

Experimental Investigating of Rotary Ultrasonic Grinding for Ceramic Edging

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Abstract—In order to reduce the grinding force, cutting heat, grinding wheel abrasion and improve the qualities of the ceramic production, my paper describes the ceramic edge grinding machine spindle with ultrasonic vibration. The order of influencing factors (such as spindle speed, feed speed, grinding amount and ultrasound current) on three directions force and grinding force are sorted, and the reason is analyzed. The paper concludes that feed speed and grinding amount play a major role in the grinding force, while spindle speed and ultrasonic current intensity plays a secondary role.

Keyword—rotary ultrasonic machining; edging; three-direction force; grinding force; ceramic

I. INTRODUCTION

Ultrasonic machining has great advantages in grinding hard and brittle materials, such as low cutting force, low cutting heat, high surface quality of workpieces, easy chip handling and high tool durability^{[1][2][3]}. With the development of materials science, the demand for processing brittle materials has been rapidly increasing in recent decades^{[4][5]}. As a non-traditional machining method, rotary ultrasonic machining (RUM) is more and more used in the field of military, aerospace and high technology materials processing in recent years, such as composite materials, cemented carbide, ceramics and glass. However, the development of equipment of rotary ultrasonic machine in our country is lagging behind, and most of the research about ultrasonic processing technology still stays in the laboratory, has not appeared a market-oriented machine tools nowadays^{[6][7][8]}.

Famous rotary ultrasonic machine such as DMG company's ULTRASONIC 10 with price of about RMB 4.5 million^[9]. It's difficult to find out the ordinary processing machine with a rotary ultrasonic especially in the traditional

ceramic industry both in domestic and foreign. Based on the immature application of rotary ultrasonic processing equipment in ceramic machinery, the Institute of Manufacturing Technology of Guangdong University of Technology designed the ceramic edge grinding machine spindle with ultrasonic assisted vibration^{[10][11]}. By adding a rotating ultrasonic spindle to the existing ceramic production line, the grinding force during the grinding process of the ceramic tile is reduced, the cutting heat is reduced, the abrasion loss of the grinding wheel and the numbers of tile collapse are reduced^[12].

II. EXPERIMENTAL DETAIL

A. Experimental Setup and Cutting Force Measurement

The system of RUM ceramic edging grinding consists of three parts including motion control system, ultrasonic vibration system and data acquisition system. The experimental setup was shown in Figure 1. Among them, the ultrasonic power supply is a circuit that converts low frequency mains (50Hz) into high frequency AC signal (20KHz) that matches the ultrasonic transducer. The ultrasonic power supplies the ultrasonic transducer through a brush set inside the spindle. Receiving the signal, the transducer transforms electrical signals into high-frequency mechanical vibration, amplified by the booster and transmitted to the edge grinding wheel. Input motion control parameters into the PLC touch screen, we can control the spindle speed, grinding amount and feed rate by controlling the three-phase AC motor or the stepper motors. In order to get the best processing parameters, install the Kistler 9257B dynamometer under the fixture. Through amplify and convert the dynamometer signal, we can collect three-direction force data during processing.

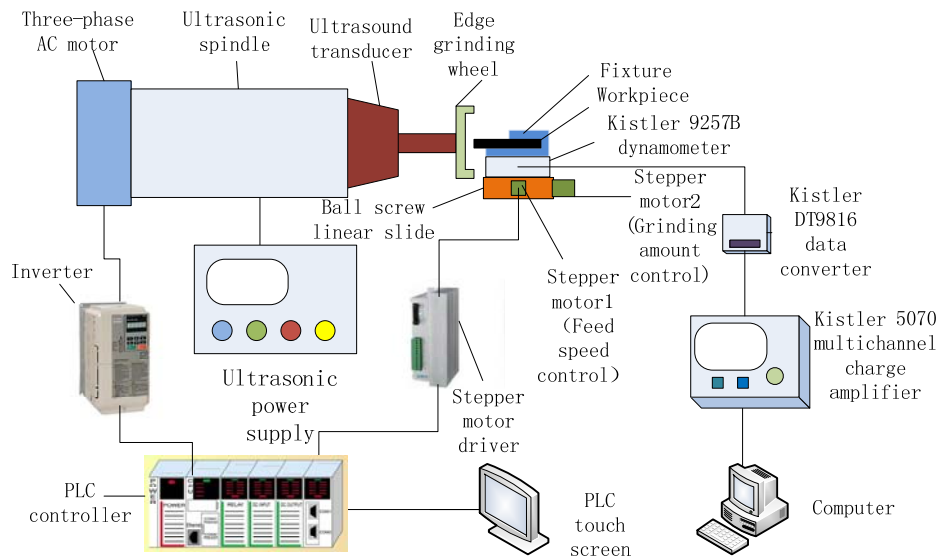


FIGURE I. SYSTEM OF RUM CERAMIC EDGING GRINDING

B. Workpiece Material Properties

The ceramic workpiece used in this experiment had the size of 300 mm × 300 mm × 7.8 mm. Properties of ceramic workpiece material are listed in Table 1.

TABLE I. PROPERTIES OF CERAMIC WORKPIECE MATERIAL

	Water absorption	Destruction strength	Rupture modulus
standard requirement	6%<E≤10%	≥800N	≥18MPa
test result	6.9%	815.5N	24.1MPa

C. Experimental Conditions

Several assumptions about RUM ceramic edging grinding include the following:

1. The material is removed by brittle fracture.
2. During the experiment, edging wheel maintain the same sharpness.
3. The ultrasonic vibration during the machining process is stable (frequency and amplitude remain unchanged) and current intensity is linear with ultrasonic amplitude.

III. ORTHOGONAL EXPERIMENT

In the tile processing, the size and direction of the force is one of the important factors that directly affect the quality of the workpiece surface and edge grinding wheel wear. In orthogonal experiments, summarize the effects of four machining variables that spindle speed, feed speed, grinding amount and ultrasonic current intensity on the grinding forces during the tile edging. The grinding force is calculated from three directions force using Equation 1.

$$F_{\text{Grinding}} = \sqrt{F_{\text{Feed}}^2 + F_{\text{Axial}}^2 + F_{\text{Radial}}^2} \quad (1)$$

As a total of four factors in this experiment, we use $L_9 (3^4)$ orthogonal table design the test. The factors and levels of orthogonal experimental design are shown in Table 2. The experimental parameters of each group are shown in Table 3.

TABLE II. FACTORS AND LEVELS OF ORTHOGONAL EXPERIMENTAL DESIGN

Level	Factor			
	Spindle speed (rpm)	Feed speed (mm/s)	Grinding amount (mm)	Ultrasound current (A)
1	900	10	0.1	0.4
2	1500	20	0.2	1.0
3	2100	30	0.3	1.6

TABLE III. GRINDING EXPERIMENT ORTHOGONAL TEST DESIGN

Experiment	Factor			
	Spindle speed (rpm)	Feed speed (mm/s)	Grinding amount (mm)	Ultrasound current (A)
1	900	10	0.1	0.4
2	900	20	0.2	1.0
3	900	30	0.3	1.6
4	1500	10	0.2	1.6
5	1500	20	0.3	0.4
6	1500	30	0.1	1.0
7	2100	10	0.3	1.0
8	2100	20	0.1	1.6
9	2100	30	0.2	0.4

After 4 repeated experiments, exported the force data into Excel during processing. First of all, take the data as absolute value and then averaged the result to obtain the size of three directions force. The average result of each direction and calculated grinding force value are shown in Table 4.

TABLE IV. ORTHOGONAL TEST RESULTS

Experiment	Factor				Result			
	Spindle speed (rpm)	Feed speed (mm/s)	Grinding amount (mm)	Ultrasound current (A)	Feed direction force (N)	Axial force (N)	Radial force (N)	Grinding force (N)
1	1	1	1	1	12.49	34.46	12.63	43.17
2	1	2	2	2	15.73	42.48	12.87	51.00
3	1	3	3	3	28.72	88.21	18.10	98.28
4	2	1	2	3	16.43	38.53	14.10	49.39
5	2	2	3	1	22.58	58.95	14.93	70.04
6	2	3	1	2	19.06	58.60	12.65	66.53
7	3	1	3	2	19.32	33.73	19.18	49.17
8	3	2	1	3	17.19	33.95	18.02	47.47
9	3	3	2	1	23.85	48.63	18.91	63.27

According to the result in table 4, we can calculate the range analysis of three directions force and grinding force as shown in table 5 to 8. The greater of range's number, the greater effect of this factor on the experimental index.

TABLE V. RANGE ANALYSIS OF FEED DIRECTION FORCE

	Spindle speed (rpm)	Feed speed (mm/s)	Grinding amount (mm)	Ultrasound current (A)
Mean 1	18.980	16.080	16.247	19.640
Mean 2	19.357	18.500	18.670	18.037
Mean 3	20.120	23.877	23.540	20.780
Range	1.140	7.797	7.293	2.743

TABLE VI. RANGE ANALYSIS OF AXIAL FORCE

	Spindle speed (rpm)	Feed speed (mm/s)	Grinding amount (mm)	Ultrasound current (A)
Mean 1	55.050	35.573	42.337	47.347
Mean 2	52.027	45.127	43.213	44.937
Mean 3	38.770	65.147	60.297	53.563
Range	16.280	29.574	17.960	8.626

TABLE VII. RANGE ANALYSIS OF RADIAL FORCE

	Spindle speed (rpm)	Feed speed (mm/s)	Grinding amount (mm)	Ultrasound current (A)
Mean 1	14.533	15.303	14.433	15.490
Mean 2	13.893	15.273	15.293	14.900
Mean 3	18.703	16.553	17.403	16.740
Range	4.810	1.280	2.970	1.840

TABLE VIII. RANGE ANALYSIS OF GRINDING FORCE

	Spindle speed (rpm)	Feed speed (mm/s)	Grinding amount (mm)	Ultrasound current (A)
Mean 1	64.150	47.243	52.390	58.827
Mean 2	61.987	56.170	54.553	55.567
Mean 3	53.303	76.027	72.497	65.047
Range	10.847	28.784	20.107	9.480

Therefore, it can be concluded from table 5 that the influencing factors on the feed direction force in the order of feed speed, grinding amount, ultrasonic current and spindle speed. Due to the direction of feed speed and feed direction force in the same line, it is obvious that the results in line with

the actual processing conditions.

It also can be concluded from table 6 that the influence of axial force in the order of feed speed, grinding capacity, spindle speed and ultrasonic current. It can be seen from the above sequence that among the factors that affect the feed direction force and the axial force, the feed speed and the grinding amount play a major role, while the spindle speed and the ultrasonic current intensity have a secondary influence.

The order of influence on the radial force is the spindle speed, grinding amount, ultrasonic current and feed rate. When the spindle rotates, the force generated by the edging wheel removing the edge material of the ceramic tile is collinear with the radial force, so the spindle speed has a major influence on the radial force.

Calculate the grinding force through the formula 1, the order of the influence of the grinding force is the feed speed, grinding amount, spindle speed and ultrasonic current. Obvious, the factors affect the size of grinding force are the same as the order of axial force. Because the two sizes of feed direction force and radial force have the same magnitude and the magnitude of axial force is 2 to 3 times the feed direction force. Therefore, the size of the axial force plays a major role on the size of the grinding force. Based on the result, we should ensure strength of axial direction when we design the spindle with ultrasonic.

IV. CONCLUSIONS

The explore about rotary ultrasonic machining of composites or cemented carbide used a smaller feed speed and grinding amount to ensure the effectiveness of ultrasonic vibration in the past. This study innovatively applied rotary ultrasonic processing in the occasion of large feed speed and grinding amount, using in the ceramic edging production line. Some main conclusions were drawn as follows:

1. The size of the axial force has the greatest impact of grinding force in the three-direction force. In the design of the mechanism, it is necessary to ensure the axial rigidity and reduce the axial force with the help of ultrasonic vibration.

2. Feed speed and grinding amount play a major role in the grinding force, while spindle speed and ultrasonic current intensity plays a secondary role.

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