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Experimental Investigation on the Hard Turning Performance of DIN 17350-Tool 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 surface roughness R_q in the hard turning process of DIN 17350 tool steel (60HRC). The interaction effects of cutting speed, feed rate and depth of cut on surface roughness R_q were specified by using Box-Behnken experimental planning design. The obtained findings showed the trend of interaction effects of two input factors while the rest was fixed. From there, the proper value ranges were provided to achieve the smaller surface roughness R_q values. In detail, the cutting speed V=800÷950 rev/min, feed rate f=0.05÷0.07mm/rev, and depth of cut t=0.1÷0.15mm should be chosen to achieve the smaller surface roughness R_q values, which will play the significant meanings in further studies and production practice.

Keywords: Hard Turning, Hardened Steel, Cutting Condition, Surface Roughness

1. Introduction

Up to now, the metal cutting processes play a vital area within manufacturing and mechanical engineering, which focuses on the material removal from a workpiece to produce components with specific shapes, dimensions, and surface qualities. This process plays a crucial role in various industries, including aerospace, automotive, consumer goods, and so on. Metal cutting can be achieved through several methods, such as turning, milling, drilling, and grinding, each suited for different applications and workpiece geometries [1]. These operations rely on cutting tools made from such the materials as high-speed steel, carbide, ceramics, cubic boron nitride (CBN), and polycrystalline diamond (PCD). Also, the cutting tool geometry, including rake and clearance angles, along with cutting parameters like cutting speed, feed rate, and depth of cut, significantly influence the machining efficiency, the machined quality of the final products, and the tool life. The understanding of the cutting mechanics involves chip formation, heat generation, and cutting forces, which are critical for optimizing tool life and improving surface finish [2]. During cutting, various types of tool wear such as flank wear, crater wear, and the formation of built-up edges can degrade performance, making tool monitoring essential. Cutting fluids are often used to reduce heat and friction, thereby enhancing tool life and surface integrity. Modern developments in the field are focusing on sustainable machining practices, advanced tool materials, and digital manufacturing integration, including real-time monitoring and adaptive control systems. As manufacturing demands grow more precise and materials become harder to machine, ongoing research in metal cutting remains essential for improving productivity, reducing costs, and achieving high-quality results. Among the cutting processes, turning is a machining method most commonly used for cylindrical parts. This process uses a single cutting tool to perform a reciprocating motion combined with the circular motion of the workpiece to form the primary cutting motion. The cutting depth is derived from the reciprocating motion, which is perpendicular to the axis of rotation of the workpiece. The proper selection of cutting modes plays the important key to determine the turning efficiency, especially for hard turning. In the hard turning process, the cutting inserts are required to have the high hardness and strength as well as good wear resistance in order to withstand the high cutting forces and cutting temperature. The cutting tool materials commonly used in this process are carbide, ceramics, CBN, PCBN and so on [3].

In the work on hard turning of the engine crankpins using CBN cutting tools [4], the feed rate causes the strongest impact on surface roughness, followed by the cutting speed, while the depth of cut has little influence. The growth of cutting temperature and cutting forces led to accelerate the abrasive flank wear. Another study on investigation of CBN tool performance and wear mechanism was conducted for the hard turning process of AISI 52100 steel. The obtained results indicated that the abrasive wear was the main wear mode and the transferred layer on the flank wear may also cause the adhesive wear, which significantly promotes the tool wear [5]. The machined surface quality obtained in hard turning is greatly affected by the feed rate [6]. For the cutting force, the thrust force component is often the highest value in hard turning, and it is very sensitive to workpiece hardness and flank wear. The equivalent surface finish makes hard turning an alternative or supplementary solution to the grinding process [7]. Accordingly, the investigation of cutting conditions on the machined surface quality brings the practical and technical meaning [8], but there is limited information on the studies on hard turning of DIN 17350 tool steel (60HRC). Hence, this presented work aims to study the interaction effects of cutting speed, feed rate and depth of cut on surface roughness R_q in hard turning of DIN 17350 tool steel (60HRC) using coated carbide tools.

2. Materials and Methods

Figure 1 is the set-up image of hard turning experiments. The coated carbide inserts were used. SJ-210 Surface Roughness Tester (Japan) was used for measuring the surface roughness R_q. The DIN 17350 tool steel samples (60HRC) were used and the chemical composition is given by Table 1.

Table 1: Elemental composition in weight (%) of DIN 17350 tool 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

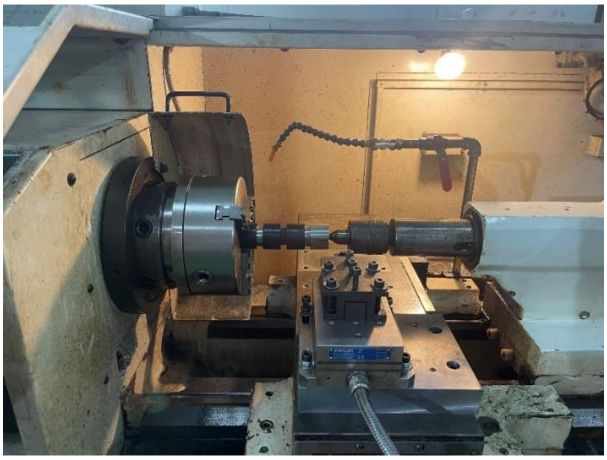

Fig 1: The set-up of hard turning experiments

The design of experiment was created by following Box-Behnken experimental design. The three input cutting factors and their levels are given by Table 2. The hard turning trials were carried out by following the run order of Box-Behnken design. The values of surface roughness R_q were measured three times right after each trial and taken by the average values.

Table 2: Box-Behnken design of the three input cutting factors and their levels

Input machining variables	Symbol and unit	Low level	High level
Cutting speed	V (*rev/min*)	650	950
Feed rate	f (*mm/rev*)	0.05	0.15
Depth of cut	a_p (*mm*)	0.1	0.2

3. Results and Discussion

Following the Box-Behnken experimental design, the hard turning experiments were conducted, and the R_q values were measured and processed. The contour plot of effects of cutting speed and feed rate on surface roughness R_q with depth of cut t=0.15mm is shown in Figure 2. The contour plot of effects of cutting speed and depth of cut on surface roughness R_q with feed rate f=0.1mm/rev is shown in Figure 3. The contour plot of effects of feed rate and depth of cut on surface roughness R_q with cutting speed V=800 rev/min shown in Figure 4.

In Figure 2, in case of the depth of cut fixed at 0.15mm, the combination of low level of feed rate with the investigated range of cutting speed bring the smaller surface roughness R_q (R_q<0.5µm). Specifically, the feed rate of 0.05÷0.07mm/rev and cutting speed of 650÷950 rev/min should be used to achieve the surface roughness R_q <0.5µm.

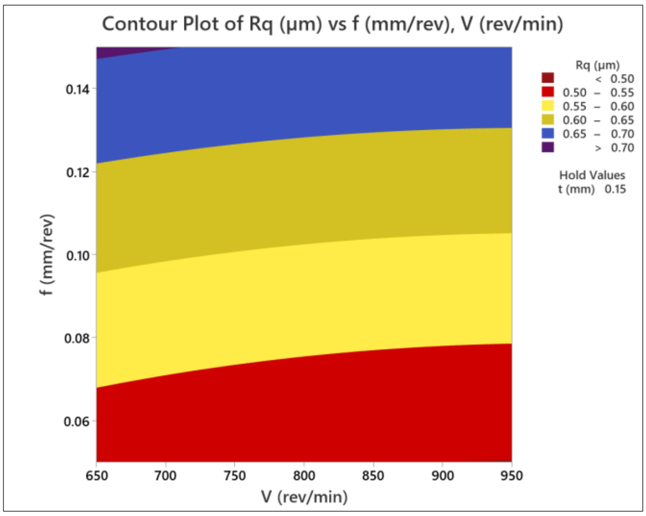

Fig 2: Contour plot of effects of cutting speed and feed rate on surface roughness R_q with depth of cut t=0.15 mm

In Figure 3, in case of the feed rate fixed at 0.1mm/rev, the combination of low level of cutting depth with the high level of cutting speed can achieve the smaller surface roughness R_q (R_q<0.59 µm). Specifically, the depth of cut in the range of 0.11÷0.14 mm and cutting speed of 920÷950 rev/min should be used to achieve the surface roughness R_q <0.59 µm.

In Figure 4, when the cutting speed is fixed at 800rev/min, the feed rate of 0.05÷0.07mm/rev and cutting depth of 0.1÷0.2 mm should be suggested to achieve the surface roughness R_q <0.55µm.

In order to facilitate the application in production practice, the cutting speed *V*=800÷950 rev/min, feed rate *f*=0.05÷0.07mm/rev, and depth of cut *t*=0.1÷0.15mm should be chosen to achieve the smaller surface roughness R_q values as well as the productivity.

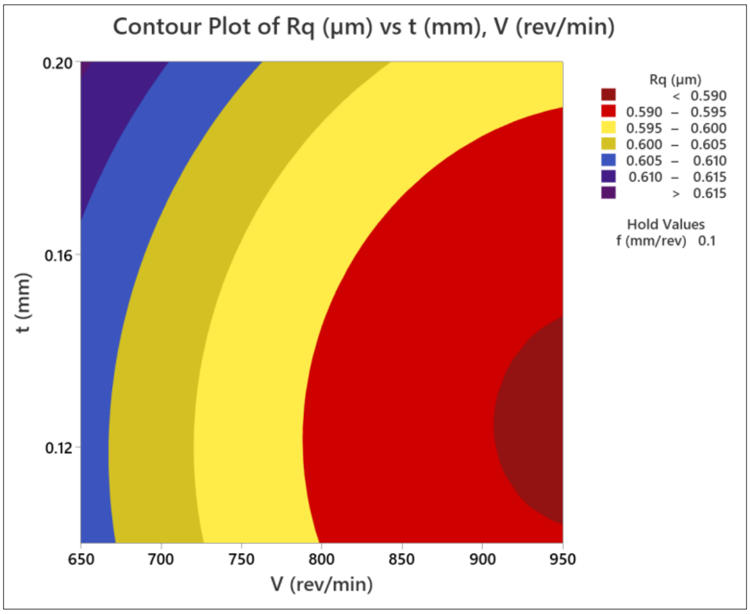

Fig 3: Contour plot of effects of cutting speed and depth of cut on surface roughness R_q with feed rate f=0.1 mm/rev

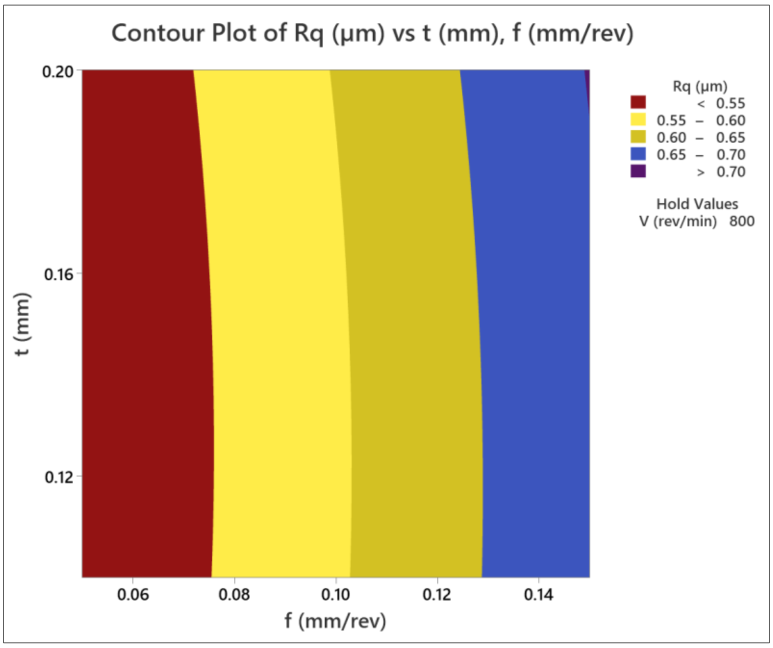

Fig 4: Contour plot of effects of feed rate and depth of cut on surface roughness R_q with cutting speed V=800 rev/min

4. Conclusion

In this article, the impacts of the cutting speed, feed rate and cutting depth were studied and investigated in the hard turning process of DIN 17350 tool steel (60HRC). The Box-Behnken experimental planning design with the help of Minitab 21 software was applied to create the experimental matrix. The interaction effects of input machining parameters were evaluated to reveal the interactive influence trend of two input factors while the remaining one was fixed. From there, the appropriate value ranges of input factors were provided to achieve the smaller surface roughness R_q. Specifically, the cutting speed *V*=800÷950 rev/min, feed rate *f*=0.05÷0.07mm/rev, and depth of cut *t*=0.1÷0.15mm should be selected to achieve the smaller surface roughness R_q values. This obtained finding will play the significant meanings in further studies and production practice. In further research, more investigation should be focused on optimizing the cutting parameters and surface microstructure.

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6. References

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