Research on the relationship between workpiece surface machining quality and turning tool wear

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Abstract. In order to apply the workpiece surface machining quality detection data to tool wear prediction, an experiment on the relationship between workpiece surface machining quality and turning tool wear was carried out. Firstly, the experimental parameters are selected, and the workpiece surface quality is determined as the parameter to study the tool wear law; Secondly, by changing the tool material and workpiece material, the change law of tool wear is analyzed, and the internal reason of blade initial wear is revealed; Finally, the relationship between workpiece surface machining quality and tool wear is analyzed by measuring workpiece surface machining quality parameters. The experimental results show that the relative hardness of workpiece material and tool is the main factor determining the wear speed of tool flank, and the tool geometry is the main factor of rapid tool wear in the initial stage. The workpiece surface roughness increases gradually with tool wear. When the tool enters the severe wear stage, it decreases slightly and then continues to increase. The outer diameter of the workpiece decreases with the tool wear in the initial stage, and then fluctuates and increases gradually. The influence of tool wear on the cylindricity error of shaft parts can be ignored.

1. Introduction

The development of mechanical manufacturing technology has created conditions for the improvement of product quality. Consumers' strict requirements for product quality have promoted the improvement of industrial product quality. Therefore, it has also given birth to product quality detection technology and research under various industrial production environments, especially basic quality detection, including workpiece surface roughness [1-5], workpiece outer diameter [6-11] Form and position error [12-14]. In the process of mechanical production and processing, the tool wear of processing equipment, especially the wear of tool flank, will cause the decline of machining surface quality [15], which has a significant impact on the surface quality of workpiece.

Before the workpieces leave the factory, quality inspection is required to improve the product quality. Some workpieces are tested for quality in the production process, and some unqualified workpieces are screened out without and subsequent processing, so as to save energy and time consumption and improve production efficiency [16,17].

Therefore, studying the correlation between workpiece surface machining quality and tool wear can estimate and predict the degree of tool wear according to the change trend of surface quality, and apply it to tool life management, which will effectively reduce production cost and improve production efficiency.
At present, workpiece surface quality parameters are mostly used for product quality inspection. These inspection data, including workpiece surface roughness, workpiece outer diameter, form and position error, are used to guide and predict some production processes, which is an important breakthrough and vertical development of inspection technology and production technology. At present, there are many relevant studies. Ding Yan et al. [18] verified the influence of the change of milling cutter tooth number and cutting parameters on milling cutter wear and surface machining quality; Yao Songlin et al. [19] studied the influence of ultrasonic vibration assisted grinding technology on the machined surface quality, and within a certain range, the increase of vibration frequency, amplitude and spindle speed can optimize the surface quality; Sharma et al. [20] studied the influence of tool workpiece interaction on the surface properties of heterogeneous cube workpiece materials; Chaari et al. [21] studied the vibration characteristics of flexible workpiece in milling process, and studied the vibration characteristics and quality of machined surface without passive damper and with passive damper by using finite element model.

The relationship between workpiece surface quality and tool wear has been preliminarily studied, but it is not enough for tool life management. In this experiment, a comparative cutting experiment is designed according to the possibility of changes in the actual processing materials and cutting tools, which is closer to the actual production process. The relationship between workpiece surface machining quality and tool wear is studied, and the variation trend of relevant surface quality parameters with tool wear is obtained. This will promote the transition from research to practical application, and use the workpiece inspection quality for tool life management in the production process.

2. Experimental content

2.1. Programme overview

Under the same processing conditions, the wear of turning tool will lead to the increase of workpiece outer diameter, the change of cylindricity error and the increase of surface roughness [22-24]. The experiment selects three representative workpiece surface processing quality parameters: workpiece outer diameter, cylindricity error and surface roughness. At the same time, the tool flank wear is selected to characterize the degree of tool wear. The experiment uses two kinds of material turning tools to cut two kinds of material workpieces respectively, measure the surface quality of the machined workpiece and the wear of the tool flank in the machining process, and explore the relationship between the workpiece surface quality and tool wear.

2.2. Experimental materials and equipment

2.2.1. Experimental materials. The experimental materials include NC blade and workpiece. The blade and its schematic diagram are shown in Figure 1. The top angle of the blade is 80°, The blade rear angle is 0°, blade with cylindrical hole and double-sided chip breaking groove, the cutting edge length is 12mm, thickness is 4.76mm, and the arc radius of the tool tip is 0.8mm. Workpiece blank and 3D model are shown in Figure 2.
The workpiece materials used in the experiment are 30CrMnSi and 45#steel respectively, and their mechanical properties are excellent. The two steels have high strength, good plasticity and toughness, so they are widely used in mechanical production.

2.2.2. Experimental equipment. The experimental equipment mainly includes processing equipment and measuring equipment. Ck7520c CNC lathe is selected as the processing equipment. The strength, dynamic and static stiffness and machining accuracy of the whole machine meet the experimental requirements [25]. The measuring equipment is shown in Table 1.

| Equipment name       | Model              | Measurement content          | Measuring range | Accuracy |
|----------------------|--------------------|------------------------------|-----------------|----------|
| Spiral micrometer    | JDE05              | Outer diameter of workpiece  | 25 – 50mm       | 0.001mm  |
| Roughness tester     | TESA RUGOSU 90G    | Roughness                    | 1000µm          | 0.001µm  |
| Blu ray scanner      | PrimeScan          | Cylindricity error           | -               | 0.001mm  |
| Imager               | TESA ISSO 200      | Tool wear                    | -               | 0.001mm  |

2.3. Experimental scheme
Different chip schemes are formed by changing tool material, workpiece material and cutting parameters, as shown in Table 2.

| Parameter                          | First group | Second group | Third group |
|------------------------------------|-------------|--------------|-------------|
| Blade material                      | MC6035      | MC6035       | MC6025      |
| Workpiece material                 | 30CrMnSi    | 45#steel     | 45#steel    |
| Blank specification(ϕ × L/mm)      | 50 × 150    | 50 × 150     | 50 × 150    |
| Outer diameter after machining(ϕ/mm)| 43          | 40           | 40          |
| Cutting length(l/mm)               | 111         | 111          | 111         |
| Cutting speed(vc/m · min⁻¹)        | 180         | 180          | 180         |
| Back cut(ap/mm)                    | 1           | 1            | 0.5         |
| Feed rate(f/mm · r⁻¹)              | 0.2         | 0.2          | 0.25        |

2.4. Experimental results and analysis

2.4.1. Analysis of tool flank wear. The tool flank wear data obtained from the three groups of experiments are shown in Table 3. In the table, No represents serial number, t represents tool cumulative cutting time and VB represents tool flank wear.
Table 3. Variation of tool flank wear with the number of cutting workpieces and cumulative cutting time.

| No | First group |  | Second group |  | Third group |  |
|----|-------------|---|-------------|---|-------------|---|
|    | t/s | VB/μm |    | t/s | VB/μm |    |
| 1  | 111 | 53 | 1  | 133 | 59 | 1  | 206 | 68 |
| 3  | 334 | 105 | 3  | 401 | 110 | 3  | 620 | 108 |
| 4  | 446 | 120 | 4  | 534 | 132 | 4  | 827 | 122 |
| 6  | 669 | 130 | 6  | 802 | 150 | 6  | 1241 | 146 |
| 7  | 780 | 132 | 8  | 1069 | 158 | 8  | 1655 | 153 |
| 8  | 892 | 136 | 10 | 1336 | 159 | 10 | 2069 | 160 |
| 9  | 1004 | 145 | 12 | 1603 | 165 | 12 | 2482 | 160 |
| 11 | 1227 | 167 | 16 | 2138 | 180 | 16 | 3310 | 169 |
| 12 | 1338 | 171 | 18 | 2405 | 185 | 18 | 3724 | 171 |
| 14 | 1561 | 183 | 22 | 2940 | 197 | 22 | 4552 | 183 |
| 15 | 1673 | 189 | 24 | 3207 | 208 | 24 | 4965 | 188 |
| 16 | 1785 | 219 | 26 | 3475 | 212 | 26 | 5379 | 194 |
| 17 | 1896 | 234 | 28 | 3742 | 215 | 28 | 5793 | 207 |
| 19 | 2119 | 287 | 36 | 4811 | 243 | 32 | 6621 | 264 |
| 20 | 2231 | 311 | 38 | 5079 | 256 | 34 | 7035 | 287 |
| 21 | 2342 | 323 | 40 | 5346 | 270 | 36 | 7448 | 318 |
| 22 | 2454 | 328 | 42 | 5613 | 292 | 38 | 7862 | 348 |
| 23 | 2566 | 338 | 44 | 5881 | 326 | 40 | 8276 | 386 |

The change of tool flank wear is shown in Figure 3, and the processed workpiece is shown in Figure 4.

![Figure 3](image-url)  
(a) After machining 1 workpiece  
(b) After machining 8 workpiece  
(c) After machining 14 workpiece  
(d) After machining 20 workpiece  
(e) After machining 26 workpiece  
(f) After machining 32 workpiece  
(g) After machining 38 workpiece  
(h) After machining 44 workpiece

Figure 3. Change of flank wear of the second group of tools.

![Figure 4](image-url)  
Figure 4. Workpiece after machining.
The workpiece cutting quantity is converted into cutting time, and the variation curve of flank wear of three groups of tools with cutting time is obtained in Figure 5.

Comparing the first group and the second group of experimental results, it can be obtained that under the same cutting conditions, the greater the hardness of workpiece material, the faster the tool wear speed. Comparing the second group with the third group, it can be concluded that the higher the hardness of blade material, the slower the wear speed. Comparing the three groups of experimental results, it can be obtained that the relative hardness (the ratio of the hardness of the material to be cut to the hardness of the blade material) is the main factor affecting the blade wear speed. The greater the relative hardness, the faster the blade wear.

2.4.2. Analysis of variation of workpiece outer diameter. The relative change of workpiece outer diameter after machining is shown in Figure 6.

Comparing the three groups of experimental results, it can be obtained that under the same cutting conditions, the hardness of workpiece material is high, the overall change of workpiece outer diameter is large, and the fluctuation is also large. Because under the same cutting conditions, the harder the workpiece material, the greater the cutting force and the higher the instability (including tool deformation, vibration during cutting, etc.). In general, the outer diameter of the workpiece increases with the increase of tool wear. In addition, the outer diameter of the workpiece decreases at the beginning and then increases gradually.

2.4.3. Analysis of cylindricity error variation. The cylindricity error of the workpiece after machining is shown in Figure 7.
According to the overall variation in 2.4.1, it is estimated that the cylindricity error left by tool wear on the 110mm outer circle cutting of the workpiece is less than, which is much less than the radial error caused by the axial feed of the machine tool ball screw. Therefore, the cylindricity error of shaft parts effected by tool wear can be ignored.

2.4.4. Roughness change analysis. The surface roughness of the workpiece after machining is shown in Figure 8.

Comparing the first group and the second group of experimental results, it can be obtained that the workpiece surface roughness increases with the increase of feed rate; Under the same cutting conditions, the change of workpiece material will affect the surface roughness. By comparing the three groups of experimental results, it can be seen that in the second half of tool wear, the workpiece surface roughness has an obvious decline (as shown at the three elliptical marks in Figure. 8), and then the roughness increases gradually. This is related to the wear of the tool flank. As shown in Figure 9, the wear develops outward from the flank. In the initial stage, the flank wear will gradually reduce the arc radius of the tool tip. After the wear develops outward, the arc radius of the tool tip will increase briefly. At this time, the tool is about to enter the stage of severe wear. The wear speed of the flank will accelerate and the radius of the tool tip will continue to decrease, Increase workpiece surface roughness.

Figure 9. Schematic diagram of tool wear process.

3. Conclusion
By turning two materials with two different blades and exploring the relationship between workpiece processing quality and tool wear, the following conclusions can be drawn:

- The relative hardness of workpiece material and tool is the main factor of tool flank wear speed; Tool geometry has a certain influence on the wear speed of tool flank, and it is also the main factor for rapid tool wear in the initial wear stage.
- In the machining of shaft parts, the outer diameter of the workpiece decreases briefly with tool wear in the initial stage, and then increases slowly in a fluctuating manner. The greater the relative hardness, the greater the fluctuation.
- The workpiece surface roughness will gradually increase with the tool wear, decrease before the severe tool wear stage, and then continue to increase.
- The influence of tool wear on the cylindricity error of shaft parts can be ignored.

References
[1] Lu N. (2014) Establishment of three-dimensional evaluation system and detection method of casting surface roughness [D]. Harbin University of technology.
[2] Zhang J. (2011) Research on workpiece surface roughness detection system based on image method [D]. Nanjing University of Aeronautics and Astronautics.
[3] Jia,X.,Xiao,Z. (2007) Research on image processing of surface roughness detection based on light cutting method [J]. Optics and Optoelectronics Technology, 06: 42-44.
[4] Liu, Z.H., Xiao, Z.Y. (2016) Development of cutting surface quality prediction software based on MATLAB [J]. Machine tools and hydraulics, 44(10): 34-37.

[5] N. D M, M. R M, M. N R. Improved measure of workpiece surface deterioration during turning using non-contact vision method[J]. Precision Engineering, 2021, 68.

[6] Chen, S.X., Han, S., Tu, D.J. (2021) et al. Bearing inner and outer diameter measurement based on graph optimization [J]. Modular machine tool and automatic machining technology, 02: 103-106.

[7] Peng, Y.R., Tian, Y.L., Peng, L. (2020) Bearing outer diameter size detection based on machine vision [J]. Science and technology innovation, 31: 90-91.

[8] Liu, D., Gao, H., Gao, G.D. (2020) Research on on-line measuring device for cylinder liner blank size [J]. Internal combustion engine and accessories, 07: 34-35.

[9] Feng, Z.J., Wang, L., Luo, X.G. (2007) Workpiece outer diameter measurement system based on laser sensor [J]. Journal of electronic measurement and instruments, 21(06): 82-84.

[10] Li, W. (2007) Research on three-dimensional detection technology of train wheel outer diameter based on line structured light [D]. Huazhong University of science and technology.

[11] Lei, L.Y., Zhou, X.J., Pan, M.Q. (2005) Bearing inner and outer diameter measurement system based on machine vision [J]. Journal of agricultural machinery, 03: 131-134.

[12] Wang, D. (2017) Research on on-line detection method and system development of form and position error of chassis frame of large harvester [D]. China Agricultural University.

[13] Wang, B.J. (2017) Research on the application of machine vision technology in shaft parts inspection [J]. Information recording materials, 18(03): 31-33.

[14] Liu, X.Y., Zhang, J.X., Chen, B.G., (2015) Research on measurement method of four-way perpendicularity of large aperture telescope [J]. Laser and infrared, 45(12): 1462-1466.

[15] Li, X. (2020) Research on tool wear and prediction of machined surface roughness during machining of H13 steel [D]. Shandong University.

[16] TAN, F., Huang, H.F., Lu, H.N. (2018) Research on automatic design scheme for machining quality measurement of small and medium-sized parts [J]. Equipment manufacturing technology, 03: 51-53.

[17] Han, X. (2014) Surface texture defect detection of machined parts [J]. Scientific and technological innovation and application, 32: 131.

[18] Ding, Y., Cui, C., Jiang, B. (2021) Analysis of influence of milling cutter wear on machining quality of machine tool box joint surface [J]. Mechanical engineer, 04: 45-47.

[19] Yao, S.L., Zheng, J.T., Mu, D.Q. (2021) Study on surface quality of ultrasonic vibration assisted grinding [J]. China instrumentation, 02: 33-37.

[20] A. S, S. J S, D, D, (2020) Investigation of Tool and Workpiece Interaction on Surface Quality While Diamond Turning of Copper Beryllium Alloy [J]. Journal of Manufacturing Science and Engineering, 142(2).

[21] CHAARI, R., HADDAR, M., DJEMAL, F., (2019) Passive vibration absorber effect on the machining surface quality of a flexible workpiece [J]. Comptes rendus - Mécanique, 347(12).

[22] Han, S.Q. (2009) Discussion on surface quality control in machining [J]. China new technology and new products, 05: 108.

[23] Zheng, D., Sun, L.Y. (2002) Research on tool wear and life based on machining dimension detection data [J]. Modular machine tool and automatic machining technology, 08: 34-37.

[24] Dong, C. (2014) Research on NC Turning Accuracy Prediction Technology Based on virtual manufacturing [D]. Changchun University of technology.

[25] Luoyang, Y.J. (2016) Technical description of CK7520 CNC lathe [EB / OL] (2016-02-22)[2021/6/9]. https://wenku.baidu.com/view/7e9fcee87c24028915fc3eb.html.