Simulation Analysis of the Influence of Micro-texture Parameters on Tool Strength Based on ANSYS

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Abstract. In this paper, the influence of the micro-texture parameters of the tool surface on the tool strength is studied, and the texture parameters with less influence are selected. Firstly, the cutting force of the PCBN tool in the actual cutting process is measured by the dynamometer, and then the 3D model of the tool is imported through the finite element analysis software ANSYS. After the mesh is divided, certain constraints and the measured cutting force are applied, and finally get the deformation and equivalent stress of the tool for analysis. The results show that when designing the micro-texture, the width of the micro-texture should be between 90-110μm, the spacing of the micro-texture should be between 110-120μm, and the margin between the micro-texture and the cutting edge should be between 160-180μm. The depth of the micro-texture should be between 30-40μm, so that it can not only play the role of micro-texture on the cutting tool, but also reduce its impact on the strength of the tool.

1. Introduction
Green manufacturing with high efficiency, high precision, energy saving and environmental protection has become the trend of modern machining industry[1]. Turning, as the main production mode in machining, is developing towards high speed, high efficiency, intelligence and environmental protection with the continuous progress of technology. The cutting tool is an important part of the cutting process, which causes violent plastic deformation on the workpiece surface and local shear slip of the workpiece so as to remove the material. In the process of machining, the contact surface of cutter-workpiece will generate huge heat due to friction. Although most of it is taken away by the chip, there are still some residues on the surface of the cutter, which will lead to the wear of the cutter. In order to reduce tool wear, improve tool life and reduce machining cost, researchers at home and abroad have carried out research on tool wear. In a series of studies, Kaushalendra V. Pratel et al.[2] found that the parameters of the micro-groove had certain effects on the cutting force, the friction force during the cutting process and the tool wear through experimental analysis. Enomoto et al.[3] found that micro-texture can effectively improve the adhesion performance of the tool. Through wear test, Johannes et al.[4] concluded that pit texture can improve the stability of chipping, and groove texture cutter can reduce the surface roughness of the processed workpiece. Wu Ze et al.[5] found that self-lubricating tools with micro-pits can effectively reduce the cutting force and the adhesion phenomenon on the tool surface, and the texture perpendicular to the cutting direction has better anti-adhesion and anti-friction effect. In summary, previous studies have shown that the application of surface micro-texture cutter has a broad prospect. The surface micro-texture tool has an effect on the strength of the tool while improving the machinability, so this article by ANSYS finite element analysis software to establish the micro texture 3d simulation model of cutting tool, design micro-
textures with different parameters, the single factor method is adopted to form variables and stress obtained by simulation analysis and compared with no texture of the cutting tool, for later design the parameters of the micro texture of the cutting tool to provide the reference.

2. Design of simulation experiment
The experimental process of micro-texture tool strength finite element analysis is as follows: 1. Draw the tool model with 3D drawing software and import it into Workbench module for analysis; 2. Add PCBN material model through ANSYS custom material library; 3. Meshing the imported tool model; 4. Apply fixed constraints and loads to the tool model; 5. Carry out finite element simulation calculation and analyze the data to get the results.

2.1. Texture design
Since the existence of surface texture will have a certain impact on the tool, four specific parameters have been determined under the consideration of various influencing factors, including: texture width $a_1$, texture spacing $a_2$, texture and edge distance of cutting edge $a_3$, the depth of texture $a_4$, the tool geometry model is shown in Figure 1. In this simulation experiment, the surface micro-texture parallel to the cutting edge is used. The specific parameters of the texture are shown in Table 1 below.

![Figure 1. Schematic diagram of tool surface texture](image)

Table 1. Parameters of micro-texture tool.

| Number | Width (μm) | Spacing (μm) | Distance (μm) | Depth (μm) | Number | Width (μm) | Spacing (μm) | Distance (μm) | Depth (μm) |
|--------|------------|--------------|--------------|-----------|--------|------------|--------------|--------------|-----------|
| 0      | 50         | 50           | 150          | 30        | 14     | 50         | 125          | 150          | 30        |
| 1      | 20         | 50           | 150          | 30        | 15     | 50         | 50           | 150          | 30        |
| 2      | 35         | 50           | 150          | 30        | 16     | 50         | 50           | 150          | 30        |
| 3      | 60         | 50           | 150          | 30        | 17     | 50         | 50           | 150          | 30        |
| 4      | 80         | 50           | 150          | 30        | 18     | 50         | 50           | 150          | 30        |
| 5      | 95         | 50           | 150          | 30        | 19     | 50         | 50           | 150          | 30        |
| 6      | 110        | 50           | 150          | 30        | 20     | 50         | 50           | 150          | 30        |
| 7      | 125        | 50           | 150          | 30        | 21     | 50         | 50           | 150          | 30        |
| 8      | 50         | 20           | 150          | 30        | 22     | 50         | 50           | 150          | 30        |
| 9      | 50         | 35           | 150          | 30        | 23     | 50         | 50           | 150          | 30        |
| 10     | 50         | 60           | 150          | 30        | 24     | 50         | 50           | 150          | 30        |
| 11     | 50         | 80           | 150          | 30        | 25     | 50         | 50           | 150          | 30        |
| 12     | 50         | 95           | 150          | 30        | 26     | 50         | 50           | 150          | 30        |
| 13     | 50         | 110          | 150          | 30        | 27     | 50         | 50           | 150          | 30        |
| 14     | 50         | 150          | 150          | 30        | 28     | 50         | 50           | 150          | 30        |
| 15     | 50         | 150          | 150          | 30        | 29     | 50         | 50           | 150          | 30        |
| 16     | 50         | 150          | 150          | 30        | 30     | 50         | 50           | 150          | 30        |
| 17     | 50         | 150          | 150          | 30        | 31     | 50         | 50           | 150          | 30        |
| 18     | 50         | 150          | 150          | 30        | 32     | 50         | 50           | 150          | 30        |
| 19     | 50         | 150          | 150          | 30        | 33     | 50         | 50           | 150          | 30        |
| 20     | 50         | 150          | 150          | 30        | 34     | 50         | 50           | 150          | 30        |
| 21     | 50         | 150          | 150          | 30        | 35     | 50         | 50           | 150          | 30        |
| 22     | 50         | 150          | 150          | 30        | 36     | 50         | 50           | 150          | 30        |
| 23     | 50         | 150          | 150          | 30        | 37     | 50         | 50           | 150          | 30        |
| 24     | 50         | 150          | 150          | 30        | 38     | 50         | 50           | 150          | 30        |
| 25     | 50         | 150          | 150          | 30        | 39     | 50         | 50           | 150          | 30        |
| 26     | 50         | 150          | 150          | 30        | 40     | 50         | 50           | 150          | 30        |
| 27     | 50         | 150          | 150          | 30        | 41     | 50         | 50           | 150          | 30        |
| 28     | 50         | 150          | 150          | 30        | 42     | 50         | 50           | 150          | 30        |
| 29     | 50         | 150          | 150          | 30        | 43     | 50         | 50           | 150          | 30        |
| 30     | 50         | 150          | 150          | 30        | 44     | 50         | 50           | 150          | 30        |
| 31     | 50         | 150          | 150          | 30        | 45     | 50         | 50           | 150          | 30        |
| 32     | 50         | 150          | 150          | 30        | 46     | 50         | 50           | 150          | 30        |
| 33     | 50         | 150          | 150          | 30        | 47     | 50         | 50           | 150          | 30        |
| 34     | 50         | 150          | 150          | 30        | 48     | 50         | 50           | 150          | 30        |
| 35     | 50         | 150          | 150          | 30        | 49     | 50         | 50           | 150          | 30        |
| 36     | 50         | 150          | 150          | 30        | 50     | 50         | 50           | 150          | 30        |
This experiment selects No.0 group micro-texture width $a_1=50\mu m$, micro-texture spacing $a_2=50\mu m$, micro-texture and cutting edge spacing $a_3=150\mu m$, micro-texture depth $a_4=30\mu m$ as the basic group. And on this basis, according to 4 different factors, the remaining 4 groups of 27 tools were designed, respectively is: No.1-7 for different texture width groups, No.8-14 for different texture spacing groups, No.15-21 for different cutting edge distance groups, different texture depth group 22-27.

2.2. Cutting conditions
In this paper, CA6140 lathe is used for cutting to determine the size of cutting force to be applied to the tool during simulation. The test adopts PCBN tool, ISO model CNGA120408, brand FBS9300, and the physical performance parameters of the tool are shown in Table 2. The test workpiece is a Ti-6Al-4V titanium alloy bar with a diameter of 100mm and a length of 300mm. During processing, the rake angle $\gamma=-6^\circ$, the relief angle $\alpha=6^\circ$, the entering angle $K_r=91^\circ$, the cutting parameters are: Cutting speed $V=60m/min$, feed amount $f=0.1mm/r$, cutting depth $a_p=0.2mm$. The AKistler02-2825 high-sensitivity piezoelectric three-way dynamometer system is used to collect cutting force data. In order to maintain the accuracy of the force, three cutting tests were performed and the average value was taken. Finally, the cutting force values were determined to be: axial force $F_x=47N$, main cutting force $F_y=106N$, and radial force $F_z=37N$.

| Parameter                  | Density/(g·cm⁻³) | Young's modulus/Pa | Poisson's ratio |
|----------------------------|------------------|--------------------|-----------------|
| Value                      | 1.143            | 0.285              | 0.077           |

3. Simulation
This test uses the structural static analysis of Workbench module of ANSYS. First, draw the designed tool model with 3D drawing software CATIA, and then import the model into Workbench. As there is no PCBN material in the ANSYS database, additional material needs to be added, as shown in Figure 2. After setting the tool material, the model must be meshed. The precision of the meshing affects the results of the simulation analysis. In the experiment, adjust the mesh correlation degree in ANSYS to 100, the center correlation selection is refined. The divided grid is shown in Figure 3.
In the actual cutting, the rake face of the tool is the main working area, and the tip is the part with the greatest stress. In this simulation, the radius of the tip arc is chosen as the stress area, as shown in Figure 4. Assuming that all forces on the tool are concentrated in the radius of the tool tip, constraints in X, Y and Z are set, and cutting forces are added to the arc. The numerical values are axial force $F_x=47N$, main cutting force $F_y=106N$, and radial force $F_z=37N$, as shown in FIG.5.

4. Analysis
This simulation experiment selects four influencing factors of micro-texture to design the tool, and analyzes the results from these four aspects. In the simulation results, the two parameters of deformation and Von Mises equivalent stress are selected to analyze the influence of micro-texture on the strength of the tool. The deformation represents the deformation of the object under the action of external force. The Von Mises criterion is a kind of Yield criterion, the value of the yield criterion is usually called equivalent stress. It follows the fourth strength theory of material mechanics. It uses stress contours to reflect the stress distribution inside the object and can clearly depict the change of stress in the entire object, the situation and the area where the object is most dangerous. as shown in Figure 6.

4.1. Effect of texture width on cutting tools
Fig. 7 is a broken line graph showing the influence of the micro-texture width on the shape variable and the maximum equivalent stress of von Mises on the radius of the tool tip. It can be seen from the figure that the value of the tool surface deformation first decreases and then increases with the value of
the tool width, and finally tends to a stable level. As the texture width increases, the cutting of the tool rake face causes the value of its deformation variable to also decrease, but as the width of the texture becomes larger and larger, the effect of this dispersion becomes smaller and smaller. With the width of the texture, the equivalent stress on the tool surface first decreases, then increases, then decreases and then increases, and its value is relatively small between 90-110μm. Therefore, when designing the surface texture of the tool, the width of the micro-texture should be selected in the range of 90-110μm, so that the width of the texture can have a relatively small effect on the tool.

4.2. Effect of texture spacing on cutting tools
FIG. 8 is a broken line graph showing the influence of micro-texture spacing on the shape variable and the maximum equivalent stress of von Mises on the radius of the tool tip arc radius. As can be seen from the figure that the value of tool deformation and equivalent stress varies greatly with the spacing of the surface texture. The deformation value first decreases and then increases, then decreases and then increases. When the interval is 95μm, the sudden change reaches the maximum value, and finally decreases to a smaller value. The equivalent stress decreases firstly, then increases, then decreases and finally increases with the spacing of the straight texture. It also reaches the maximum value at the micro-texture spacing of 95μm, so we need to skip this area when designing the texture spacing. To prevent the tool from breaking during cutting. Considering the deformation and equivalent stress, choose between 110-120μm when designing the texture spacing, so that the micro-texture spacing has less influence on the tool strength.

4.3. Effect of texture and cutting edge distance on cutting tools
Fig. 9 is a broken line graph showing the influence of micro-texture and cutting edge edge distance on the shape variable and the maximum equivalent stress of von Mises on the radius of the tool tip arc radius. It can be seen from the figure that the deformation and equivalent stress decrease as the distance between the texture and the cutting edge increases. The farther the texture is from the cutting edge, the smaller the impact on the strength of the tool, but therefore the less the effect it has on the cutting process, so after considering the cutting effect of the tool strength and micro-texture, it should be selected between 160-180μm.
4.4. Effect of texture depth on cutting tools

Fig. 10 is a broken line graph showing the influence of micro-texture depth on the deformation of the tool tip arc radius and the maximum value of Von Mises equivalent stress. It can be seen that the values of deformation and equivalent stress both increase first, then decrease, then increase and finally decrease with the increase of texture depth, and there is a minimum value at 30-40μm, but when the depth of the texture increases, the deformation and equivalent stress change less, indicating that the depth of the texture has a relatively small effect on the strength of the tool. Therefore, when designing the texture width, choose the range of 30-40μm, which can make the texture have less influence on the tool strength.

5. Summary

In this paper, a simulation experiment of Workbench is carried out for the influence of the tool surface micro-texture on the tool strength. The single factor method is used to analyze the influence of texture width, texture spacing, texture and cutting edge edge distance, and texture depth on the strength of PCBN tools. From the simulation results, when designing the micro-texture, the width should be between 90-110μm, the spacing between 110-120μm, the edge distance to the cutting edge should be between 160-180μm, and the depth should be between 30-40μm. which can not only play the role of the micro-texture in cutting, but also reduce the influence on the strength of the cutting tool.

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