Study on the single process parameter in the cutting force of C/SiC composites by ultrasonic vibration method

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Abstract: Cutting force is an important physical quantity in the cutting process, during which the force has an effect upon the cutting heat, surface texture of the processed work, and the wear and life of cutting tool. And thus, the study on cutting force is of crucial importance in the research of processing properties and processing mechanism of C/SiC composites. Through the study on single process parameter, this paper is to find out its influence pattern on cutting force.

1. Introduction
Carbon fiber reinforced silicon carbide ceramic matrix C/SiC composites have a series of excellent properties, such as high hardness, high strength, high toughness, high temperature resistance, wear resistance, chemical corrosion resistance, oxidation resistance, creep resistance, low density and low thermal expansion coefficient[1]. It can satisfy the high temperature environment in 1650 degrees below C long life, 2000 degrees below C finite life and 2800 degrees below C instantaneous life requirements [2], also meet the needs of thermal - structure integration design. It has a wide application prospect in high temperature thermal structure materials, such as aeronautics and Astronautics [3~6].

At present, ceramic matrix composites and their processing and manufacturing technologies have been relatively mature in the developed countries such as the US, Britain, France and Germany, and have been widely applied, and are gradually moving towards industrial scale.

At present, the material properties of C/SiC composites are quite different from different development units. Therefore, the development of C/SiC composites processing technology is slower. This is particularly prominent in China, which greatly restricts the development of related technologies in China.

Because of the high hardness of C/SiC composites, the machining methods of grinding and ultrasonic assisted grinding are generally used to process holes, grooves and surfaces.

Most universities in China mostly focus on carbon fiber, ceramics, and phenolic resin and so on. There are few reports on the processing mechanism and material removal characteristics of C/SiC composites.

In this paper, through the single factor experimental study of cutting force of C/SiC composite ultrasonic vibration milling, the influence rule of processing parameters on cutting force is explored, which lays a theoretical foundation for the engineering application of the composite material.

2. Test Conditions

2.1. Test Material
C/SiC material is composed of preform braiding, interface layer deposition, machining / substrate deposition, coating treatment and so on [7].
The structure of preform is the structure of carbon / net tyres. It is a layer of tire net with a layer of carbon cloth, two layers of adjacent carbon net tire composite layer ply angle is 0 degrees and 90 degrees, the two layer is a cycle, it adopts relay acupuncture technique in perpendicular to the direction of the introduction of carbon fiber bundle layers. The density is 1.9486 g/cm³ and the volume fraction is about 45%. The mechanical properties of the material are shown in Table 1. The specimen is a rectangular body with a geometric size of 20mm × 110mm ×8mm.

### Table 1. Mechanical Properties of materials

| Material parameters                     | C/SiC Compound material |
|-----------------------------------------|-------------------------|
| Density (g/cm³)                         | 1.9486                  |
| Tensile strength (MPa)                  | 180                     |
| Interlaminar shear strength (MPa)       | 33                      |
| In-plane shear strength (MPa)           | 66.6                    |
| C fiber volume fraction                 | 40%–50%                 |

#### 2.2. Test Equipment and Tools

The cutting test is carried out on the ULTRASONIC 50 machine tool. By controlling the start of the ultrasonic system, the comparison test of the rotary ultrasonic vibration and the ordinary milling machining is carried out. The machine has an accurate linear driving mode, a feed resolution of 1μm, a maximum ultrasonic machining speed of 8000rpm, a maximum general machining speed of 10000rpm, an amplitude of 6μm -7μm, and a frequency of $f= 17.500$Hz.

(2) Test Tool

Electroplated diamond grinding wheel is selected for the experimental tool. The diameter of the grinding wheel is 5mm and the size of the grinding wheel is 126 mesh.

(3) Process Conditions

This test uses surface milling processing, it uses Ruibeide cooling liquid, the cooling liquid concentration was 10%.

#### 2.3. Cutting Force Measuring System

The measuring system of cutting force is generally composed of three parts: dynamometer, data acquisition system and computer. The dynamometer is fixed on the worktable of the machine tool and is responsible for picking up the cutting force signal and turning the cutting force signal into the weak electric signal. The data acquisition system is responsible for the acquisition and processing of the weak electric signal and transforming it into the available digital signal; The computer displays the cutting force signal through a specific software platform and analyzes the signal. The measurement system is shown in Figure 1.

![Figure 1. Cutting force measurement system](image-url)
3. Test Scheme and Results

3.1. A single Factor Test Scheme for Cutting Force
Compared with conventional metal materials, C/SiC material has the characteristics of hard and brittle, which is a difficult material to be machined. The factors that affect the cutting force are mainly the cutting depth, the rotating speed and the cutting speed. Because there are not many scientific research units that study the processing characteristics of C/SiC materials at home and abroad, and the processing parameters that can be used for reference are few. Therefore, the research carried out in this chapter is mainly an exploratory experiment on the processing methods and processing characteristics of C/SiC materials. The selected cutting parameters are relatively conservative. The milling depth $a_p$ selects 0.005mm, 0.010mm, 0.015mm and 0.020mm, and the Spindle speed $n$ select 2000r/min, 4000r/min, 6000r/min, 8000r/min. The feed speed $V_f$ is 2 mm/min, 5 mm/min, 8 mm/min, 11 mm/min.

The cutting force comparison test takes feed speed, cutting depth and spindle speed as the factors. The influence of these factors on cutting force is studied respectively, and the influence rule of each factor is obtained. At the same time, the cutting force of rotating ultrasonic vibration milling and ordinary milling is compared, and the cutting efficiency of both of them is analyzed.

3.2. Typical Cutting Force Curve
In the milling process, the regularity of changes of cutting force $F_x$, $F_y$, $F_z$ and $M_x$, $M_z$ of torque with time $t$ is shown in Figure 2, milling grinding head began to cut into the sample after cutting force increases from zero, When the cutting edge of the whole diameter of the milling head is all involved in the cutting, The cutting force is stable in a certain range of wave peak - wave valley law.

This is determined by the preparation process of the material itself. The SiC matrix is surrounded by carbon fibers and contains a small amount of pores. When the tool enters the high content of SiC matrix, the hardness is high and the cutting force is large. When cutting the carbon fiber bundles and pores, the cutting force decreases.

Keep this stable state in the milling head before leaving the material, See Figure 2 as shown in the middle area of the two dotted lines.

After the tool milling sample process, the rigidity of the specimen is reduced to the support of the tool, and the axial force gradually decreases until the tool completely leaves the sample and its value changes to zero. It is found that under two modes of ultrasonic and ordinary milling, this rule is the same under different cutting parameters.

In addition, it is shown that, because the test is surface processing, feed direction cutting force $F_x$, radial direction cutting force $F_y$ and torque of $M_x$, $M_z$ is far less than the axial cutting force $F_z$, so the axial force $F_z$ is the main factor of material removal, surface generation, so focus on the influence of various factors on the axial cutting force, The following cutting force refers to the axial cutting force $F_z$. 
3.3. Single Factor Test Results

3.3.1. The Effect of Cutting Depth on Cutting Force.

The depth of the cutting is the depth of the single grinding in the vertical grinding plane, and the improvement of the grinding depth can greatly improve the grinding efficiency. The changing rule of axial force with the depth of grinding is studied in the two processing modes of ultrasonic vibration milling and grinding, and the grinding depth is changed under the same processing parameters. The specific processing parameters are shown in Table 2.

Table 2. The machining parameters of the cutting force vary with the cutting depth

| n(r/min) | a_p (mm) | V_f (mm/min) | Ultrasonic vibration F_z (N) | Ordinary milling mill F_z (N) |
|---------|----------|--------------|----------------------------|------------------------------|
| 5000    | 0.005    | 10           | 3.59                       | 7.67                         |
| 5000    | 0.01     | 10           | 6.57                       | 12.92                        |
| 5000    | 0.015    | 10           | 10.04                      | 15.78                        |
| 5000    | 0.020    | 10           | 10.88                      | 16.08                        |

The effect of cutting depth on the axial force Fz is shown in Figure 3.

![Figure 3. The curve of the cutting force changing with the depth of the cutting](image)

From Figure 3, we can see that under the same cutting depth, the cutting force of rotary ultrasonic vibration milling is smaller than that of common milling, and the cutting force is reduced by 30% to
50%, which indicates that ultrasonic vibration milling can greatly reduce the cutting force. At the same time, with the increase of cutting depth, the cutting force of rotary ultrasonic vibration milling and ordinary milling is obviously increasing. Main cause:

1) In the process of rotary ultrasonic milling, the tool is added to the hammer on the surface of the workpiece, the surface contact of the tool and the workpiece has periodic separability, so compared to ordinary milling processing, the impact between the workpiece and the grinding zone tool grinding particles is increased, the impact forces the machining surface to form a large number of micro-breakages. It is beneficial to crack propagation and material removal, so the ultrasonic vibration can greatly reduce the cutting force.

2) With the increase of cutting depth, the number of abrasive grains involved in the machining of diamond grinding wheel in the same time increases, which leads to the increase of cutting force. In addition, the maximum cutting thickness of single abrasive particles also increases, resulting in an increase in the cutting force of a single abrasive grain, thus increasing the total cutting force.

It can be seen that in the range that the machine tool can bear, rotary ultrasonic vibration milling can be processed with larger cutting depth, which can effectively improve the machining efficiency. At the same time, in the same cutting depth, the cutting force of ultrasonic vibration is far less than that of the ordinary milling. It can improve the stability of the machining.

3.3.2. The influence of feed speed on cutting force. The feed speed is the speed of the electroplated diamond grinding wheel moving in the direction of feed after the cutting depth and the spindle speed are set. In the experiment, the same spindle speed and cutting depth were given to study the cutting force variation of rotary ultrasonic vibration milling and conventional milling at different feed speeds. The specific test parameters and test results are shown in Table 3.

From Figure 4, we can see that under the same technological conditions, the cutting force of rotary ultrasonic vibration milling is smaller than that of common milling, and the magnitude of reduction is 50%, which means that rotary ultrasonic vibration machining can reduce cutting force and improve processing stability. In addition, the cutting force increases with the increase of feed speed in two kinds of machining methods of rotating ultrasonic vibration milling and milling and ordinary milling. This is mainly because with the increase of feed speed, more material is grind in per unit time, resulting in grinding and plowing pear, which leads to the increase of cutting force.

| $n$ (r/min) | $a_p$ (mm) | $V_f$ (mm/min) | Ultrasonic vibration $F_z$ (N) | Ordinary milling $F_z$ (N) |
|-------------|------------|----------------|-------------------------------|---------------------------|
| 5000        | 0.01       | 2              | 2.46                          | 5.53                      |
| 5000        | 0.01       | 5              | 4.21                          | 10.03                     |
| 5000        | 0.01       | 8              | 5.39                          | 11.54                     |
| 5000        | 0.01       | 11             | 7.17                          | 14.75                     |

The effect of feed speed on cutting force is shown in Figure 4.
3.3.3. The Influence of Spindle Speed on Cutting Force.

The spindle speed directly determines the grinding speed of the diamond grinding grain on the tool grinding head. The faster the spindle speed is, the more grinding particles are involved in the grinding. The cutting speed and the cutting force along with the change of speed were studied, and the cutting force variation of ultrasonic vibration machining and general grinding was compared. The specific test parameters and test results were shown in Table 4.

| Sample | $F_z$ (N) |
|--------|-----------|
| 2000   | 6.32      |
| 4000   | 6.15      |
| 6000   | 5.68      |
| 8000   | 5.67      |

The influence of the spindle speed on the cutting force is shown in Figure 5.

![Figure 4. The curve of the cutting force changing with the feed speed](image)

![Figure 5. curve diagram of cutting force changing with spindle speed](image)

It can be seen from the diagram that with the increase of the spindle speed, the cutting forces of ordinary grinding and ultrasonic vibration milling are all decreasing. This is because with the increase of spindle speed, feed rate and cutting depth have not changed. The work done by a single abrasive has
not changed significantly, but the cutting track becomes longer, resulting in a reduction of cutting force. Meanwhile, under the same process parameters, the cutting force of ultrasonic vibration machining is much smaller than that of common milling, which means that ultrasonic vibration can improve machining stability and make machining process more stable. Indirectly prolonging the life of the tool and improving the processing efficiency.

4. Conclusion
Through single factor experiment, the effect of single technological parameters on cutting force is obtained. The cutting force increases with the increase of cutting speed and feed speed, and decreases with the increase of spindle speed. By comparing the cutting force between rotary ultrasonic vibration and common milling, the rotary ultrasonic vibration machining can greatly reduce the cutting force and reduce the amplitude to more than 50%.

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