [6] reported that the overall performance in terms of cutting force, tool life, surface finish, cutting ratio, cutting temperature and tool–chip contact length during MQL to be superior to that of dry and conventional wet turning. Vikram Kumar and Ramamoorthy [7] reported better performance of the cutting tools under MQL than that of dry and conventional wet turning during turning of AISI 4340 alloy steel.

Kang et al. [8] observed that cutting under flood coolant condition resulted in the shortest tool life. However, better performance in terms of tool life was observed by them under MQL condition in high-speed machining of AISI D2 cold-worked die steel (62 HRC). Chinchanikar et al. [9] performed air assisted hard turning to investigate the effect of cutting conditions on surface roughness. For almost all the cutting conditions investigated by them, they observed values of surface roughness in the range of 0.5 to 1.6 µm. They claimed that air-assisted hard turning with coated carbide insert could become an economical alternative to costly grinding operations and PCBN and ceramic inserts which are commonly used in hard turning.

Leppert [10] experimental analysis concluded that the effectiveness of the cooling and lubricating technique to a large extent depends on the cutting parameters, namely the cutting speed and feed rate. They claimed that by properly selecting cutting parameters better surface characteristics can be obtained under dry or MQL condition. From the literature reviewed it has been observed that hard turning under MQL provide better machining performance. However, almost no attempt has been made so far to develop a model which can predict the machining performance(s) during hard turning under MQL.

With this view, in the present work, the cutting force and surface roughness models have been developed based on experimental results obtained during hard turning of AISI 52100 alloy steel under minimum quantity lubrication. Experiments were carried out to investigate the effect of cutting parameters, namely the cutting speed, feed and depth of cut on the performance measures in the wide range of cutting conditions. Predicted results of the performance measures, namely, values of three components of cutting force and surface roughness were validated with the experimental results which were obtained at various cutting conditions.

2. EXPERIMENTAL DETAILS

Hard turning tests were carried out on a CNC lathe (Model: Simple Turn-5075, Ace Micromatic, India) using hardened AISI 52100 steel (60-62 HRC). The workpiece used has a length and diameter of 600 and 60 mm, respectively. Experiments were performed using PVD-coated nanolaminated TiSiN-TiAlN carbide inserts (ISO class P10). All the insets have identical geometry designated by ISO as CNMG 120408 (80^0 diamond shape with 0.8 mm nose radius) with integral chip breaker geometry of type MF2. A right hand style tool holder designated by ISO as PCLNR 2525M12 was used for mounting the inserts. Cutting force and surface roughness values were measured by a strain-gauge type three component dynamometer and Surtronics DUO surface roughness tester (Taylor and Hobson make). Surface roughness was measured at different points on the machined surface, and the average surface roughness value was noted.

Experiments were carried out using a very small quantity of fluid of 60 ml/hr and compressed air of 5 bar pressure. A MQL set-up which was developed to control a fluid flow to 60 ml/hr at the outlet is shown in Figure 1. The air pressure was adjusted using the pressure regulator and was kept constant (5 bar) throughout the experiment. The ratio of oil to water was kept 1:20. Experiments were planned using central composite rotatable design (CCRD) matrix varying the cutting speed ($100 \leq V \leq 200$ m/min), feed ($0.1 \leq f \leq 0.3$ mm/rev)and depth of cut ($0.1 \leq d \leq 0.5$ mm). Ranges of cutting parameters were decided on the basis of machine capability, literature review and tool manufacturer's recommendation. Experimental matrix to develop a surface roughness and cutting force model is shown in Table 1.

3. MATHEMATICAL MODELING

Hard turning experiments were performed to develop cutting force and surface roughness models considering the effect of cutting speed, feed and depth of cut. Mathematical models developed to predict cutting force and surface roughness during hard turning of AISI 52100 alloy steel (62 HRC) under minimum quantity lubrication using PVD-coated nanocrystalline TiSiN-TiAlN coated carbide tool, showing the effect of cutting speed (V), feed (f) and depth of cut (d) can be expressed as:

$$R = k\ V^{a} f^{b} d^{c} \tag{1}$$

where, R is a response measured. In the present investigation, responses are three components of cutting forces, namely, the tangential or main cutting force (F_c), feed force (F_f) and radial cutting force (F_r) and surface roughness (R_a). The experimental results (as shown in Table 1) were analyzed using the least square error method.

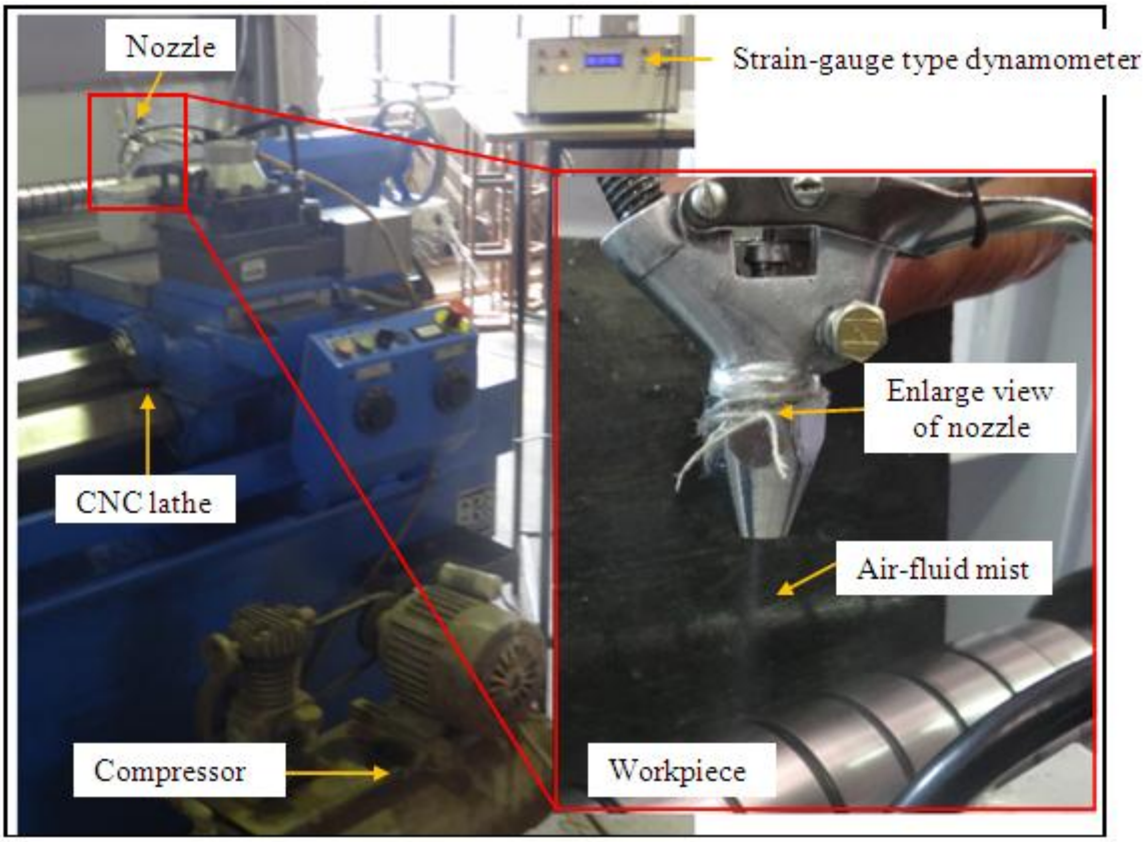


Fig. 1 Minimum quantity lubrication (MQL) set-up

Table 1 Experimental matrix showing force and surface roughness results

Expt. No.	Input variables (parameters)			Responses (performance measures)			
	V (m/min)	*f* (mm/rev)	*d* (mm)	F_c (N)	F_f (N)	F_r (N)	R_a (μm)
1	150	0.2	0.3	146	109	304	0.76
2	150	0.1	0.3	116	89	273	0.35
3	150	0.2	0.1	86	68	241	0.42
4	175	0.25	0.4	194	134	348	1.38
5	125	0.25	0.2	124	118	288	0.93
6	100	0.2	0.3	176	139	335	1.12
7	175	0.15	0.2	112	98	266	0.56
8	150	0.2	0.5	244	144	399	1.44
9	125	0.25	0.4	204	137	348	1.62
10	125	0.15	0.2	104	96	256	0.61
11	150	0.3	0.3	167	134	342	1.89
12	175	0.15	0.4	168	129	339	0.46
13	125	0.15	0.4	156	138	346	0.75
14	200	0.2	0.3	135	98	328	0.84
15	175	0.25	0.2	133	93	278	0.99

The unknown coefficients were determined using Data-Fit software (Version 8.1). The models for the three components of cutting forces and surface roughness is expressed as below.

Cutting force and surface roughness models,

$$F_c = 1400.292 (V)^{-0.162} (f)^{0.3523} (d)^{0.6898} \quad (2)$$

$$F_f = 1770.385 (V)^{-0.3661} (f)^{0.2271} (d)^{0.4314} \quad (3)$$

$$F_r = 709.2689 (V)^{-0.032} (f)^{0.149} (d)^{0.332} \quad (4)$$

$$R_a = 198.2932 (V)^{-0.4} (f)^{1.6068} (d)^{0.6538} \quad (5)$$

The R-Squared values of the developed cutting force and surface roughness models are in the range of 0.9 to 0.95, indicate that the developed models are valid and could be used to predict the surface roughness and three components of cutting force during hard turning of AISI 52100 steel with PVD-applied nanocrystalline TiSiN-TiAlN coated carbide tool under MQL cooling environment. However, these developed equations are valid for the given combination of work and tool material and the domain of the cutting parameters selected in the present investigation.

4.RESULTS AND DISCUSSION

In this section, effect of different cutting parameters, namely the cutting speed, feed and the depth of cut on three components of cutting force and surface roughness is discussed based on the developed regression equations obtained during hard turning of AISI 52100 steel using PVD-applied nanolaminated TiSiN-TiAlN coated carbide inserts. Curves showing the various responses investigated are plotted by varying one of the input parameters and keeping the other parameters constant at the central level.

Fig. 2 depicts the variation of responses with cutting speed and values of feed and depth of cut of 0.2 mm/rev and 0.3 mm respectively. Decrease in the surface roughness can be observed with the increase in cutting speed. However, at higher cutting speeds, decrease in surface roughness can not be seen as significant as observed at lower cutting speeds. This may be attributed to the changes in frictional conditions at the tool face due to increase in tool wear and hence, tool failure, especially at higher cutting speeds.

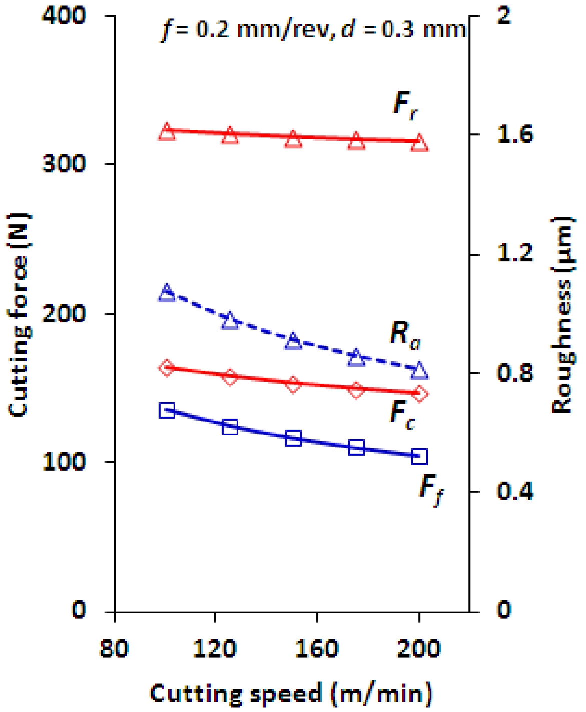
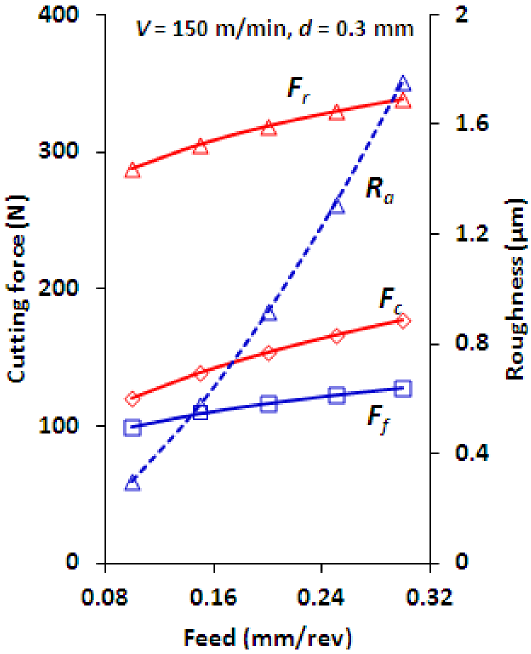


Fig. 2 Varation of responses with cutting speed

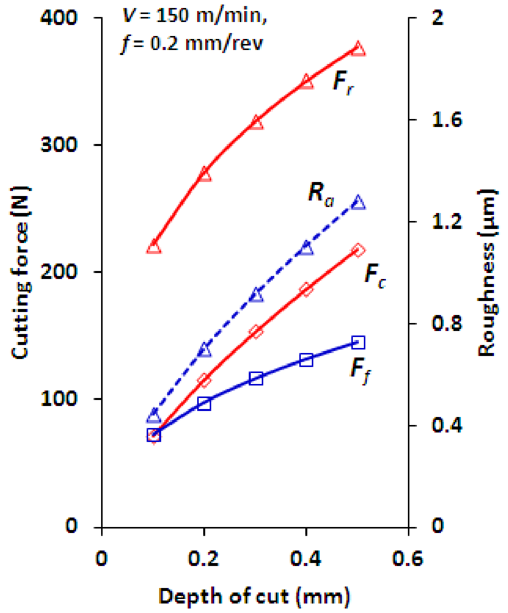
Variation of cutting forces and surface roughness with respect to feed and depth of cut are shown in Figures 3(a) and (b), respectively. Almost linear variation of surface roughness can be seen with feed and depth of cut. However, variation in surface roughness can be seen as more prominent with feed value in comparison to cutting speed and depth of cut. This can be also confirmed from the values obtained for exponent and constant of surface roughness equation (5). Further, it can be seen that depth of cut followed by feed is having most significant effect on cutting forces with almost negligible influence of cutting speed on three components of cutting forces. However, it can be seen that feed and radial components get affected mostly by depth of cut and less affected by feed and cutting speed.

5. CONCLUSION

In the present work, mathematical models to predict three components of cutting force and surface roughness were developed based on experimental observations during hard turning of AISI 52100 bearing steel. Experiments were performed to investigate the effect of cutting parameters, namely the cutting speed,feed and depth of cut on the performance measures under minimum quantity lubrication condition employing PVD-applied nanocrystalline TiSiN-TiAlN coated carbide tool. The correlation coefficients for all the developed mathematical models found close to 0.9, which showed that the developed models are reliable and could be used effectively to predict the surface roughness and three components of cutting forces for the given combination of tool and work material and within the domain of the cutting parameters selected in the present investigation. Decrease in the surface roughness was observed with the increase in cutting speed. However, this effect was not significant at higher cutting speeds.



(a)



(b)

Fig. 3 Varation of responses with (a) feed and (b) depth of cut

Further, almost linear variation of surface roughness was observed with increase in the values of feed and depth of cut. However, this effect was more prominent with feed value in comparison to cutting speed and depth of cut. Also, it has been observed that depth of cut followed by feed was having most significant effect on cutting forces with almost negligible influence of cutting speed on components of cutting forces. However, feed and radial components of cutting forces has been observed to get mostly affected by depth of cut in comparison to increase in the values of feed and cutting speed, respectively.

REFERENCE

[1] J. Stein, D.A. Dornfeld, Integrated Design and Manufacturing for Precision Mechanical Components, *Proc. 1st International Conf. on Integrated Design and Manufacturing*, PRIMECA, Nantes, France, 1996, 195–204.

[2] S. Chinchanikar, S.K. Choudhury, Machining of hardened steel: Experimental investigations, performance modeling and cooling techniques: A review, *International Journal of Machine Tools and Manufacture*, *89*, 2015, 95–109.

[3] N.R Dhar, M.T. Ahmed, S. Islam, An experimental investigation on effect of minimum quantity lubrication in machining AISI 1040 steel. *International Journal of Machine Tools and Manufacture*, *47*, 2007, 748-753.

[4] S. Chinchanikar, S. K. Choudhury, Hard turning using HiPIMS-coated carbide tools: Wear behavior under dry and minimum quantity lubrication (MQL), *Measurement*, *55*, 2014, 536- 548.

[5] S. Chinchanikar, A.V. Salve, P. Netke, A. More, S. Kendre, Comparative evaluations of surface roughness during hard turning under dry and with water-based and vegetable oil-based cutting fluids, *Procedia of Material Science*, *5*, 204, 1966-1975.

[6] A.S. Varadarajan, P.K. Philip, B. Ramamoorthy, Investigations on hard turning with minimal cutting fluid application (HTMF) and its comparison with dry and wet turning, *International Journal of Machine Tools and Manufacture*, *42*, 2002, 193–200.

[7] CH.R. Vikram Kumar, B. Ramamoorthy, Performance of coated tools during hard turning under minimum fluid application. *Journal of Materials Processing Technology*, *185*, 2007, 210–216.

[8] M.C. Kang, K.H. Kim, S.H. Shin, et al., Effect of the minimum quantity lubrication in high-speed end-milling of AISI D2 cold-worked die steel (62 HRC) by coated carbide tools. *Surface and Coatings Technology*, *202*(22-23), 2008, 5621–5624.

[9] S. Chinchanikar, P. Netke, A. More, Air-assisted hard turning: Experimental investigation of surface roughness though mathematical modeling using response surface methodology, *International Colloquium on Materials, Manufacturing and Metrology*, IIT Madras, Chennai, India, 2014 (ISBN 978-93-80689-18-0).

[10] T. Leppert, Effect of cooling and lubrication conditions on surface topography and turning process of C45 steel, *International Journal of Machine Tools and Manufacture*, *51*, 2011, 120–126.

[11] K. Dhandapani, P. Vasanthkumar, S. Nagarajan, A Meta-Heuristic Evolutionary Algorithm to Optimize Machining Parameters in Turning AISI 4340 Steel, *Journal of Advanced Engineering Research*, 1 (2), 2014, 105-113.