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Effect of Cutting Parameters and Machining Environment in Surface Roughness in hardened Steel (52HRC) Using Design of Experiment

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Abstract

The impact of cutting condition and machining environment on surface roughness during hard turning, a procedure chosen over traditional turning and grinding for its efficiency has been investigated in this study. D2SKD steel, heat-treated to 52 HRC, was machined with coated carbide inserts under constant conditions of material hardness and cutting fluid. A Design of Experiment (DOE) technique was applied to test altering cutting speed, feed rate, and depth of cut, examining their impact on surface roughness. Impact of cutting parameters has been assessed by the Analysis of variance (ANOVA). The result showed that feed rate had the most important influence on surface roughness, then cutting speed and depth of cut. These findings offer important insights into optimizing cutting parameters for enhancing surface quality and performance in hard turning processes, establishing hard turning as a viable alternative to conventional machining methods.

Keywords: Hard turning, Surface roughness, Design of experiment, Analysis of variance

1. Introduction

Hard turning is a highly precise machining technique that is frequently used in place of grinding on hardened items. With this procedure, even harder cutting tools, ranging from 45 to 70 HRC, are used to convert materials with a hardness between 38 and 65 HRC. Hard turning became an economically viable finishing procedure in the early 1990s with the development of new tool materials and more durable, accurate, and stable turning machines. Specialized tools such as ceramics, silicon nitrides, sintered carbides, cermets, polycrystalline diamonds, and cubic boron nitrides (CBN) are needed for it. Hard turning is used in the automotive, aerospace, and marine industries for components like axle shafts, gears, and bearings. Using the shared principles of soft turning and machine rigidity, the approach improves productivity and flexibility in machining operations. Coated tools have been especially successful in decreasing production expenses by as much as thirty times when turning hard materials to manufacture complex pieces [1]. Hard turning is popular due to its ability to generate complex geometric surfaces with high form accuracy in a single pass [2]. Research has primarily focused on tool geometry, tool wear, cutting temperature, and forces [3, 4, 5]. Suggested conditions for hard turning are cutting speeds of 100-250 m/min, feed rates of 0.05-0.2 mm/rev, and depths of cut less than 0.25 mm [6]. Surface roughness is significantly affected by the feed rate [7, 8]. with minimal roughness achieved at lower feed rates and higher cutting speeds [9]. The machining environment, including high-pressure coolant application, also affects surface integrity [10]. Increased tool nose radius improves surface finish but increases tool wear [11]. Surface roughness influences the component's functional properties, such as corrosion and fatigue resistance [12], necessitating precise tailoring for many applications [13]. Various chip types, such as continuous, segmented, and saw tooth, are produced during machining [14]. Cutting forces, cutting condition and chip formation affecting tool performance and surface quality [15, 16]. Soft computing tools like neural networks and genetic algorithms have been applied to hard turning to optimize machining processes [17]. Statistical methods are also commonly used to improve surface finish [18]. However, optimizing the hard turning of 55 HRC hardened D2SKD steel with a CBN tool remains unexplored, despite its potential influence on surface roughness.

The purpose of this study is to evaluate the surface roughness of high carbon hardened D2SKD cold work steels during turning operations. The study focuses on how the surface roughness is affected by cutting parameters such as cutting speed, feed rate, and depth of cut, as well as machining situations such as dry versus flooded turning. D2SKD steels are chosen to use in cold extrusion tools, stamping tools dies, and punches in Bangladesh because of their increasing demand. These tools are most widely used in Bangladesh.

For the purpose of cutting peation the research makes use of a conventional lathe machine, which is widely used everywhere in the country for the purpose of metal machining. The machine tool imposes limitations on the depth of cut and revolutions per minute (RPM), and cemented carbide tools are more readily available than CBN tools. The research makes use of a DOE technique in order to discover the ideal combinations of cutting parameters. ANOVA was utilized for determining how these characteristics and machining circumstances influence surface roughness.

2. Experimental

For the turning operation, D2SKD steel has been used as the workpiece. The workpiece was a cylindrical bar (Length = 400 mm, diameter = 60 mm). Table 1 illustrate the chemical properties of the workpiece material. Before turning operation, the existing hardness of the material was 20-22 HRC. Then the material was heat treated to a 52±2 HRC, which had been conducted at the heat treatment lab of the Bangladesh Industrial and Technical Assistance center (BITAC).

Table 1. Chemical composition of D2SKD steel.

Elements	Volumetric Percentage
C	1.40-1.60
Si	0.10-0.60
Mn	0.20-0.06
Cr	11.0-13.0
Mo	0.70-1.00
V	0.70-1.00

Table 2. Tool Insert specifications

Nomenclature	Type
Insert	Coated carbide inserts SNMG120408)
Co held	PSBNR2525M12
Coating	TiCN & WC
Back rake angle	-6º
Side rake angle	-6º
End relief angle	6º
Side relief angle	6º
End cutting edge angle	15º
Side cutting edge angle	75º
Nose Radius	0.8 mm

The hardening process involves heating the components over the critical (normalizing) temperature, maintaining them for one hour per inch of thickness, and then rapidly cooling the material to allow it to convert into a much harder, stronger structure. The workpiece was pre-heated at 500℃ to reduce the risk of cracking. The workpiece was then heated to 950-1000℃ for 8-9 hours. After that the material was air cooled. Oil cooling was not done because of getting the desired hardness. As we are using high-carbon steel, which could be harder than the desired hardness if cooled in oil. Therefore, to get the desired hardness, the material was air cooled rather than oil quenched. The hardness at the end of the procedure was greater than 55 HRC. The workpiece was then tempered to prevent cracking and to minimize hardness. The material was tempered for 6 hours at a temperature of 500-550°C. Five hardness readings were taken along the surface at the end of the tempering, and the average hardness of the workpiece was 52±2 HRC. Then the machining operation has been done.

In order to systematically collect the corresponding responses, a DOE approach was employed to create a matrix of every potential combination of machining conditions. The analysis is based on three quantitative 3-levels and one qualitative 2-levels factors. The factors levels are given in Table 3.

Table 3. Attribution of the levels of factor.

Cutting Parameters	Level 1	Level 2	Level 3
Cutting Speed, v (mm/min)	68	96	136
Feed Rate, f (mm/rev)	0.10	0.14	0.20
Depth of Cut, d (mm)	0.1	0.2	0.4
Machining Condition	Dry	Wet	

To complete the statistical analysis, the Taguchi method's L18 orthogonal array was used. Cutting parameters such as cutting speed, feed rate, and depth of cut has been varied during the experiment. The experiment was

carried out in both dry and flooded conditions, with the chips being collected after each run. Before beginning the experiment to skin out the outer surface, a rough incision of 0.2 mm was made. The experiment was then carried out, with the value of surface roughness for each run being measured. A total of 18 sets of machining conditions and responses are shown in Table 4:

Table 4. Machining conditions from L18 orthogonal array with response

Run	Cutting Parameters			Condition	Surface Roughness (R_a) (µm)
	Cutting Speed (mm/min)	Feed Rate (mm/rev)	Depth of Cut (mm)		
1	68.03	0.100	0.1	DRY	0.9663
2	68.03	0.136	0.2	DRY	1.0439
3	68.03	0.200	0.4	DRY	7.5177
4	95.82	0.100	0.1	DRY	1.1412
5	95.82	0.136	0.2	DRY	1.2021
6	95.82	0.200	0.4	DRY	2.5787
7	136.06	0.100	0.2	DRY	0.6183
8	136.06	0.136	0.4	DRY	1.0553
9	136.06	0.200	0.1	DRY	0.9098
10	68.03	0.100	0.4	WET	2.8422
11	68.03	0.136	0.1	WET	1.5320
12	68.03	0.200	0.2	WET	2.7467
13	95.82	0.100	0.2	WET	0.8046
14	95.82	0.136	0.4	WET	1.4966
15	95.82	0.200	0.1	WET	6.4804
16	136.06	0.100	0.4	WET	1.1943
17	136.06	0.136	0.1	WET	1.6156
18	136.06	0.200	0.2	WET	1.8937

3. Results and Discussion

An analysis of variance had been used to determine the statistically significant trends in the measured response data. The results of the ANOVA for the surface roughness are shown in Table 5. This analysis was carried out for a confidence level of 95% (∞=.05). Table 5 contains the F-value and P-value (F-value and p-value are statistical measures used to determine the significance of the observed results, and %C tell us the percentage of contribution of a parameter to the variation in the outcome.); from there, we can understand the main effects of cutting speed, feed rate, depth of cut, and feed rate. Feed rate has the most significant impact on surface roughness, followed by speed, depth, and environment, respectively. Feed rate contains an F-value of 4.61 and a P-value of 0.038, and these two statistical indicators indicate that feed rate is the most significant factor. Cutting speed has an F-value of 1.54 and a P-value of 0.262, and these two values clearly indicate that speed is the second most statistically significant factor. Similarly, depth of cut and machining environment have the third and fourth positions, respectively.

Table 5. Analysis of variance for surface roughness

Source	DF	Adj SS	Adj MS	F-Value	P-Value	%C
Environment	1	0.7178	0.7178	0.29	0.603	3.81%
Speed	2	7.6339	3.8170	1.54	0.262	20.23%
Feed	2	22.9141	11.4570	4.61	0.038	60.58%
Depth	2	5.8185	2.9092	1.17	0.349	15.37%
Error	10	24.8629	2.4863			
Total	17	61.9471				

The main effect of the four factors, i.e., environment, speed, feed rate, and depth of cut on the surface roughness is plotted in Fig. 1. The horizontal line in the middle represents the mean value of the responses. The graph shows that, in dry conditions, the mean surface roughness value decreases. At higher speed (136.06), the mean roughness value decreases; on the other hand, at lower speed (68.03), the mean roughness value increases. In addition, at a higher feed value, the mean roughness value increases significantly. However, at lower feed values, the roughness value decreases. Interestingly, for a moderate depth of cut, the mean roughness value is lower. The mean roughness value is higher at low depths, decreases accordingly at a middle value, and then increases again after that point.



Fig. 1. Main effects plot for surface roughness, Ra (µm)

A three-dimensional surface roughness plot is shown in Fig. 2. These figures showed the 3D response surface plots of surface roughness versus cutting speed, feed rate, and depth of cut. When the feed rate decreases and speed increases, the surface roughness will decrease.

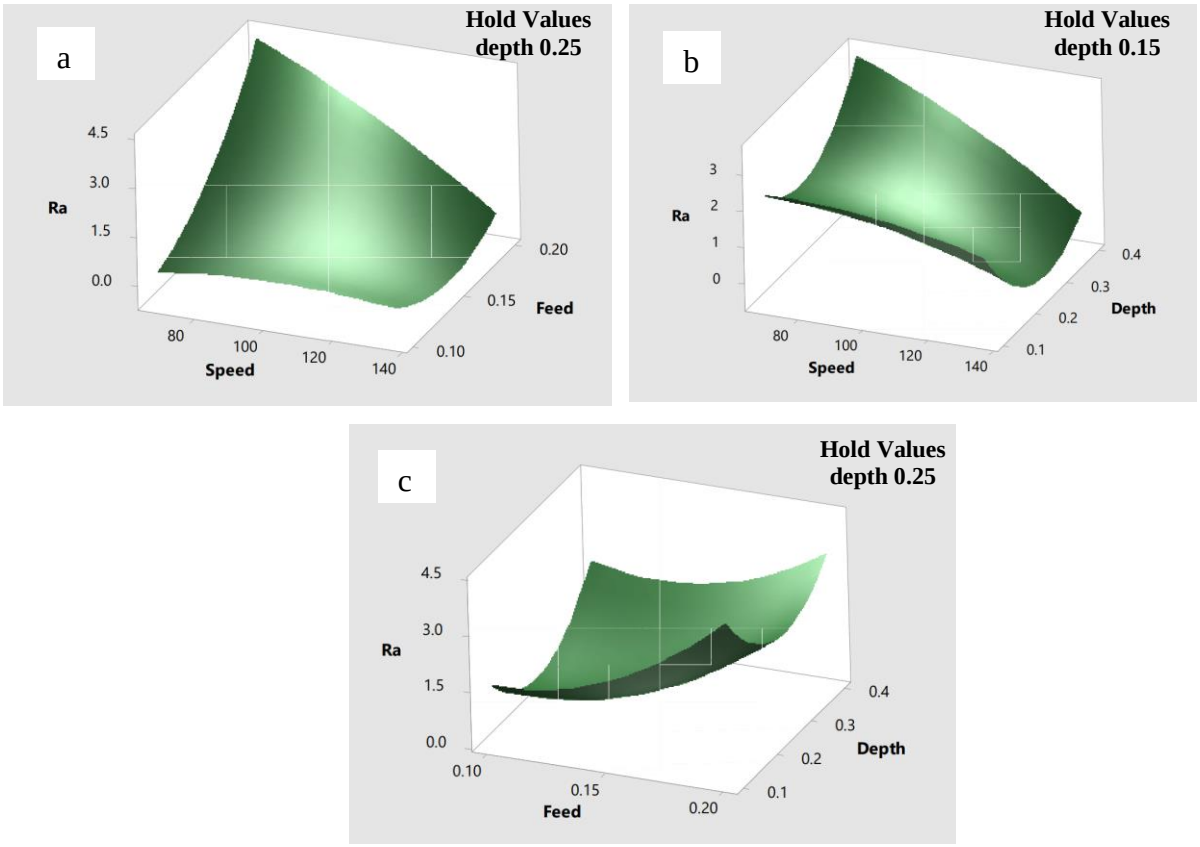


Fig. 2. 3D response surface plots of roughness versus cutting speed, feed rate and depth of cut ; (a) Surface roughness vs Feed and speed, (b) Surface roughness vs Depth and speed, (c) Surface roughness vs Depth and speed

The increase in feed rate means higher chip thickness, which requires more cutting force to deform the material to shear the material as chip [19]. High cutting force tends to provide vibration and chatter effect on the machine tool, which tend to generate high surface roughness. On the other hand, low cutting speed is adhered to the high coefficient of friction and machine chatter.

Fig. 2(b) shows that, at moderate DOC and high speed, the sufrace roughness tends to lower. Moderate depth of cut combined with high speed promotes the formation of continuous chips rather than discontinuous or segmented chips. Continuous chips are generally associated with better surface finish. Similarly, Fig. 2(c) shows that a lower feed rate and moderate depth of cut create the best surface finish. Reducing the feed rates leads to decreased tool wear, thereby preserving the sharpness of the cutting edge for extended durations. This contributes to the attainment of a uniform and smooth surface texture. Decreasing the feed rates also decreases the cutting forces, hence reducing the chances of tool deflection and vibration, resulting in an improved surface finish.

4. Conclusion

The current work is a contribution to determining the effect of cutting parameters (feed, speed, depth, and environment) on surface roughness when turning of hardened D2 SKD steel (52±2) by coated carbide tool using DOE in order to reduce production costs while maintaining quality in manufacturing. According to the ANOVA study, the feed rate is the most important parameter, followed by cutting speed, depth of cut, and environment. Trade of between cutting speed and feed rate provides better surface finish i.e. lower feed and higher cutting speed tend to reduce the surface roughness. The best surface quality is recorded for cutting speed =136 m/min, Feed rate = 0.100 mm/rev and Depth of cut = 0.2 mm.

5. References

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