The Influence of Loading Force on Ultrasonic Drilling Garnet Ferrite

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Abstract. In order to achieve high precision microholes of garnet ferrite, the rotary ultrasonic assisted machining and the tool load matching system were employed. An ultrasonic precise microholes technology experiment platform was built to machine garnet ferrite materials. A series of drilling experiments to machine garnet ferrite were presented in this paper, which were used to explore the influence of cutting force on tool wear. And the holes’ exit aperture and wall surface roughness were applied to be evaluation parameters to explore the effect of loading force on machining quality. As a result, tool wear is aggravates as cutting force increases. And loading force shows different influence tendency on exit aperture size precision and wall surface roughness, the selection of proper loading force does good to control exit aperture size and hole wall surface roughness effectively.

1. Introduction
Garnet ferrite is a porous insulating composite composed of many grains and pores. It has excellent physical and chemical properties, such as high hardness, high electrical resistivity, high magnetic permeability, etc., which make garnet ferrite widely used in consumer equipment such as nuclear magnetic resonance, computer and other information equipment, and aerospace equipment such as aircraft and rockets. However, the unique structure makes it hard to process because of its high hard and brittle properties. Thus, How to machine it efficiently and accurately becomes an important research field[1].

In order to meet dimensional accuracy and assembly accuracy requirements, the ferrite product after fired needs to be machined. In view of the unique processing characteristics of ferrite materials, grinding is carried out generally. The surface topography of the parts obtained by grinding has a important impact on the performance of the parts[2]. Under the current technical conditions, the drilling experiment of microwave ferrite is usually processed by a tool for sintering or electroplating diamond abrasive grains. The processed microholes will have large inlet and outlet collapse, high hole wall roughness value, and make it hard to meet the expected requirements. To solve this problem, the cutting force should be controlled as low as possible during processing firstly. Secondly, the cutting force should be controlled as smooth as possible.
Ultrasonic-assisted machining is widely used in modern machining due to its low grinding force and good surface quality. However, traditional abrasive ultrasonic machining uses ultrasonic vibration of tools or workpieces to process hard and brittle materials through a suspension between the workpiece and cutting tool[3]. The material removal efficiency of this processing method is very low, at the same time, when the abrasive grains and the chip mixture return to the surface of the workpiece, the side walls of the processed hole wall will be worn again. This phenomenon is especially noticeable in microholes’ processing[4]. Therefore, in order to solve the shortcomings of the traditional abrasive ultrasonic processing method, rotary ultrasonic assisted machining (RUAM) came into being. In RUAM, axial vibration together with tool rotation does the machining[5]. Allowing for ferrite materials’ high hardness, strong brittleness and too much stomatas which go against processing, it’s necessary to apply RUAM into machining ferrite materials. Comparing with conventional drilling in previous studies, RUAM was used to drilling and polishing holes, low cutting force was provided and the machining accuracy was improved [6-7]. What’s more, the smallest-diameter holes drilled by grinding can be obtained with Ultrasonic grinding[8].

RUAM provides less cutting force for precision hole making, but the cutting force during machining cannot be stabilized and is usually fluctuating. Therefore, in order to ensure the stable cutting force and improve the machining quality during the machining process, the load matching system is applied to the machining process. J F Zhang and others of Chongqing University designed a new type of ultrasonic pressurizing device during the study of ultrasonic machining principle and process parameter optimization of brittle materials. In the ultrasonic machining process, the lifting movement of the pontoon can be controlled by the liquid level which means relatively stable load[8]. G Ya, et al. [9-10] used a mechanical device such as a spring or a weight to establish a tool load matching system. Based on the theory of hydraulic loading, P. Legge established a load matching system with an ultrasonic resonance frequency of 20 kHz, drilling glass and crystalline alumina, respectively, with dimensional accuracy of 0.0254 mm and 0.0127 mm[11].

Ultrasonic machining technology and tool load matching system are widely used in various machining fields, and load force also has an important impact on machining quality. However, the effect of load force on tool wear and machining accuracy has rarely been reported in papers. Therefore, a drilling experiment research was carried out, garnet ferrite was used as the workpiece, and air-floating guide rail and cylinders were used to achieve precise load force to explore the influence of load force on tool wear. In the process of analysis, the outlet diameter and surface roughness of the hole were used as indicators to evaluate the parameters to study the effect of different load forces on machining accuracy.

2. Experimental conditions and schemes

2.1 Material and cutting tools

The experimental specimens are composed of fully sintered garnet ferrite (molecular formula R₃Fe₅O₁₂). The cutting tools are electroplated diamond tools. The related parameters of the experimental materials and cutting tools are shown in Table 1.

| Tool substrate | Material | Stainless steel |
|---------------|----------|----------------|
| Tool abrasive | Material | Diamond        |
|               | Granularity | 200#           |
| workpiece     | Material | Garnet ferrite |
|               | Dimension | 30×25×4 mm³    |
|               | Density   | 3.69×10³ kg/m³|
2.2 Experimental and measuring devices

The ultrasonic vibration system consists of an ultrasonic generator, a power amplifier and an Ultrasonic Processing Head. As shown in Figure 1, the ultrasonic processing head can be mounted on the spindle of the machine to clamp tools of different sizes, and the ultrasonic electrical signal can be transformed to be ultrasonic mechanical vibration of the cutting tool.

\[ F_R = P \cdot S - G - F \]  \hspace{1cm} (1)

\( F_R \) represents the resultant force on the moving guide rail of PFW. \( P \) is the stable air pressure at the top of the cylinder. \( S \) is the effective area of the cylinder. \( G \) means the whole weight of the moving guide rail, fixture and workpiece of PFW. Finally, \( F \) represents the carrying capacity between the cutter and the workpiece.

The Ultrasonic Processing Head and load matching system invented by authors can be directly connected to the ordinary machine spindle. In this paper, XH716D HanChuan CNC machine was selected as the test machine. The ultrasonic processing head was connected to machine spindle. PFW was directly installed on the working platform of CNC machine.

After machining microholes, The WE6800-3 high precision microscopy was used to observe the diameter. The nanovea ST400 profile meter was employed to test the hole wall line roughness. In order to collect reliable data, each test was repeated three times and the average value was obtained by results.

2.3. Experimental scheme

2.3.1 The impact of loading force on tool wear. In this experiment, microholes was drilled by ultrasonic processing head and load matching system. The hole diameter is \( \Phi 0.65 \text{mm} \), each cutting tool drilled 4 holes. The loading force \( F \) was set as 5N, 10N, 16N, 29N and 35N, and the other processing parameters were feed speed \( V_w=1.0 \text{mm/min} \), tool linear speed \( V_s=0.191 \text{m/s} \), and ultrasonic power \( P=40\% \) (ultrasonic maximum power 25W).

2.3.2 The impact of loading force on processing quality. Based on the previous technical accumulation in the laboratory, taking the interaction of different machining parameters into account, three groups of optimized machining parameters were selected for carrying out optimization experiment. Feed speed \( V_w \), cutter linear speed \( V_s \), and ultrasonic power \( P \) are shown in Table 2. To drill different microhole
separately under the above three groups of processing parameters, the loading force were set to 5N, 10N, 16N, 29 N, 35N. The theoretical diameter is Φ 0.65 mm. The diameter and surface roughness data were used to be the evaluation index of processing parameters, which had been recorded.

| Group | Feed speed $V_w$ (MM/min) | Tool linear speed $V_s$ (M/S) | Ultrasonic power $P$ (%) |
|-------|--------------------------|-----------------------------|------------------------|
| 1     | 1.0                      | 0.191                       | 40                     |
| 2     | 1.5                      | 0.157                       | 40                     |
| 3     | 1.5                      | 0.225                       | 30                     |

3. Experimental results and analysis

3.1 The impact of loading force on tool wear
Under different load conditions, the tool wear state is as shown in Figure 3a. to Figure 3f.

a) Tool wear state before machining  
b) Tool wear state under 5N  
c) Tool wear state under 10N  
d) Tool wear state under 16N
Focus on Figure 3a - f, it can be found as followed. There was a small amount of diamond grits wear when the loading force set to 5N and 10N and a large number of grits dropped down when loading force was 16 N. Binder began to fall off when loading force was 29N, and the base of cutting tool had been involved in processing. When the loading force was set to 35N, cutting tools began to fracture at the variable cross-section (effective length). Consequently, when other parameters didn’t changed, with the increase of the load, tool wear became serious. This is because with the increase of the loading force, the tool grinding effect was enhanced, the impact force was increased, at the same time, the size of the chip became larger, material removal rate increased. All of this means, chip removal became more difficult, and the gap between the tool and the workpiece got smaller, so the tool wear became faster.

It was also found that the most worn area was the tool neck. Combined with the mechanism of drilling ultra-precision hole, considering the sufficient supply of cooling fluid for this experiment, the effect of cooling fluid would not be taken into account here. The analysis showed that in the machining process, due to the improvement of the loading force, the cutting efficiency was significantly improved, and the tool abrasive passivation was intensified. At this time, the chip was hard to be removed, and would accumulate in the back of the tool head. With rapid rotation of the cutting tool, there was a serious erosion caused by the abrasive particle and matrix of tools. All of this caused the neck destroyed more and more seriously with the improvement of loading force.

3.2 The impact of loading force on exit aperture diameter
In the process of machining garnet ferrite, the amplitude range of the cutting force is 4.5N-18N. Thus, the loading force is set to 5N, 10N, 16N and 29N. The experimental results of diameter are recorded in Table 3:

| Group | Loading force F | Unit: mm |
|-------|----------------|----------|
|       | 5N | 10N | 16N | 29N |
| 1     | 0.667 | 0.724 | 0.798 | 0.682 |
| 2     | 0.664 | 0.757 | 0.734 | 0.698 |
| 3     | 0.668 | 0.753 | 0.726 | 0.694 |
In Figure 4, with the gradual increase of the loading force, the variation trend of pore size under three experimental parameters increased firstly and decreased in the following time. It could be anticipated that the action of drilling microholes combined the action of the cutter and the air floating worktable. With the increase of the loading force, the influence of cutting on the workpiece was strengthened. However, when the load exceeds the critical point, either way, when the loading force exceeded the maximum cutting force in the traditional drilling, the tool wear becomes quite acute, and the tool diameter would decreased significantly (as shown in Figure 3b-3f). Therefore, although the damage to the surface of the microhole would trend to get serious and the chip may even increase when the tool is worn, the outlet diameter of the microhole will obviously decrease.

In addition, the diameter of the microhole fluctuated between 0.66 and 0.80mm, which showed that when the constant loading force was set within the change range of conventional machining cutting force, the diameter of the microhole would change in different degrees. When the loading force exceed the range of the conventional machining force, the outlet diameter of microhole decreased, but the cost was the sharp wear of the tool. Therefore, for garnet ferrite materials, the loading force should be controlled at about 5N, when a good inlet diameter is obtained.

3.3 The impact of loading force on wall surface roughness

Table 4. Surface roughness results

| Group | Loading force F | Unit: μm |
|-------|----------------|----------|
|       | 5N | 10N | 16N | 29N |
| 1     | 1.832 | 2.206 | 1.867 | 2.105 |
| 2     | 1.647 | 1.825 | 2.769 | 3.552 |
| 3     | 2.061 | 2.113 | 1.839 | 2.233 |
Figure 5. The impact of loading force on surface roughness

As shown in Table 4, under the loading force of 5N, 10N, 16N and 29N, the average roughness of the wall surface is 1.847 m, 2.048 m, 2.158 m and 2.630 m. Compared with Figure 3b-3f, it was shown that the surface roughness of the hole wall increased with the increase of the loading force. This is because the impact effect of ultrasonic tools was enhanced along with the increase of the loading force, caused in a large amount of debris. At the same time, the impact effect led to the fracture of the bond of the grinding wheel, and the grinding wheel's abrasive particles would collapse.

According to Figure 5, the surface roughness value increased gradually due to the effect of larger debris and cutter grinding grains on the ploughing and sliding friction of the inner wall of microhole. In addition, when the loading force is 16N and below, the fluctuation of PFW promoted the removal of chips to a certain extent. When the loading force was 29N, the cutter and the workpiece contact for a long time relatively, the PFW would not float up and down, the chip was hard to be removed away. when the loading force was 29N, the roughness was the worst, and the change range was largest. Therefore, the smaller of the loading force is, the better wall surface quality will obtain. In order to obtain smaller pore wall surface roughness, the loading force should be controlled at about 5N.

4. Conclusion
This paper carried out different processing experiments on garnet ferrite, and analyzed and explored the influence of load on tool wear, microhole exit diameter and micro-hole wall surface roughness in detail. The conclusions are as follows:

(1) The loading match system can be used to output different loading force to process the workpiece. During drilling, with the increase of tool loading force, tool wear would become more and more serious, and the tool neck was the most serious area of tool wear. In order to improve the tool life and machining precision, the structure and material of the tool should be designed reasonably in actual machining.

(2) The diameter of the microhole increases firstly and decreases after that. When the loading force is controlled within the floating range of the cutting force in traditional machining, the dimensional accuracy of the aperture is poor. In order to obtain the best aperture, the actual machining should be set to 5N.

(3) The surface roughness of microhole wall increases with the increase of the loading force. And when the loading force exceeds the maximum cutting force in traditional machining, the wall surface roughness will be seriously increased. In order to obtain smaller surface roughness of the hole wall, the loading force should be strictly controlled at 5N.

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