

# An experimental study on the hard turning performance of AISI 1045 steel

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## Abstract

Recently, the hard machining technology has been growing the concern in the metal cutting field. The paper objective is to study the influences of input cutting modes on thrust force  $F_x$  in the hard turning process of AISI 1045 steel (58HRC). The interaction effects of cutting speed, feed rate and depth of cut on thrust force  $F_x$  were specified by using Box-Behnken experimental planning design. The obtained findings indicated that the feed rate emerges as the most influential factor, followed by cutting speed, while the depth of cut, although significant ( $P = 0.005$ ), has a comparatively smaller effect. Besides, the quadratic terms are also statistically significant with the square of feed rate showing a pronounced nonlinear influence, whereas the quadratic effects of cutting speed and depth of cut are insignificant on the thrust force  $F_x$  values. The technological factors obtained from the findings will play the significant meanings in further studies and production practice.

**Keywords:** Hard turning, hardened steel, cutting condition, cutting speed, feed rate, depth of cut, thrust force.

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Date of Submission: 11-05-2026

Date of acceptance: 20-05-2026

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## I. INTRODUCTION

Up to now, metal cutting processes still remain a fundamental aspect of manufacturing and mechanical engineering, focusing on the removal of material from a workpiece to produce components with precise shapes, dimensions, and surface finishes [1]. These processes are essential across a wide range of industries, including aerospace, automotive, and consumer goods. Various techniques such as turning, milling, drilling, and grinding are employed, each suited to specific applications and geometries. The effectiveness of these operations depends largely on the cutting tools used, which are typically made from materials such as high-speed steel, carbide, ceramics, and cubic boron nitride (CBN) [2]. In addition, cutting tool geometry—particularly rake and clearance angles—together with key cutting parameters such as cutting speed, feed rate, and depth of cut, play a crucial role in determining machining efficiency, product quality, and tool life. A thorough understanding of cutting mechanics, including chip formation, heat generation, and cutting forces, is essential for optimizing performance and achieving superior surface finishes [3]. During machining, different forms of tool wear, including flank wear, crater wear, and built-up edge formation, can adversely affect performance, highlighting the importance of effective tool condition monitoring. During cutting process, the heat and friction generated from the contact zones strongly affect the tool wear, machined surface quality, and tool life. Hence, cutting fluids are commonly employed to minimize heat generation and friction during machining, thereby improving tool life and maintaining surface integrity [4]. Recent advancements in this field have increasingly emphasized sustainable machining practices, the development of advanced tool materials, and the integration of digital manufacturing technologies such as real-time monitoring and adaptive control systems. As the demand for higher precision grows and materials become more difficult to machine, continued research in metal cutting is vital for enhancing productivity, reducing costs, and ensuring superior product quality [5]. Among various machining operations, turning is one of the most widely used processes, particularly for producing cylindrical components like shafts, pins, bushings, and so forth.

In turning, material removal is carried out using a single-point cutting tool, where the primary cutting motion is generated by the rotation of the workpiece, combined with the linear feed motion of the tool. The depth of cut is established by the tool's movement perpendicular to the workpiece axis. The proper selection of cutting parameters is critical for achieving high machining efficiency, particularly in hard turning applications. In such conditions, cutting tools must possess high hardness, strength, and excellent wear resistance to withstand severe cutting forces and elevated temperatures. Common tool materials used for hard turning include carbide, ceramics, cubic boron nitride (CBN), and polycrystalline cubic boron nitride (PCBN) [2,4]. In a study on the hard turning using CBN cutting tools [6], feed rate was found to have the most significant influence on surface roughness, followed by cutting speed, while depth of cut showed a comparatively minor effect. Additionally, increases in cutting temperature and cutting forces were observed to accelerate abrasive flank wear. Another

investigation into the performance and wear mechanisms of CBN tools during the hard turning of AISI 52100 steel revealed that abrasive wear is the dominant wear mode. Furthermore, the formation of a transferred layer on the flank face can induce adhesive wear, thereby significantly accelerating overall tool degradation [7]. The surface quality achieved in hard turning is strongly influenced by the feed rate [6]. In terms of cutting forces, the thrust force component is typically the largest in hard turning and is highly sensitive to both workpiece hardness and flank wear. Due to its ability to produce comparable surface finishes, hard turning is increasingly considered a viable alternative or complement to conventional grinding processes [8,9]. Therefore, investigating the effects of cutting parameters on surface quality is of significant practical and technical importance. However, there is still limited research on the hard turning of AISI 1045 steel at a hardness of 58 HRC. Accordingly, this study aims to examine the influence of cutting speed, feed rate, and depth of cut on the thrust force ( $F_x$ ) during the hard turning of AISI 1045 steel (58 HRC) using carbide cutting tools.

## II. MATERIAL AND METHODS

Figure 1 is the device set-up of hard turning experiments. The coated carbide inserts were used. Kistler quartz three-component dynamometer (9257BA) was used for measuring the thrust cutting force component  $F_x$ . The AISI 1045 steel (58HRC) were used and the chemical composition is given by Table 1.

**Table 1** – Chemical composition in weight (%) of AISI 1045 steel

Element	C	Si	Mn	Ni	S	P	Cr	Mo	W	V	Ti	Cu
Weight (%)	0.85-0.95	1.20-1.60	0.30-0.60	Max 0.40	Max 0.03	Max 0.03	0.95-1.25	Max 0.20	Max 0.20	Max 0.15	Max 0.03	Max 0.3



**Figure 1.** Device set-up of hard turning experiments

The experimental design was developed using the Box–Behnken method. Three input cutting parameters and their corresponding levels are presented in Table 2. The hard turning experiments were conducted according to the run order specified by the Box–Behnken design. For each trial, the thrust cutting force ( $F_x$ ) was measured three times, and the average value was used for analysis.

**Table 2.** Box-Behnken experimental design of the three input factors and their levels

Input machining factors	Symbol and unit	Low level	High level
Cutting speed	$V$ (rev/min)	650	950
Feed rate	$f$ (mm/rev)	0.05	0.15
Cutting depth	$a_p$ (mm)	0.1	0.2

## III. RESULTS AND DISCUSSION

Following the Box-Behnken experimental design, the hard turning experiments were conducted, and the  $F_x$  values were measured and processed. The ANOVA results in Table 3 indicate that the developed model is highly significant, as evidenced by a P-value of 0.000 and a large F-value of 65.70, confirming its strong capability to explain the variability in the response. The linear terms contribute the most to the model, with feed rate emerging as the most influential factor ( $F = 348.44$ ), followed by cutting speed ( $F = 150.47$ ), while depth of cut, although significant ( $P = 0.005$ ), has a comparatively smaller effect. The quadratic terms are also statistically significant ( $P = 0.003$ ), with the square of feed rate showing a pronounced nonlinear influence, whereas the quadratic effects of cutting speed and depth of cut are insignificant. In contrast, the interaction

terms do not exhibit statistical significance ( $P = 0.207$ ), indicating that the combined effects of the parameters have minimal impact on the response, although the interaction between feed rate and depth of cut is close to significance. Furthermore, the lack-of-fit is not significant ( $P = 0.088$ ), demonstrating that the model adequately fits the experimental data. The results suggest that the response is predominantly governed by the linear effect of feed rate, with moderate nonlinear behavior, while interaction effects can be neglected, confirming the reliability and suitability of the model for prediction and optimization purposes. The regression function of the thrust force  $F_x$  is given in Equation 1 with the coefficient of determination  $R^2=99.16\%$ , which confirms that the regression model fits with the experimental data.

$$F_x (N) = 138.9 - 0.1419 V + 1109 f + 227 t + 0.000062 V*V - 3380 f*f + 160 t*t - 0.000 V*f - 0.127 V*t - 1020 f*t \quad (1)$$

Table 3. Results of ANOVA Analysis

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	2660.72	295.64	65.70	0.000
Linear	3	2348.80	782.93	173.99	0.000
V (rev/min)	1	677.12	677.12	150.47	0.000
f (mm/rev)	1	1568.00	1568.00	348.44	0.000
t (mm)	1	103.68	103.68	23.04	0.005
Square	3	282.30	94.10	20.91	0.003
V (rev/min)*V (rev/min)	1	7.24	7.24	1.61	0.261
f (mm/rev)*f (mm/rev)	1	263.64	263.64	58.59	0.001
t (mm)*t (mm)	1	0.59	0.59	0.13	0.732
2-Way Interaction	3	29.62	9.87	2.19	0.207
V (rev/min)*f (mm/rev)	1	0.00	0.00	0.00	1.000
V (rev/min)*t (mm)	1	3.61	3.61	0.80	0.411
f (mm/rev)*t (mm)	1	26.01	26.01	5.78	0.061
Error	5	22.50	4.50		
Lack-of-Fit	3	21.16	7.05	10.53	0.088
Pure Error	2	1.34	0.67		
Total	14	2683.22			

Pareto Chart of the Standardized Effects  
(response is  $F_x (N)$ ,  $\alpha = 0.05$ )

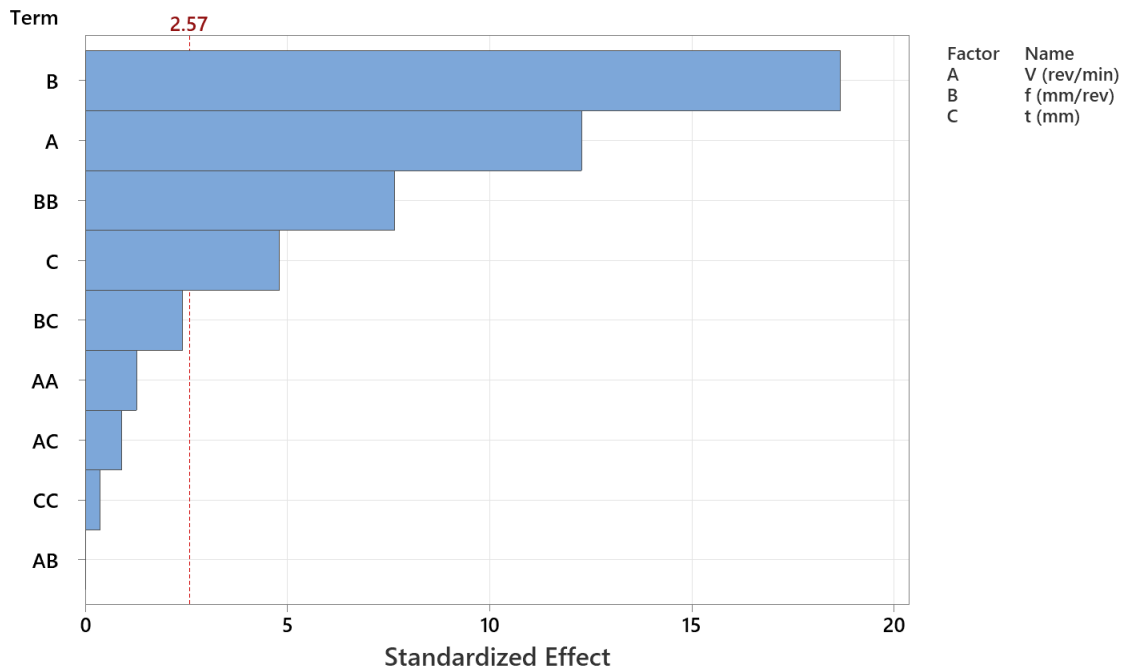


Figure 2. Pareto chart of effects of input factors on thrust force  $F_x$

In Figure 2, the Pareto chart of standardized effects clearly illustrates the relative influence of cutting parameters on thrust force  $F_x$  in hard turning process of AISI 1045 hardened steel. The red reference line (at 2.57)

represents the significance threshold at  $\alpha=0.05$ ; any factor whose bar extends beyond this line is considered statistically significant. From the chart, the feed rate ( $f$ ) (factor B) is the most dominant parameter, exhibiting the highest standardized effect by a large margin. This indicates that changes in feed rate have the strongest impact on thrust force. The cutting speed ( $V$ ) (factor A) is the second most influential factor, also well above the significance threshold, confirming its strong effect on the response. The quadratic term of feed rate ( $f^2$  or BB) is also significant, suggesting a notable nonlinear relationship between feed rate and thrust force. The depth of cut ( $t$ ) (factor C) shows a moderate but still significant effect, as its bar slightly exceeds the critical line. Among the interaction terms, only the interaction between feed rate and depth of cut ( $f \times t$  or BC) is close to significance, indicating a possible combined influence, although weaker compared to main effects. In contrast, other terms such as  $V^2$  (AA),  $V \times t$  (AC),  $t^2$  (CC), and  $V \times f$  (AB) fall below the significance threshold, implying that their effects on thrust force are negligible. The chart confirms that feed rate is the most critical factor, followed by cutting speed, while depth of cut plays a secondary role. Nonlinear effects are mainly associated with feed rate, and interaction effects are generally insignificant. This suggests that optimizing feed rate is key to controlling thrust force in hard turning under the studied conditions.

#### IV. CONCLUSION

This study investigates the effects of cutting speed, feed rate, and depth of cut on the hard turning of AISI 1045 steel (58 HRC). A Box–Behnken experimental design, implemented using Minitab 19 software, was employed to develop the experimental matrix. The results reveal that feed rate is the most influential parameter, followed by cutting speed, while depth of cut, although statistically significant ( $P = 0.005$ ), exerts a comparatively smaller effect. In addition, the quadratic terms show varying levels of significance: the square of the feed rate exhibits a strong nonlinear effect, whereas the quadratic terms of cutting speed and depth of cut have no significant influence on the thrust force ( $F_x$ ). These findings provide valuable insights for both future research and practical applications. Further studies should focus on optimizing cutting parameters and investigating surface microstructure characteristics.

#### Acknowledgments

The work presented in this paper is supported by Thai Nguyen University of Technology, Thai Nguyen University, Vietnam.

#### References

- [1] Henrik Feuk, Mattias Richter, Filip Lenrick, Rachid M'Saoubi, Volodymyr Bushlya. A novel phosphorescence-based thermometry technique for the measurement of tool temperature distribution in metal cutting, *Journal of Materials Processing Technology*, 344, 2025, 119004, <https://doi.org/10.1016/j.jmatprotec.2025.119004>.
- [2] K. Velraja, V. Srinivasan. Performance and analysis of sputtered CBN inserts in machining, *Materials Today: Proceedings*, 2023, <https://doi.org/10.1016/j.matpr.2023.06.277>.
- [3] Farbod Akhavan Niaki, Eric Haines, Roman Dreussi, Gregory Weyer. Machinability and Surface Integrity Characterization in Hard Turning of AISI 4320 Bearing Steel Using Different CBN Inserts, *Procedia Manufacturing*, 48, 2020, 598-605, <https://doi.org/10.1016/j.promfg.2020.05.087>.
- [4] Abhijeet S. More, Wenping Jiang, W.D. Brown, Ajay P. Malshe. Tool wear and machining performance of cBN–TiN coated carbide inserts and PCBN compact inserts in turning AISI 4340 hardened steel, *Journal of Materials Processing Technology*, 180, Issues 1–3, 2006, 253-262, <https://doi.org/10.1016/j.jmatprotec.2006.06.013>.
- [5] Ioan Alexandru Popan, Dan Rusu, Adrian Trif, Alina Ioana Popan, Nicolae Bălc. Innovative chip breaker machining in carbide turning inserts via abrasive water jet milling., *Procedia CIRP*, 138, 2026, 1003-1008, <https://doi.org/10.1016/j.procir.2026.01.173>.
- [6] Tamizharasan, T., Selvaraj, T., & Noorul Haq, A. (2005). Analysis of tool wear and surface finish in hard turning. *The International Journal of Advanced Manufacturing Technology*, 28(7-8), 671–679. doi:10.1007/s00170-004-2411-1
- [7] Chou, Y. K., Evans, C. J., & Barash, M. M. (2002). Experimental investigation on CBN turning of hardened AISI 52100 steel. *Journal of Materials Processing Technology*, 124(3), 274–283. doi:10.1016/s0924-0136(02)00180-2
- [8] Saswat Khatai, Ramanuj Kumar, Ashok Kumar Sahoo, Amlana Panda. Investigation on tool wear and chip morphology in hard turning of EN 31 steel using AlTiN-PVD coated carbide cutting tool. *Materials Today: Proceedings* 2022, 59, 1810-1816, <https://doi.org/10.1016/j.matpr.2022.04.387>.
- [9] Syed Adil, A. Krishnaiah, D. Srinivas Rao. Mathematical modelling and optimization of cutting conditions in turning operation on MDN 350 steel with carbide inserts, *Journal of Alloys and Metallurgical Systems*, 9, 2025, 100161, <https://doi.org/10.1016/j.jalmes.2025.100161>.