Investigations on Effect of Cutting and Cutting Fluid Application Parameters on Surface Roughness and Microhardness in Hard Turning of AISI 52100 Alloy Steel

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Abstract The cost, health, and environment concerns associated with the use of cutting fluid calls for minimizing its usage in machining. This research work is aimed to investigate machining performance in turning of AISI 52100 hardened alloy steel with multilayer-coated carbide tool under dry and minimal cutting fluid environments. A Taguchi's L9 orthogonal array was used to design the experiments. The aim was to identify the optimal combination of the cutting and cutting fluid application parameters. The response measured was the surface roughness and microhardness under different cutting environment. The experimental result showed that the hard turning with minimal cutting fluid application improves surface roughness and reduces the microhardness variation at machines surface which in turn improves fatigue life of the machined components.

Keywords Minimal cutting fluid application · Surface roughness · Microhardness

1 Introduction

Hardened alloy steels are being widely used in automotive and allied industries due to their high compressive strength and wear resistance. Attanasio et al. [1] reported that the turning of hardened alloy steels above 45 HRC is considered to be hard turning; but in actual practice, the hard turning is carried out at elevated hardness of 45–68 HRC. Huang et al. [2] reported that the manufacturing cost can be reduced by 30%, if the hard turning process is employed to machine the complex parts. Bartarya and Choudhury [3] stated that the hard turning can replace conventional grinding process,

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and surface finish of Ra 0.4–0.6 μm can be achieved with proper selection of process parameter. Krishna et al. [4]; Tzeng et al. [5]; Sahin et al. [6]; Sharma et al. [7] reported that the turning of component in hardened state can offer high accuracy but the major concern is about the surface quality. The surface integrity is an important aspect in determining the functional performance such as fatigue life and tribological properties of machined components; in turn, it affects the product quality. Khan et al. [8]; Grzesik and Wanat [9]; Ezugwu et al. [10]; Dhar et al. [11] reported that the surface roughness and microhardness are the major performance indicators of the surface integrity, which must be studied in depth for enhancing the product performance. Fernandes et al. [12] showed that the increase in value of surface roughness leads to poor surface finish and thus reduces the fatigue life of the machined components. Many researchers studied the effect of cutting parameters on surface roughness and microhardness (surface integrity) and attempted to develop the relationships between cutting parameters and the surface integrity in hard turning. In this work, an attempt has been made to investigate the effect of cutting parameters and cutting fluid application parameters on the surface characteristics, such as roughness and microhardness in turning of AISI 52100 hardened alloy steel of 58 HRC with multilayer coated carbide tool in dry turning and turning with minimal cutting fluid application (MCFA). The effects of the cutting and cutting fluid application parameters on surface roughness and microhardness were investigated, and optimal conditions were determined to achieve the better surface integrity of the machined component.

2 Experimentation

2.1 Selection of Workpiece Material

In this study, AISI 52100 hardened alloy steel having hardness of 58 HRC was selected as workpiece material. AISI 52100 hardened alloy steel has wide applications and is being used in automotive and allied industries such as bearings, forming rolls, spindles, tools, and precision instrument parts. Table 1 shows the chemical composition of the workpiece material.

Table 1 Chemical composition of AISI 52100 hardened alloy steel (weight percentage)

C %	Si %	Mn %	P %	S %	Cr %	Ni %	Cu %	Fe %
1.04	0.18	0.35	0.007	0.004	1.35	0.076	0.058	Balance

2.2 Selection of Tool

The cutting tool inserts and the tool holder were selected based on the literature review and the tool manufacturer's recommendation. The MTCVD multilayer-coated carbide (TiN/TiCN/Al_2O_3)—[HK150, K-type] cutting tool insert having specification CNMG120408 and the tool holder with PCLNR 2020 K12 specification were selected for experimentation. The experiments were carried out on a rigid high precision HMT NH-18 lathe machine.

2.3 Selection of Cutting Fluid

The quantity of cutting fluid delivered per pulse was extremely small, and a commercially available SUN Cut ECO-33 high-performance eco-friendly semi-synthetic cutting fluid was used in this investigation.

2.4 Selection of Cutting and Cutting Fluid Application Parameters

Based on the previous research carried out and the tool manufacturer's recommendations, the cutting parameters were selected. Table 2 presents the cutting parameters and their levels.

Similarly, based on the previous studies conducted, the cutting fluid application parameters were selected. Table 3 presents the cutting fluid application parameters and their levels.

Table 2 Process parameters and their levels

Cutting parameters	Units	Levels		
Cutting speed	m/min	80	110	140
Feed rate	mm/rev	0.04	0.08	0.12
Depth of cut	mm	0.2	0.3	0.4

Table 3 Cutting fluid parameters and their levels

Cutting fluid application parameters	Units	Levels		
Pressure	Bar	60	80	100
Frequency of pulsing	Pulses/min	200	300	400
Flow rate	mL/min	4	8	12
Nozzle standoff distance	mm	20	30	40

Table 4 Experimental result for surface roughness and microhardness in dry turning

Exp. No.	Cutting speed (m/min)	Feed rate (mm/rev)	Depth of cut (mm)	Surface roughness (μm)	Microhardness (HV)
1	80.000	0.04	0.15	0.671	751
2	80.000	0.08	0.30	0.701	795
3	80.000	0.12	0.45	0.752	781
4	110.00	0.04	0.30	0.575	746
5	110.00	0.08	0.45	0.657	759
6	110.00	0.12	0.15	0.827	775
7	140.00	0.04	0.45	0.667	809
8	140.00	0.08	0.15	0.922	816
9	140.00	0.12	0.30	1.170	822

2.5 Design of Experiment

The experiments were carried out with Taguchi's L9 orthogonal array to reduce the number of experimentation without losing the significance of each input parameter in turning of hardened AISI 52100 alloy steel under dry cutting condition and with minimal cutting fluid application method. The optimized values of cutting parameters were obtained under dry cutting condition. These optimized cutting parameters were kept constant, and cutting fluid jet application parameters were varied in three levels. Talysurf surface roughness measuring machine was used to measure the surface roughness and microhardness tester (FM-300e) to measure microhardness of the machined surface. Table 4 shows the experimental design and results for surface roughness and microhardness of machined surface in dry turning.

The cutting parameters that were optimized in dry turning were kept constant, and fluid application parameters were varied in three levels. Table 5 shows the design of experiment based on Taguchi's L9 orthogonal array and results for surface roughness and microhardness of machined surface in turning of hardened AISI 52100 alloy steel under minimal cutting fluid application (MCFA) environment.

3 Result and Discussion

Table 6 shows the percentile contribution effect of the cutting parameters on the surface roughness and microhardness in dry turning through analysis of variance (ANOVA).

It was observed that the feed rate and cutting speed are the most significant cutting parameters affecting the surface roughness, whereas the depth of cut has no considerable effect on the surface roughness. On the other hand, the microhardness

Table 5 Experimental result for surface roughness and microhardness in MCFA turning

Pressure (bar)	Frequency (pulses/min)	Quantity (mL/min)	Nozzle standoff distance (mm)	Surface roughness (µm)	Microhardness (HV)
60	200	4	20	0.668	774
60	300	8	30	0.446	765
60	400	12	40	0.522	772
80	200	12	30	0.453	771
80	300	4	40	0.428	768
80	400	8	20	0.401	763
100	200	8	40	0.433	759
100	300	12	20	0.310	745
100	400	4	30	0.413	752

Table 6 Percentile contribution of cutting parameters on responses in dry turning

Factors	Effect on surface roughness (%)	Effect on microhardness (%)
Cutting speed	37.97	76.52
Feed	44.57	16.07
Depth of cut	10.83	1.18
Other error	6.63	6.24
Total %	100.00	100.00

is significantly affected by the cutting speed. The feed rate has less significant effect, and the depth of cut has no effect on the microhardness of machined surface.

Figure 1 shows the column effect graph for surface roughness and microhardness. Figure 1a shows that the cutting speed V2 = 110 m/min, feed f2 = 0.04 mm/rev, and

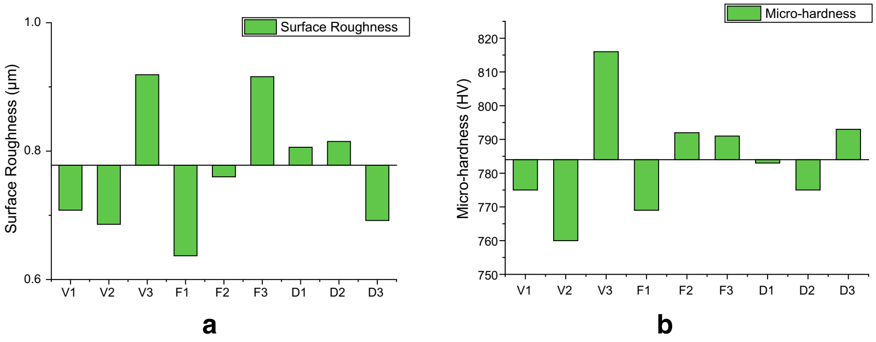
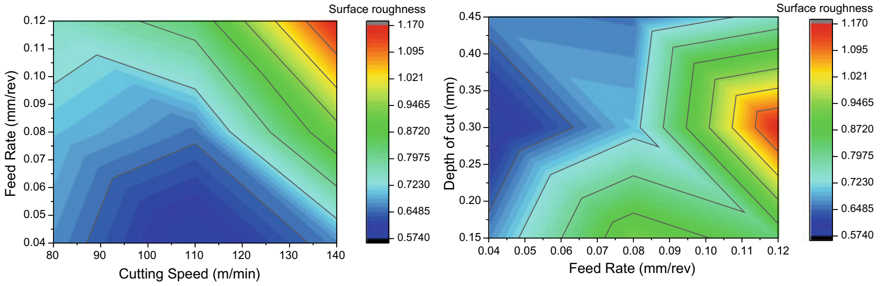


Fig. 1 Column effect graphs of **a** surface roughness, **b** microhardness in dry turning

depth of cut d3 = 0.45 mm contributed most in minimizing the surface roughness. Figure 1b presents the cutting speed V2 = 110 m/min, feed f2 = 0.04 mm/rev, and depth of cut d3 = 0.30 mm contributed more on reduction in variation of microhardness at surface and subsurface layer of machined surface.

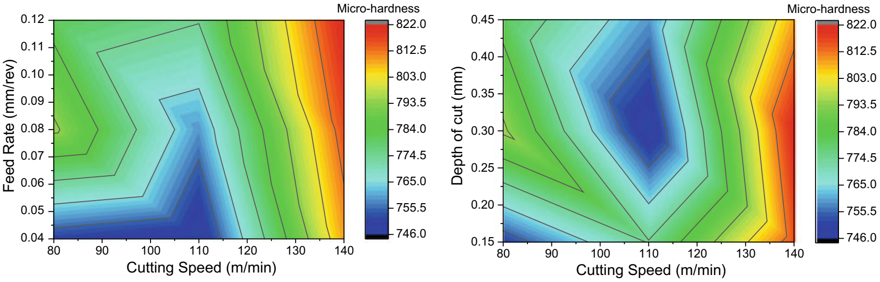
Figure 2 shows the contour plot of surface roughness versus cutting parameters. The minimum value of surface roughness 0.5–0.6 μm observed between a cutting speed of 100–110 m/min, feed rate of 0.04–0.08 m/min, and depth of cut 0.20–0.45 mm. Figure 2a, b shows that the feed rate is the most influential parameter on surface roughness followed by the cutting speed and depth of cut have less significant effect on surface roughness.

Figure 3 shows the contour plot of microhardness versus cutting parameters. The microhardness value of 745–750 HV observed between a cutting speed of 100–110 m/min, feed rate of 0.04–0.08 m/min, and depth of cut 0.15–0.45 mm. Figure 3a, b shows that the feed has less significant effect and depth of cut has no effect on microhardness, whereas the cutting speed is the most influential parameter on microhardness.



(a) (b)

Fig. 2 Contour plot for surface roughness **a** cutting speed versus feed, **b** feed versus depth of cut in dry turning



(a) (b)

Fig. 3 Contour plot for microhardness **a** cutting speed versus feed, **b** cutting speed versus depth of cut, **c** FEED versus depth of cut in dry turning

Table 7 Percentile contribution of fluid application parameters on responses in MCFA turning

Factors	Effect on surface roughness (%)	Effect on microhardness (%)
Pressure	64.65	72.65
Frequency of pulsing	17.45	9.34
Flow rate	8.71	8.28
Nozzle standoff distance	8.10	7.61
Other error	1.10	2.11
Total	100.00	100.00

Table 7 shows the percentile contribution effect of the cutting fluid application parameters on the surface roughness and microhardness in turning under MCFA environment through analysis of variance (ANOVA). It has been observed that the cutting fluid pressure is the most influential cutting fluid application parameter affecting the surface roughness and microhardness followed by the frequency of pulsing. The flow rate and nozzle standoff distance have less significant effect on surface roughness and microhardness.

Figure 4 shows column effect graph of surface roughness and microhardness. The cutting fluid pressure at level-3 (100 bar), frequency at level-2 (300 pulses/min), quantity at level-3 (12 mL), and nozzle standoff distance at level-1 (20 mm) contributes more on the reduction of surface roughness and less variation in the microhardness values at machined surface.

Figures 5 and 6 show the comparison of effect of cutting speed on microhardness and surface roughness in dry turning and turning with MCFA respectively. The results obtained validated the optimized cutting fluid application parameters. The considerable reduction in the variation of microhardness value in the range of 20–100 HV compared to base hardness of material and significant reduction of 40–50% in the surface roughness have been observed in turning with MCFA when compared to dry turning.

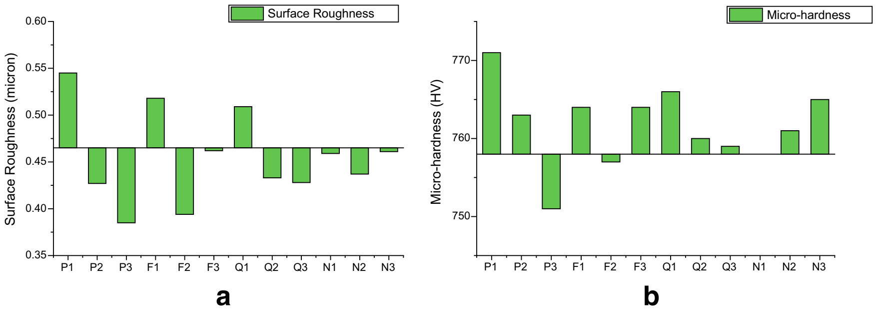


Fig. 4 Column effect graphs of **a** surface roughness, **b** microhardness in turning with MCFA

Fig. 5 Cutting speed versus (μH)

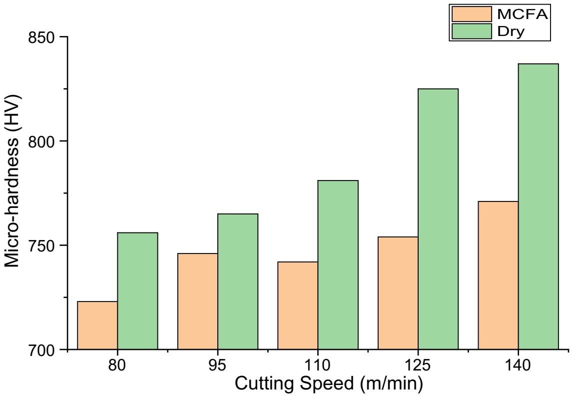
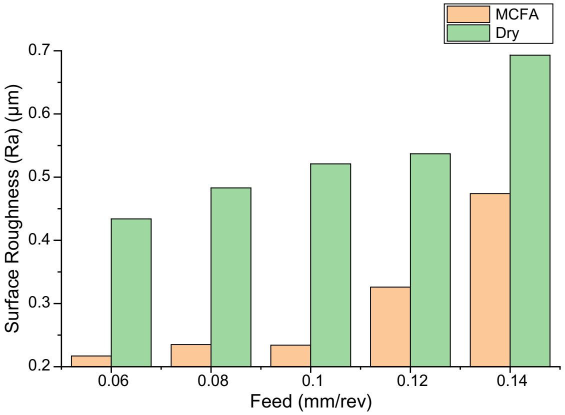


Fig. 6 Feed rate versus Ra



4 Conclusion

The surface integrity of a machined component is greatly influenced by the surface roughness and microhardness as found in this study. The optimum dry cutting conditions observed were cutting speed: 110 m/min, feed rate: 0.04 mm/rev, and depth of cut: 0.30 mm, and the optimized values of fluid application parameters observed were cutting fluid pressure: 100 bar, frequency of pulsing: 300 pulses/min, flow rate: 12 ml/min, and nozzle standoff distance: 20 mm. The variable speed and feed tests conducted proved that the optimized results are correct and MCFA method of cutting fluid application is more efficient. The surface roughness and microhardness variation decreased significantly under MCFA environment, as compared to dry turning . The reduction in surface roughness by 40–50% and less variation in microhardness values in the range of 20–100 HV compared to base hardness of material were observed in turning with MCFA compared to dry turning. Minimal cutting fluid application method helped in minimizing the usage of cutting fluid and to overcome the problems associated with cutting fluid such as its cost, storage, disposal, health, and environmental concerns.

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