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Comparative study of cutting performance of Al7050-T6 by carbide and CBN tools

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Abstract: *In this paper, using orthogonal test method, the cutting test on carbide tools and CBN tools for turning Al7050-T6 aluminum alloy, through the cutting force, cutting temperature, surface roughness of the workpiece in the cutting process of the polar analysis, the study found that: in the selected experimental range, the carbide cutter is more effective in reducing the cutting force, improve the quality of the surface; its special chipbreaker groove improves the direction of chip flow to avoid chip entanglement; but its wear resistance is not as good as CBN tools, the cutting edge is partially broken and a slight "groove" formed on the front face to accelerate heat dissipation; but its wear resistance is not as good as CBN tools. The special chipbreaker groove improves the direction of chip flow, avoids chip entanglement, and accelerates heat dissipation; however, its wear resistance is not as good as that of CBN tools. The carbide tool is partially broken at the cutting edge and forms a slight "gully" on the front face.*
Keywords: *CBN tools, carbide tools, cutting parameters, cutting force, surface quality, tool wear*

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I. Introduction

AL7075-T6 aluminum alloy has the advantages of a compact structure, high strength, low density, and good mechanical properties, making it widely used in the aerospace and automobile manufacturing industries [1]. However, due to the low melting point of the aluminum alloy material, it is easy to soften and experience the phenomenon of sticking to the knife during cutting and machining [2], which affects machining accuracy and surface roughness. Consequently, the cutting and machining of aluminum alloy attracts many scholars at home and abroad to study [3].

Literature [4] investigates the effect of cutting triad and tip radius on roughness during dry turning of 2A14-T6511 aluminum alloy by a PCD tool. Literature [5] investigated the cutting force and tool tip temperature on cutting force by PCD tool parameters for turning ZL109 aluminum alloy. Literature [6] investigates the effect of cutting speed, feed, and backdraft on the residual stress on the surface of the workpiece during dry cutting of 7075-T651 aluminum alloy by carbide tools. Literature [7] uses the Taguchi L27 orthogonal array method and response surface design to optimize the process parameters for turning of aluminum alloy 7050. Literature [8] investigates the effect of cutting parameters on the surface quality of dry-cutting 7050-T6 aluminum alloy by establishing empirical equations.

Although there are more studies on the cutting performance of aluminum alloys, there are fewer comparative studies on the cutting performance of two types of tools: cemented carbide and CBN, for dry cutting aluminum alloys. Therefore, a comparative turning test was carried out to analyze the cutting performance, including cutting force, surface roughness, tool wear morphology, and cutting temperature, during the cutting process. This aims to provide a relevant reference basis for tool selection during cutting and machining of Al7050-T6 aluminum alloy.

II. Test materials and test program

2.1 Material parameters of the workpiece

The workpiece is selected from Al7075-T6 aluminum alloy bars commonly used for 7-series aluminum alloys, and T6 refers to its solid solution treatment followed by an artificial aging process [9]. The diameter of the round bar is 50mm, and the length is 300mm. The chemical composition of Al7075-T6 aluminum alloy is shown in Table 1; the physical and mechanical properties are shown in Table 2 [10].

Table 1 Chemical composition of Al7050-T6 aluminum alloy

Alloying elements	Zn	Mg	Cu	Cr	Si	Fe
Concentration	5.0-6.1	2.1-2.9	1.2-2.0	0.18-0.28	≤0.040	≤0.50

Table 2 Physical and mechanical properties of Al7050-T6 at room temperature

Densities （g/cm^3）	Elastic modulus （Gpa）	Tensile （MPa）	Yielding strength （MPa）	Durometer （HBS）	Thermal conductivity （W/(m·K)）	Poisson's ratio
2.81	71.7	572	503	150	56	0.25

2.2 Material parameters of the tool

The cutting test selected carbide tool model CCMT120408, material code T9015, coated, with a full circumference chip breaker groove, as shown in Figure 1 below, is Teclo's product; the selected CBN tool model CNMG120408, brand name YCB011, as shown in Figure 2 below, is the product of Zhuzhou Diamond Company.

Figure 1 Carbide inserts

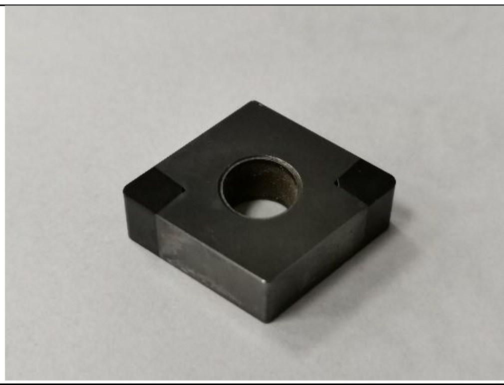


Figure 2 CBN inserts

2.3 Pilot program

In the orthogonal test program, three factors and three levels are employed, with the cutting amount of three elements serving as the test factors in the CA6140A lathe turning test. Due to the high hardness of cemented carbide and CBN, the wear resistance is good. Therefore, this test is selected for the general public on cars with higher cutting speeds. The specific parameters are shown in Table 3. The specific program's orthogonal test is shown in Table 4.

Table 3 Test cutting parameters

Level of factors	cutting speed V_c（m/min）	feed rate f(mm/r)	back draft α_p(mm)
1	190	0.1	0.1
2	150	0.2	0.2
3	125	0.3	0.3

Table 4 Orthogonal test program

Test No.	V_c （m/min）	f (mm/r)	α_p (mm)
1	190.00	0.10	0.10
2	190.00	0.20	0.20
3	190.00	0.30	0.30
4	150.00	0.10	0.20
5	150.00	0.20	0.30
6	150.00	0.30	0.10
7	125.00	0.10	0.30
8	125.00	0.20	0.10
9	125.00	0.30	0.20

III. Comparative analysis of test results

3.1 Comparative analysis of cutting force

The data on three-way dynamic cutting force obtained by the Kistler piezoelectric crystal cutting force measurement system represents the real-time cutting force. The average value of the three-way cutting force during the stable cutting period is analyzed and calculated to obtain the cutting force results of orthogonal tests, as shown in Table 5.

Table 5 Cutting force orthogonal test results

Test No.	1	2	3	4	5	6	7	8	9
CBN	51.12	109.41	168.26	73.58	127.06	104.03	88.20	52.67	118.11
Cemented carbide	47.04	94.16	143.57	67.11	118.88	75.31	72.30	60.78	99.16

Cutting force as a test index for the analysis of extreme difference, get Table 6. the lower corner of the table marked with c value that cutting test with CBN tools, the lower corner of the table marked with y value that cutting test with carbide cutting tools; table Ki corresponding to the value of the table were expressed in Table 3 in any column of the level of the number of i when the corresponding value of the cutting force of the average value of the extreme difference R for any column of the K1, K2, K3 in the maximum value and the minimum value of the difference; the more the extreme difference indicates that the influence factor on the cutting force has the greatest impact. The extreme difference R is the difference between the maximum value and the minimum value of K1, K2 and K3 in any column; the larger the extreme difference, the greater the influence of the influencing factor on the cutting force.

Table 6 Cutting force extreme difference analysis table

	V_c（m/min）	f(mm/r)	α_p(mm)
Kc1	109.596	70.964	69.274
Kc2	101.559	96.381	100.365
Kc3	86.323	130.132	127.839
Rc	23.273	59.168	58.565
Ky1	94.925	62.15	61.041
Ky2	87.1	91.275	86.814
Ky3	77.413	106.014	111.584
Ry	17.512	43.864	50.534

The analysis of Kc1, Kc2, Kc3, and Ky1, Ky2, Ky3 in Table 6 shows that the cutting forces increase with the increase in the amount of backdraft and feed. This is because the increase in the amount of backstroke and feed in the longitudinal turning of the outer circle will significantly increase the cutting thickness and cutting width of the cutting layer, thus significantly increasing the cutting area. This results in an increase in the cutting force. With the increase in cutting speed, the cutting force instead increases slowly due to the effect of chip-accumulation and the fluctuating influence of the cutting force caused by the stiffness of the cutting process.

The analysis of the extreme difference value *Rc* shows that the extreme difference values of feed and backfeed are approximately equal and larger, and the extreme difference value of cutting speed is significantly smaller than the first two, indicating that in the CBN tool cutting test, the backfeed and feed have a larger degree of influence on the cutting force, and the degree of influence of the two is approximately equal; the influence of cutting speed is the smallest; from the extreme difference value Ry, it can be seen that the extreme difference value of the backfeed is the largest, and the extreme difference value of cutting speed is the smallest, indicating that in the carbide tool cutting test, the influence of the backfeed on cutting force is the greatest, followed by the feed, while the cutting speed has the greatest influence on cutting force. From the extreme difference value Ry, it can be seen that the extreme difference value of cutting speed is the largest and the extreme difference value of cutting force is the smallest. This indicates that in the cutting test of cemented carbide tools, the degree of influence of the backdraft on cutting force is the largest, followed by the amount of feed, and the cutting speed has the smallest influence on the cutting force.

It was found that the degree of influence of feed in the test appeared to be significantly different in the two kinds of tool cutting tests. This difference is due to the fact that CBN tools cannot break chips in time during cutting, resulting in the deformation coefficient not decreasing with the increase of feed. Thus, the degree of influence of the back-eating amount of the tool and feed on the cutting force is approximately equal. In the cutting process of cemented carbide tools, their special chip-breaking groove effectively solves the chip-breaking problem, so the deformation coefficient is slightly decreased.

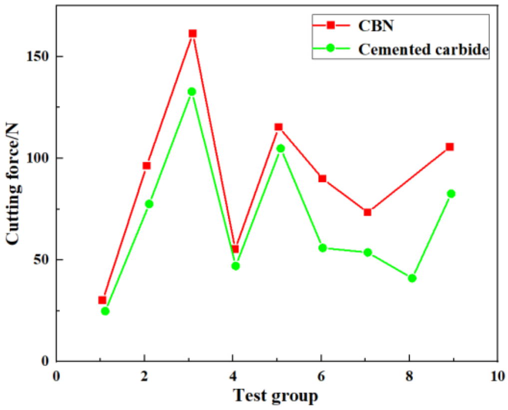


Fig. 3 Comparison of cutting force of CBN and carbide

Fig. 3 shows the orthogonal test cutting force comparison graphs of the two tools, and it is observed that the carbide tool can effectively reduce the cutting force within the selected test range; therefore, from the point of view of cutting force, the carbide tool should be selected, and the optimal combination is the cutting speed V_c=125m/min, the feed f=0.1mm, and the back-eaten tool a_p=0.1mm.

3.2 Comparative analysis of surface roughness

When measuring the surface roughness of the outer circle of the workpiece, in order to reduce the measurement error of the surface roughness, three positions are randomly selected for roughness measurement. The average of the three measurements is calculated, and the obtained surface roughness results are shown in Table 7.

Table 7 Measured surface roughness of CBN, carbide tools

Test No.	1	2	3	4	5	6	7	8	9
CBN	2.165	2.079	3.591	1.585	2.623	2.821	1.313	2.505	3.893
Cemented carbide	1.262	1.792	2.952	1.638	1.760	2.850	1.316	2.016	2.920

Surface roughness as a test index for the extreme difference analysis, obtained in Table 8, the lower corner of the table marked with the value of c indicates that the cutting test with CBN tools, the lower corner of the table marked with the value of y indicates that the cutting test with cemented carbide tools; Ki in the table corresponds to the value of the table respectively indicates that any column of the table 3 level of the number of the corresponding surface roughness when the mean value of i, the extreme difference of R for any column of the K1, K2, K3 in the extreme difference R is the difference between the maximum and minimum values of K1, K2 and K3 in any column, and the larger the extreme difference is, the greater the influence of the influence factor on the cutting force is.

Table 8 Surface roughness polar analysis

	V_c（m/min）	f(mm/r)	α_p(mm)
Kc1	2.613	1.687	2.500
Kc2	2.340	2.403	2.517
Kc3	2.570	3.433	2.507
Rc	0.273	1.746	0.017
Ky1	2.002	1.405	2.043
Ky2	2.083	1.856	2.117
Ky3	2.084	2.907	2.009
Ry	0.082	1.502	0.108

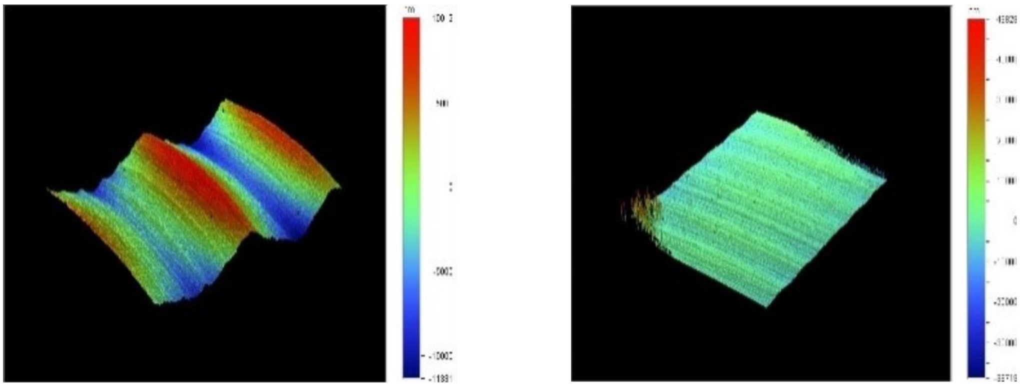
Analysis of Kc1, Kc2, Kc3 and Ky1, Ky2, Ky3 in Table 8 shows that the machined surface roughness increases with the increase of feed, on the one hand, this is because with the increase of feed, the thickness of the cutting layer increases significantly, which makes the nominal cutting area increase significantly, the cutting force increases, the cutting conditions become worse, and the surface roughness decreases; on the other hand, the increase of feed On the other hand, the increase of the feed directly causes the residual area of the cutting layer to increase significantly, which has a direct impact on the decrease of surface roughness. The increase in cutting speed during the cutting process of both tools did not have a significant effect on the range of changes in surface roughness, which is due to the fact that the lower cutting speed in the selected test range did not have a disproportionate effect on the formation and growth of chip-accumulating tumors and scaling spurs. The pattern of influence of back draft on surface roughness was not significant due to measurement errors, tool wear incontinuous cutting tests, and lathe stiffness.

The analysis of the extreme difference values Rc and Ry shows that the greatest influence on the surface roughness in the cutting process of both types of tools is the feed rate, while the influence of cutting speed and backdraft amount is smaller.

When the surface roughness results were analyzed, it was found that the roughness of test No. 4 had a large discrepancy with the other test roughness values during the carbide cutting process, so test No. 4 was redone using a new carbide tip, and the values in Table 8 are those after the second test. The comparison of the results of the two tests for Test No. 4 is shown in Table 9.

Table 9 Comparison of two roughness results of test No. 4

	first point	second point	third point
1st	2.37096	3.87407	3.73462
2nd	1.54172	1.68842	1.68363
Difference	0.82924	2.18565	2.05099



(a) Outline map of test 1, test 4 (b) Outline map of the 2nd Test No. 4

Figure 4 Contours of the two test 4s

Observation of Figure 4 reveals that the difference in surface quality of the workpiece between the two tests is obvious because the No. 4 experiment is the last set of cutting tests in the carbide tool cutting test (the test sequence will be flexibly adjusted according to the changes in bar diameter and the gear of the lathe spindle speed). The carbide tool enters the stage of intense wear, and the cutting edge is obviously blunted in the process of hard turning. The bluntness of the cutting edge has a great impact on the chip tumors and scale spurs, so the surface quality deteriorates significantly. The wear resistance of CBN tools is better than that of cemented carbide tools, so this situation did not occur in the CBN tool cutting test. In addition, in the cutting process, it was found that the chipbreaking groove of the carbide tool can improve the chip flow direction and promote chipbreaking, and the chip entanglement in the machining process was improved [11], which improved the turning safety.

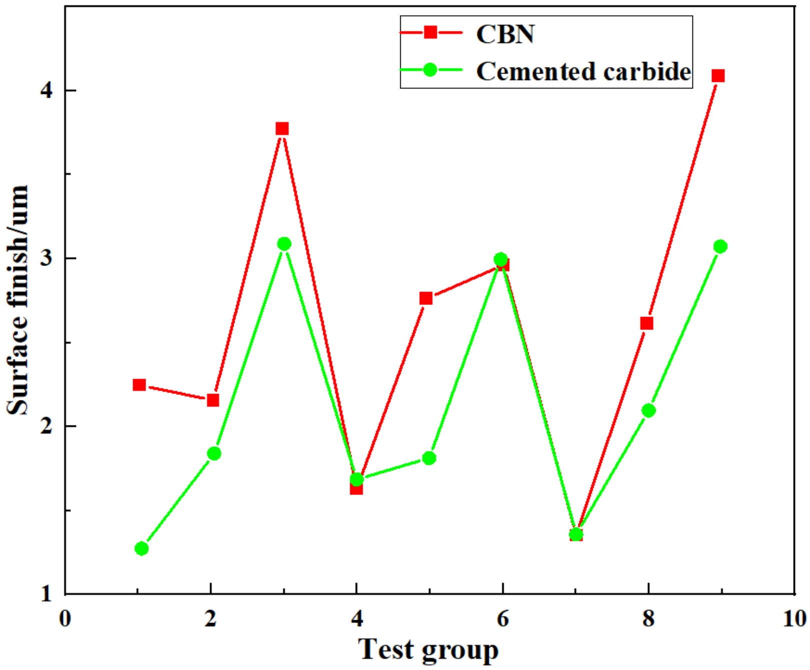


Fig. 5 Surface roughness of two tools cutting test

Fig. 5 shows the results of the orthogonal test surface roughness for the two tools. Overall, the carbide tool can effectively reduce the surface roughness within the selected test range. Therefore, from the perspective of surface roughness, the carbide tool should be selected, and a feed amount of 0.1mm should be used. However, the selection of carbide tools will increase the number of tool changes and the downtime caused by tool changes.

3.3 Comparative analysis of tool cutting temperature

Record the temperature changes captured by the thermal imager during the cutting process; playback research on cutting temperature. Due to the rapid change in cutting temperature, it is more difficult to conduct precise quantitative analysis. This paper carries out a qualitative and reasonable analysis. Comparison found that in most of the cutting processes, the cutting temperature of carbide tools is lower than that of CBN tools. Figure 6(a) shows a certain instantaneous cutting temperature during test No. 7 using CBN tools, and Figure 6(b) shows a certain instantaneous cutting temperature during test No. 7 using carbide tools. The comparison shows that the temperature of the carbide tool is significantly lower than that of the CBN tool, which is due to the special chipbreaker groove of the carbide that improves the chip flow direction and also facilitates chip disconnection, thereby accelerating heat dissipation.

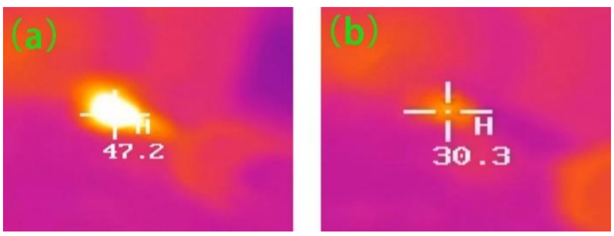


Fig. 6 Comparison of cutting temperature of two kinds of tools in test No. 7

3.4 Tool Wear Morphology Analysis

Figure 7 shows the topography of the front face of the two tools before and after the test, where "a" represents the topography of the front face of the CBN tool, and "b" represents the topography of the front face of the carbide tool. Through observation, it is found that the front face of both carbide tools and CBN tools has wear, but the wear of CBN tools is less severe than that of carbide tools due to their better wear resistance. There are two main reasons for the abrasion, one is that there is a great pressure and strong friction between the bottom surface of the chips and the front tool face, which produces the chipoma, and the shedding of the chipoma will repeatedly squeeze the front tool face, which makes the wear particles of the tool material to be taken away, resulting in tool wear; the second is that the 7075 aluminum alloy mainly contains two elements of magnesium and silicon, which form the highly brittle Mg_2Si in the process of cutting and machining, and the shedding of the Mg2Si high hardness grain constantly sliding friction before and after the knife surface, resulting in abrasive wear.

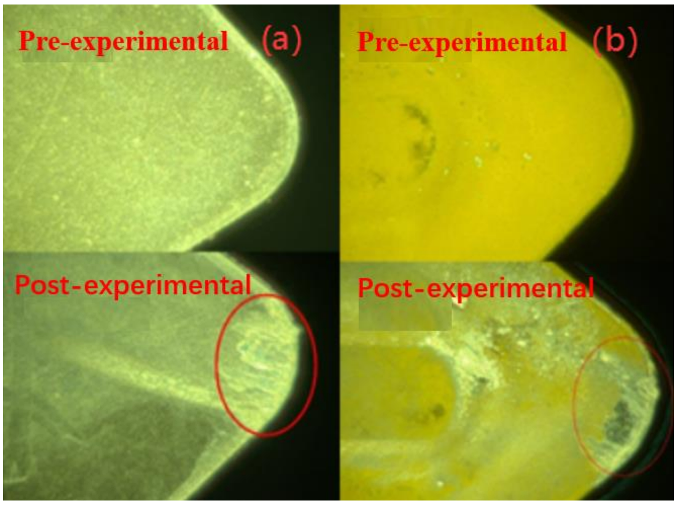


Fig. 7 Morphology of the front face of CBN and carbide tools before and after the test

IV. Conclusion

In this paper, an experimental study was conducted on turning aluminum alloy with CBN and carbide tools to analyze the effects of the three elements of cutting on cutting force, cutting temperature, surface roughness, and tool wear, and the conclusions are as follows.

(1) Within the range of cutting data set by the test, the carbide tool can effectively reduce the cutting force. When carbide cutting, the optimal combination of cutting dosage is cutting speed V_c=125m/min, feed f=0.1mm, and back draft a_p=0.1mm.

(2) Within the range of cutting data set by the test, the carbide tool with a chipbreaker groove is favorable for reducing the surface roughness of the machined surface. When cutting, choosing a low feed rate can obtain good surface quality.

(3) The cutting temperature of the carbide tool is lower than that of CBN within the range of cutting data set in the test.

(4) Under the same cutting conditions and time, the wear on the front face of the carbide tool is more severe than that on the CBN tool.

Reference

[1]. Pei Hongjie, Liu Chengshi, Wang Guicheng & Zou Ye. (2018). Experimental study on MQL high-speed turning of 7075 aluminum alloy. Tool Technology (03),32-34. doi:10.16567/j.cnki.1000-7008.2018.03.007

[2]. Liu LY, Wang JF, Tu ZB, Qing ZH & Ye ZZ. (2018).Study on surface roughness and tool wear of dry cutting aluminum alloy by YG8 carbide tool. Manufacturing Technology and Machine Tools (06), 120-123. doi:10.19287/j.cnki.1005-2402.2018.06.024.

[3]. Xiu-Jie Yue, Ping Zhang, Aili Song, Baoshun Li & Xiao Yu. (2021).Surface quality and tool wear mechanism of 7075 aluminum alloy high-speed milling. Nonferrous Metal Engineering(02),9-16.

[4]. Yang, H.D., Si, Cong, Qing, Z.H., Han, Q.G., Wu, Y.S. & Wang, X. (2020).Study on roughness of PCD tools for high-speed cutting of hard aluminum alloys. Tool Technology(06),7-10.

[5]. Jingjin, Kang Hongjun & Liu Aijun. (2020). Study on the influence of PCD tool parameters on cutting performance in turning ZL109 aluminum alloy. Mechanical Design and Manufacturing (07), 229-231+235. doi:10.19356/j.cnki.1001-3997.2020.07.053.

[6]. Ma Mang & Wang Minghong. (2019).Simulation and parameter optimization of residual stress on turning surface of 7075-T651 aluminum alloy. Mechanical Design and Research (03), 127-130. doi:10.13952/j.cnki.jofmdr.2019.0201.

[7]. Akhtar, M. N., Sathish, T., Mohanavel, V., Afzal, A., Arul, K., Ravichandran, M., ... & Saleh, B. (2021). Optimization of process parameters in CNC turning of aluminum 7075 alloy using L27 array-based Taguchi method. Materials, 14(16), 4470.

[8]. Chengyan Zhang, Lixin Wang, Wuzhou Meng & Xiaoli Zhan. (2020).Study on surface integrity of 7075-T6 aluminum alloy by dry cutting. Combined Machine Tools and Automated Machining Technology (03), 148-151. doi:10.13462/j.cnki.mmtamt.2020.03.035.

[9]. Deng-Wen Ma, Chun-Gen Shen, Yu Zhang & Yang Yao. (2020).Study on cutting performance of PCD tools for turning superhard aluminum alloys. Tool Technology(03),15-20.

[10]. Shi, H.; Ma, C.; Wang, B.; Li, Q. Influence of Lubrication Status on Milling Performance of Bionic Micro-Textured Tools. *Lubricants* **2024**, *12*, 118. https://doi.org/10.3390/lubricants12040118

[11]. Xu, T.; Ma, C.; Shi, H.; Xiao, K.; Liu, J.; Li, Q. Effect of Composite Bionic Micro-Texture on Cutting Performance of Tools. *Lubricants* **2024**, *12*, 4. https://doi.org/10.3390/lubricants12010004