Experimental study on Multi-material composite surface polishing by Abrasive Water Jet

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ABSTRACT

Abrasive water jet processing technology is a processing method developed in recent decades using high-energy beams, which is suitable to removal and processing different materials, because its processing process has its own cooling effect and has incomparable advantages in other processing methods. Process studies involving multiple materials in the same area have not been reported. In this paper, the influence of abrasive water jet processing technology parameters on the removal rate of different materials in a small area is studied experimentally, and the removal rate of high-purity quartz glass, doped quartz glass and epoxy resin adhesive layer is tested by single factor and orthogonal test method. Experiments show that within a certain range of process parameters, jet pressure, nozzle diameter and nozzle height have obvious effects on the removal rate, while abrasive particle size have the lowest impact. Experiments are used to derive optimal process parameters for simultaneous removal of different materials.

Keywords: Abrasive water jet, multi-material composite surface, roughness, orthogonal test method, removal rate.

1. INTRODUCTION

Jet polishing technology is a new processing technology developed in recent years, compared with the traditional contact processing method, the technology belongs to the non-contact form, similar to the ion beam polishing method, and has the characteristics of high processing accuracy and no subsurface damage[1]. However, compared with the ion beam processing method, it also has a significant feature, no thermal stress, and avoids the influence of thermal expansion and contraction on the processed parts during processing. It is especially suitable for the processing of optical components that are sensitive to thermal effects and have high steepness. The processing principle is to spray the suspension liquid mixed with polishing powder particles at a certain pressure in a small-diameter nozzle, flow and spread out after colliding with the workpiece, and realize the microscopic removal of the surface material of the workpiece with instantaneous strong shear force and impact force. Theoretical research believes that when jet abrasive particles erode the surface of the workpiece, the contact process with the workpiece can be divided into several stages such as elastic slippage, ploughing and micro-cutting, but affected by

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the particle size, the removal of the material is also very weak, and it is generally believed that the mirror surface can reach sub-nanometer damage to obtain an ultra-smooth surface[2].

However, the application of abrasive jet polishing technology also has great limitations, currently only limited to the processing of the same material at a time, limited by the immature research on jet erosion mechanism, so that the application of abrasive processing is restricted. The research of domestic and foreign scholars on jet polishing mainly focuses on the experiment and simulation of a single material. Oliver W Fahnle[3] et al. of the early Dutch University first used jet technology to obtain an ultra-smooth surface with a surface roughness of 1.6nm on the surface of BK7 glass for complex optical surfaces, indicating that it is feasible for ultra-smooth surface processing. Fang Hui[4] et al. of Soochow University in China carried out finite element simulation of the jet mechanism, and studied the influence of various process parameters on the removal amount of material based on experiments, and believed that the radial shear force generated by the radial flow of abrasive particles in the polishing liquid on the workpiece was the key to material removal, and the influence of injection angle, injection pressure, spray distance and spray time on material removal was obtained. Hou Rongguo, Cao Mingming and others of Shandong University of Technology took blade profile polishing as an example to study the implementation method of jet polishing of complex surfaces and cavity surfaces, and realized the precision control of curved motion trajectory through the optimization and improvement of software and hardware[5]. Chen Fengjun et al. of Hunan University studied the profiling nozzle in view of the limited polishing of the microstructure array, combined with the characteristics of jet adaptability, and obtained the side wall and bottom wall surface of the groove with better processing quality by optimizing the nozzle type and process parameters [6]. Therefore, based on abrasive waterjet polishing, this paper mainly analyzes the polishing method of abrasive waterjet pressure, nozzle size and working distance on the composite surface of abrasive jet processing of a variety of materials, solves the problem that the surface of composite structure is difficult to process uniformly, and studies the influence of process parameters on composite surface polishing through experiments.

2. ABRASIVE WATER JET PROCESSING PRINCIPLE

Figure 1 is a schematic diagram of abrasive waterjet processing, and the jet processing process is: the pre-mixed abrasive solution is added in the jet tank, the motor is fully stirred, and the pump is added by the conduit, and after pressurization, it enters the nozzle along the conduit and is shot out to the surface to be processed. The moment the research liquid ejected by the nozzle contacts the workpiece, part of its kinetic energy is dissipated in the form of internal energy, elastic waves, etc., and the other part of the abrasive particles continuously hit the surface of the workpiece to achieve a trace removal of the material. Abrasive waterjet polishing materials belong to a fluid-structure interaction process, and the motion of abrasive particles can be described by Newton's second law and the Hertzian equation, and the expression of the abrasive impact depth z is

$$z = \left[\frac{9}{16}\frac{F^2}{R}\left(\frac{1-\nu_1^2}{E_1}+\frac{1-\nu_2^2}{E_2}\right)^2\right]^{1/3} \quad (1)$$

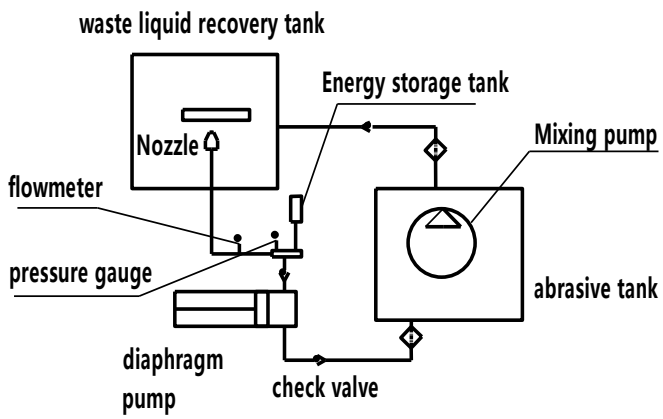

Figure 1. Schematic diagram of abrasive waterjet processing

where E1 is the elastic modulus of the abrasive; E2 is the elastic modulus of the workpiece; υ1 is the Poisson's ratio of the abrasive, and υ2 is the Poisson's ratio of the workpiece, both constants.

The equation of motion of a single abrasive

$$mvdv = -Fv_y \tag{2}$$

It can be obtained that the general abrasive jet single-particle abrasive impact wear removal volume is

$$V_{single} = \frac{1}{3}\pi M^2 R^2 (v sin\theta)^{8/5}\left(3 - R^{-1/2}(v sin\theta)^{4/5}\right) \tag{3}$$

where R is the abrasive radius and M is the constant related to properties such as material density.

3. SURFACE TEST ANALYSIS OF ABRASIVE WATERJET RESEARCH AND POLISHING COMPOSITES

This experiment is carried out on a self-developed pre-mixed abrasive research and polishing processing system, and the actual equipment is shown in Figure 2.

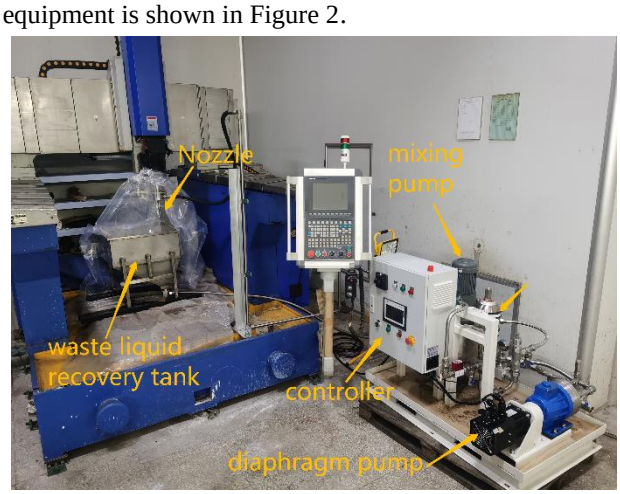

Figure 2. Jet research and ejection experimental device

The workpiece material used in the experiment is flat quartz glass cemented with quartz fiber pipe, the polishing liquid is mixed with cerium oxide and water according to the mass ratio of 1:50, the nozzle is a cylindrical shape with a length of 50mm, in which the nozzle is a conical nozzle processed by ruby, and the workpiece is fixed.

In this study, scientific statistical analysis methods and orthogonal test methods were used to analyze the role of various parameters in the process of research and polishing composite substrates and the order of factors. In order to scientifically analyze the effective results and reduce the number of tests as much as possible, the test uses orthogonal table L_9 (3^4) to arrange the test, and the nozzle and the workpiece to be thrown are perpendicular in each group of tests. The parameters and levels involved in the orthogonal test are shown in Table 1.

After the parameter level is determined, the target results of the experiment should be clarified and used as the indicators for analysis. When abrasive jets are compounded, the measurement of the removal rate of different materials is cumbersome. From the perspective of ease of measurement, the roughness of the end face of doped fiber glass is proposed as the criterion. The specific experimental results are shown in Table 2.

Table 1. Test level and factors

Level	**A (jet pressure)/MPa**	**B (nozzle diameter) /mm**	**C (working distance)/mm**
1	0.5	0.4	30
2	0.8	0.6	50
3	1.2	0.8	70

Table 2. Orthogonal test results and analysis

Number	**A**	**B**	**C**	**roughness (nm)**
1	0.5	0.4	30	1.1
2	0.5	0.6	50	2.65
3	0.5	0.8	70	1.33
4	0.8	0.4	50	2.68
5	0.8	0.6	70	3.1
6	0.8	0.8	30	6.3
7	1.2	0.4	70	2.8
8	1.2	0.6	30	1.9
9	1.2	0.8	50	2.4

4. RESULTS AND DISCUSSION

The results of the orthogonal test are listed in Table 3. According to the orthogonal test analysis method, the influence of various factors on the test index was analyzed. It can be seen from Table 4 that the roughness PA, roughness value and ZA and its average KA of multi-material composite surfaces when the A factor (jet pressure) is taken at level 1 (0.5MPa):

$$Z_{A1} = P_{A1} + P_{A2} + P_{A3} = 1.1 + 2.65 + 1.33 = 5.08$$

$$K_{A1} = Z_{A1}/3 = 1.69$$

Similarly, when the jet pressure is 0.8MPa and 1.2MPa, the roughness is:

$$K_{A2} = 4.03, \quad K_{A3} = 2.37$$

The calculation data for each factor is presented in Table 4, and the influence of each factor on the test results is analyzed. The range value SA for factor A (jet pressure) is:

$$S_A = K_{A\_max} - K_{A\_min} = 4.03 - 1.69 = 2.34$$

Similarly, the range value SB of factor B and the range value SC of factor C can be found.

Table 3. Orthogonal test results of multi-material composite surface polishing by water jet

Number	roughness（nm）
1	1.1
2	2.65
3	1.33
4	2.68
5	3.1
6	6.3
7	2.8
8	1.9
9	2.4

As can be seen from Table 4, the range size comparison for multiple factors is S_A>S_B>S_C. According to the range analysis method of orthogonal tests, the larger the range value of the factor, the more important the influence of this factor on the test results. Therefore, it can be concluded that the jet pressure has the lowest effect on the roughness value, followed by nozzle size, and the least influence is the working distance.

Table 4. Surface roughness analysis of multi-material composite layer by jet research and throwing

Level	**A**	**B**	**C**
I	5.08	6.58	9.3
II	12.09	7.65	7.73
III	7.11	10.03	7.23
K_1	1.69	2.19	3.1
K_2	4.03	2.55	2.58
K_3	2.37	3.34	2.41
S	2.34	1.15	0.69

5. CONFIRMATORY EXPERIMENTS

According to the comparative analysis of orthogonal test results, it can be concluded that the experimental combination with the lowest roughness value of jet polished multi-material composite surface is A1B1C3, and the roughness of the preferred scheme for multi-material composite surface is measured on 4D Nanocam Sq, and the microscopic morphology in a large area is observed with a high-magnification microscope. This is shown in Figure 4 and Figure 5.

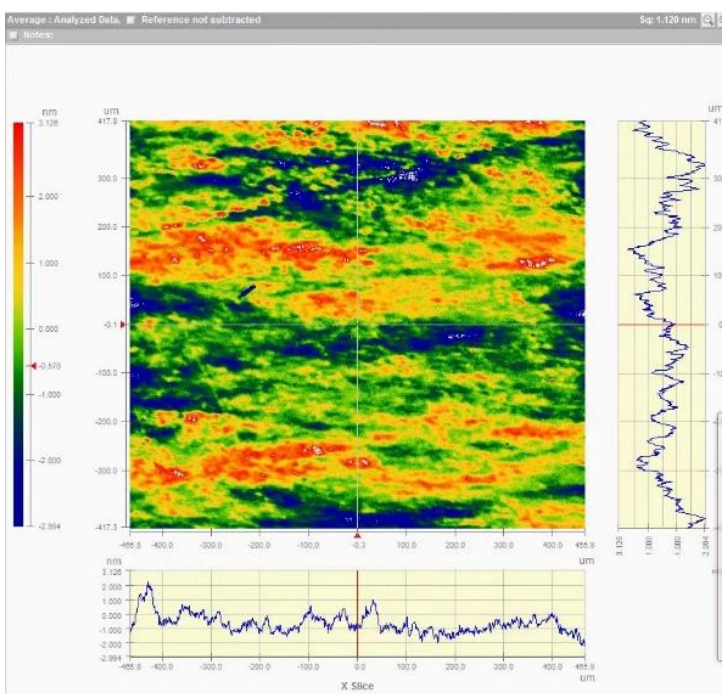

Figure 4. roughness

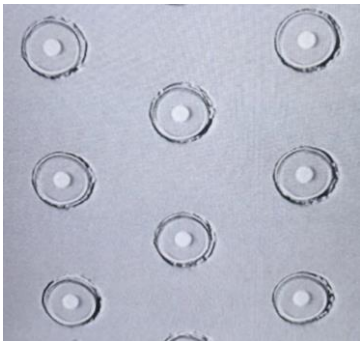

Figure 5. High-magnification microscopic photograph

6. CONCLUSION

(1) Through the orthogonal test method, the influence trend of three factors of jet pressure, nozzle size and working distance on the multi-material composite surface of jet research and polishing was analyzed, and it was concluded that the spray pressure had the greatest influence in the process of research and polishing, followed by nozzle size and the least influence of working distance, and the optimal combination of research and polishing parameters was given as $A_1B_1C_3$.

(2) The reason why the injection pressure has the greatest influence on the polishing effect is that this method is different from other processing methods, mainly relying on the erosion of the abrasive on the surface of the material to obtain the removal of the material, so the pressure dominates here. However, due to the grinding and polishing of the composite layer, which has to meet the requirements of different materials for removal, excessive pressure will lead to a large amount of removal of the softer adhesive layer, resulting in poor surface roughness.

(3) The size of the nozzle mainly affects the size of the removal area, and the effect on roughness is less than the injection pressure. The reason for the least influence of working distance is that the jet beam is relatively stable within a certain distance from the nozzle, and this distance is exactly within the range of this experiment, so the impact is minimal compared to the previous two. After the working distance exceeds the range of the jet beam divergence, the effect on roughness will be significantly higher than the first two.

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