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An Experimental Study: Effect of Technological Parameters on Cutting Force in Processing Hetian Jade by Ultrasonic Grinding

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Abstract
Jade is hard to be processed into jewelry, and it is even more difficult for the Hetian jade that produced in Xinjiang, China. In a conventional processing technology, the cutting force can hardly be controlled precisely, which would result in a low level of product quality. With taking into account of Hetian jade's characteristics, the ultrasonic vibration grinding, a processing method, is used in our experimental study in this article, in which, the effect of different processing parameters on cutting force has been controlled. Experimental results show that changes of

the cutting force are significantly related to both size and number of the diamond grits during grinding the jade. The cutting force increases when the number of the grits becomes larger, while ultrasonic amplitude shows a slight effect on the force. When ultrasonic amplitude increases, the force doesn't change significantly. The action on the jade surface becomes strong when the cutting force is too large, giving rise to micro-cracks. As can be concluded from the comparison between processing efficiency and processing quality, the optimum parameters of the ultrasonic vibration processing method are: the number of diamond grits m=350; the radius of diamond r=0.05, and; amplitude A=0.035.

Keywords: HETIAN JADE, ULTRASONIC GRINDING, MECHANICAL MODEL, CUTTING FORCE

1. Introduction

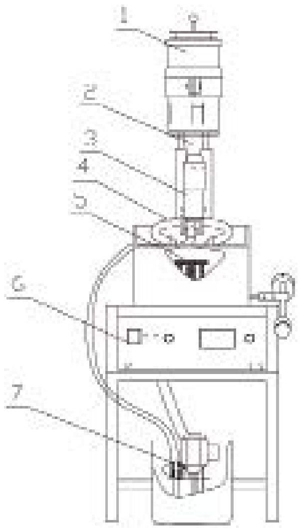
Jade has always been an intractable stone. conventional processing technologies now cannot meet people's increasing demand for gemstones. It has been proven that the high artistic and commercial values of jades can only be maximized with ingenious ideas as well as exquisite carving[1]. Hetian jade, produced in Xinjinag, China, consists of a matrix of tremolite mineral particles that form a tightly compact block structure with fine and soft texture. Hetian jade exists mainly as felt-shaped crystalloblast and, with a less reserve, as radially-patterned crystalloblast and fibrous column-shaped crystalloblast. Its Mohs hardness is 6.5-6.9, and its tenacity (also called as grinding hardness) is so high that can reach 9 if[2] measured by the Mohs hardness. The tenacity of Hetian jade, however, is largely different from the concept of metal toughness in physics. The jade has a strong ability to resist abrasion, stretching and pressing, which increases the carving difficulty. conventional processing methods can also cause internal cracks that affect the quality. In jade processing industry, the method of ultrasonic vibration grinding has enjoyed a wide application for its relatively high efficiency in processing gemstones. Though the breakage ratio has been lowered greatly, the effect of optimum technological parameters on cutting force during processing remains to be figured out. Either too large or too small cutting force has influence on both internal and surface quality of the jade, which makes it.

By now, few studies on processing of Hetian jade have been reported. Liao Jie'an conducted an experimental study on the technology of drilling deep and tiny holes through Hetian jade and analyzed factors that had impact on the drilling force[3]. However, very few studies on technological parameters of ultrasonic vibration grinding for processing Hetian jade have been carried out. The mechanism of diamond grinding under ultrasonic vibration is sill unclear. In the light of previous achievements about the ultrasonic vibration-based processing technologies, Qin Na investigated the changes of cutting force when rotary ultrasonic was used to grinding holes through ceramic materials. She obtained the optimum parameters from a multi-factor experiment, in which, vibration amplitude, spindle speed and feeding velocity had been taken into consideration. These parameters were also used to build a cutting force model[4-5]. Yan Meng made a theoretical analysis on and a simulation to brittle materials processed by ultrasonic vibration, and built a drilling model for such case[6]. Xiaoxiao Ling et al. introduced the ultrasonic vibration into a magnetic grinding process, which raised the grinding efficiency as the cutting force of the grinding particles became strong[7]. The above mentioned methods have been applied for many difficult-to-cut materials, and, therefore, can be used for reference to improve conventional jade processing methods by introducing ultrasonic vibration for grinding Hetian jade.

According to Hetian jade's characteristics and based on conventional grinding processes, the ultrasonic vibration cutting technology has been employed in the current article to make an experimental study. Under the ultrasonic energy field, this technology applies a sinusoidal vibration to diamond grits on the surface of a piece of Hetian jade, so as to find out the optimum technological parameters by increasing the pressure on the jade as well as by measuring the cutting forces under different parameters.

2. The mechanical model of Hetian jade ultrasonic grinding engraving machine

Fig. 1 shows for ultrasonic grinding engraving machine. By using the principle of ultrasonic vibration, this machine can load the ultrasonic energy, after being amplified, onto an amplitude transformer bar. The engraving head is mounted at the bottom of the bar is driven together with the diamond grits to grind the fixed jade specimen. In working mode, the ultrasonic generator (6) is turned on, which transmits the ultrasonic to the amplitude transformer bar (2) via the amplifier (1), and the engraving head (3) on the surface of jade specimen (5) is driven to vibrate at a high frequency. Under the ultrasonic energy, at the meantime, the prepared liquid mixture of diamond grits is pumped (7) through the spray pipe (4) to strike the surface of the specimen at a very high speed, so as to form the shape or holes of the jade. This is the whole process of engraving jade by ultrasonic.



1. amplifier 2. amplitude transformer bar 3. engraving head 4. spray pipe 5. surface of jade specimen 6. Ultrasonic generator 7. Pumps

Figure 1. The ultrasonic grinding engraving machine

According to the principle of ultrasonic vibration machining[8-9], a single diamond grits on the mechanical model of jade as shown in figure 2. The r for the diamond grits radius, the δ for the indentation depth.

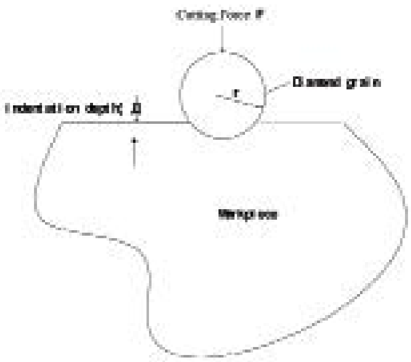


Figure 2. The mechanical model of diamond grits

Assuming a single diamond grits of jade artifacts for Fd, the impulse I in a cycle of diamond grits jade can be obtained by formula (1).

$$I = \int_{cycle} F_d dt \qquad (1)$$

According to the principle of ultrasonic vibration machining[10], diamond grits of engraving head face is under the action of ultrasonic vibration energy, Diamond grits of sinusoidal motion on the tool, in a W vibration amplitude and vibration frequency F, the trajectory equation can be expressed as:

$$Z = A * \sin(2\pi ft) \qquad (2)$$

In the formula (2), A is ultrasonic vibration amplitude, f for ultrasonic vibration frequency. Within A sine period T, when the maximum of diamond grits from vibration Z = A, movement to the vibration of the minimum Z = A - for the time needed for delta T / 2, T can be obtained by formula(3).

$$T = \frac{1}{\pi f} * [\frac{\pi}{2} - \arcsin(1 - \frac{\delta}{A}) \qquad (3)$$

Based on the relation between the impulse and the cutting force F I = F/F, the introduction of the maximum contact stress Fc (related to the intensity of the jade material), simultaneous formula (1), (2), (3), engraving head end surface can be obtained between tool and work cutting force F.

$$F = F_c \frac{1}{\pi} * [\frac{\pi}{2} - \arcsin(1 - \frac{\delta}{A}) \qquad (4)$$

$$F_c = m * \sigma_y * \pi * \delta(2r - \delta) \qquad (5)$$

$$F = m * \sigma_y * \delta(2r - \delta)[\frac{\pi}{2} - \arcsin(1 - \frac{\delta}{A}) \qquad (6)$$

In the Formula (6), m is the number of diamond grits, the radius r of diamond grits, the strength coefficient of σy as Hetian jade material, take 180 Mpa. δ for diamond grits on a working period of indentation depth, the parameters of material removal volume w is used to determine whether.

$$w = \frac{\pi d D_i}{2f} \qquad (7)$$

Formula (7), d for grinding feed parameters, be determined by test; Di for engraving head the difference between the outer diameter and inner diameter[11]. Therefore, through the test to determine the d value, can calculate the diamond on the pressure into the depth of the workpiece, thereby cutting force and the F value.

3. Materials and Methods

3.1. Materials

Green Hetian jade originating from Xinjiang, China is used as the material for our experiment. In accordance with grinding requirements, the jade is cut into rectangle samples of the size of 40mm×30mm×10mm (length×width×thickness). Before the experiment, the samples are coded and their surfaces are polished to ensure that these surfaces are same with each other.

3.2. Experimental devices

(1) Jade processing device

The 3030-1 ultrasonic grinding engraving machine with a microcomputer control module (produced by Taidong Limited) is used for experiment, as shown in fig. 1. The machine can automatically adjust its ultrasonic frequency from 0 to 2500HZ.

(2) Mechanical tester

Mechanical tester is mainly used to test the cutting force acting on specimen's surface. The tester for our measurement is the KISTLER piezocrystal dynamometer, a product of American Diamond Tool Inc. Measurement signals, after being treated by an amplifier, are transmitted to a PLC system, where the signals of cutting force are collected and processed.

(3) Electron microscope for observation

Electron microscope scanner used Quantum China 37xb-DM type products. Used the SEM imaging mode, can the processed surface of the hetian jade electron microscopy detection and measurement of Hetian jade surface machining quality.

3.3. Methods

Before starting the experiment, the engraving head shall be mounted in position, and the ultrasonic generator shall be debugged as well, to determine the scope of frequency for ultrasonic processing. During the experiment, a holder is used to fix the jade specimen, under which there is a mechanical testing sensor. Start the pump to drive the circular flow of the suspension liquid of diamond grits on jade specimen. Next, start the ultrasonic generator and press the engraving head onto the specimen, which is then continuously processed by diamond grits under the high-frequency vibration of the engraving head. Each process lasts 10 minutes. After the process is finished, the jade specimen is coded and observed with using an electron mirror.

A single-factor orthogonal experiment for testing the effect of the size of diamond grits, the amplitude of ultrasonic vibration and the number of diamond grits on cutting force, is planned out. Table 1 shows the level of factor for the orthogonal experiment. In the table, interactions between factors are neglected. According to Hetian jade's processing parameters, the orthogonality of L9 (33) is used for the experiment. To raise the accuracy, the F values of the cutting force in each experiment are measured repeatedly (18 times in total) in accordance with the levels. After removing abnormal data, we can calculate the mean F values of the cutting force and obtain nine sets of the test data.

Table 1. The orthogonality of experiment

Factors / level	A number m	B e size r(mm)	C amplitude A(mm)
1	250	0.025	0.015
2	350	0.05	0.025
3	450	0.075	0.035

4. Results and analysis

Changes of the cutting force (F), under the effect of the number of diamond grits (m), the size of the grits (radius r) and the amplitude of ultrasonic vibration (A), are listed in table 2, in which, the value of d, a dimensionless coefficient in the cutting force's mechanical model (6), is determined by table look-up. K is the sum of the test results corresponding to each factor; k is the mean value of the test results corresponding to each factor; and R is the range. Results of the range analysis show suggest that A has the greatest effect on the cutting force, followed by B and C, among which, the effects of A and B are significant. If judged from the maximum cutting force, the optimal level of the number of diamond grits is A2 (350/mm3); the optimal level of the size of diamond grits (radius r) is B3 (0.075), and; the optimal level of the amplitude of ultrasonic vibration is C1 (0.015mm). This indicates that both the number and the size of diamond grits have significant effect on the cutting force. The cutting force becomes larger with increasing the number and the size of diamond grits. The amplitude of ultrasonic vibration does not show a significant effect. When R=3.59, the mean difference for each level is small. According to the experimental results, the average of 0.001403 d, which is a value of d.

Table 2. Under the influence of various factors of test results

factors / level	A m	B r(mm)	C h(mm)	test results F(N)	test results d
1	1	1	1	68.43	0.001409
2	1	2	2	78.28	0.001389
3	1	3	3	84.09	0.001394
4	2	1	2	86.27	0.001411
5	2	2	3	102.30	0.001421
6	2	3	1	117.88	0.001501
7	3	1	3	91.30	0.001399
8	3	2	1	101.28	0.001443
9	3	3	2	112.27	0.001487
K1	230.8	246	287.59		
K2	306.45	281.86	276.84		
K3	304.85	314.24	277.69		
k1	76.93	82	95.86		
k2	102.15	93.95	92.27		
k3	101.62	104.75	92.56		
range R	25.22	22.75	3.59		

5. Analysis on changes of cutting force affected by single factors

Through the range analysis on test results, we have made clear of the major and minor factors that have effect on the cutting force and their optimal levels. In practice, however, cutting force changes in a dynamic process with time. As the processing goes further, the processing volume increases and the grinding tool is consumed. As a matter of fact, therefore, the cutting force keeps increasing. The maximum cutting force doesn't mean that the experimental parameters are optimal. To elaborate this course as well as to find out the combination of the optimum processing parameters, the time-varying cutting force under the action of single factors has been measured after the experiment level parameters being optimized.

5.1. Effect of the size of diamond grits on cutting force

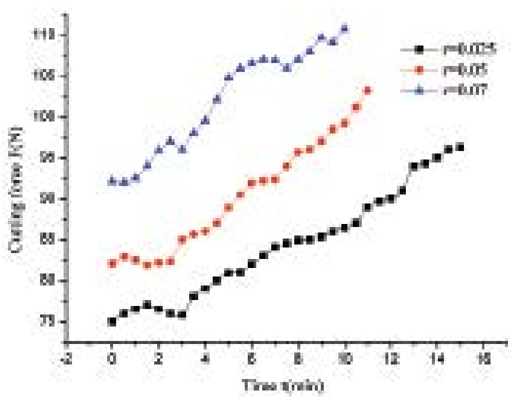
Fig. 3 shows the relation between the size of diamond grits and the cutting force. When the experiment is conducted at the optimum level, say, the number of diamond grits m=300 and the ultrasonic amplitude A=0.015, changes of the cutting force are measured when different sizes (radii) of diamond girts are used during processing the jade specimen. The cutting force increases remarkably with increasing the radius. When the radius is 0.025, the cutting force increases from 75.5N to 95.44N and the time for processing is 15 minutes. When the radius is 0.05, the cutting force is in its most stable state, with the maximum value of 104N. When the radius is 0.075, it increases from 92.5N to 110.06N and the processing time is shortened to be 10 minutes. As can be seen from the changes of the cutting force, the depth pressed by a single diamond grit increases as the radius becomes larger. As a result, more volume of the specimen is cut, which enlarges the cutting force and, therefore, raises the processing efficiency. By the single-factor analysis to the effect of diamond grit size on cutting force we know that the optimum cutting force as well as a better processing efficiency can be realized when the girt radius is r=0.05. With comparison to the range analysis, therefore, the optimum radius of diamond grits is adjusted to r=0.05.

5.2. Effect of the number of diamond grits on cutting force

Fig. 4 shows the relation between the number of diamond grits and the cutting force. When the experiment is conducted at the optimum level, say, the radius of diamond grits r=0.05 and the ultrasonic amplitude A=0.015, changes of the cutting force are measured when different numbers of diamond girts are used during processing the jade specimen. The cutting force increases with increasing the number of diamond grits. When the number is 350/mm3, the cutting force changes evenly from 76N to 108N. In this case, the force is positively related to the number. When the number increases, the volume of the specimen cut by diamond grits under the ultrasonic vibration also increases, namely, the processing efficiency is raised. When the number is overlarge, however, the cutting force increases at a much smaller speed.

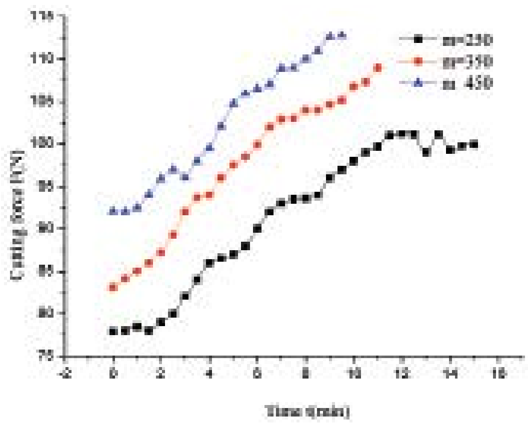
5.3. Effect of ultrasonic amplitude on cutting force

Fig. 5 shows the relation between the ultrasonic amplitude and the cutting force. When the experiment is conducted at the optimum level, say, the number of diamond grits m=300 and the radius of diamond grits r=0.05, changes of the cutting force are measured when different ultrasonic amplitudes are used during processing the jade specimen. The cutting force basically keeps unchanged as the amplitude increases. When the amplitude (A) varies from 0.015 to 0.035 by controlling the ultrasonic frequency, changes of the three cutting force curves are basically the same, indicating that changing the amplitude does not have significant effect on cutting force. In this case, the cutting force is much stable and the difference value during processing is small as well.



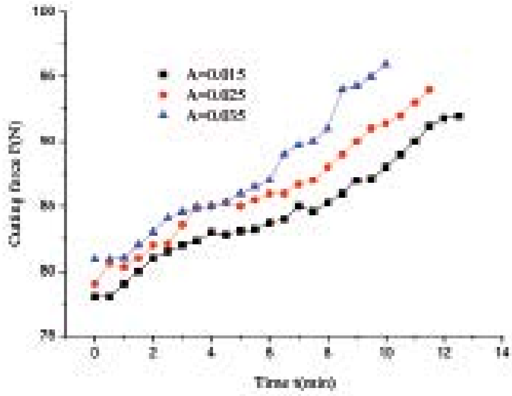
m=300, A=0.015

Figure 3. The relation between the size of diamond grits and the cutting force



r=0.05, A=0.015

Figure 4. the relation between the number of diamond grits and the cutting force



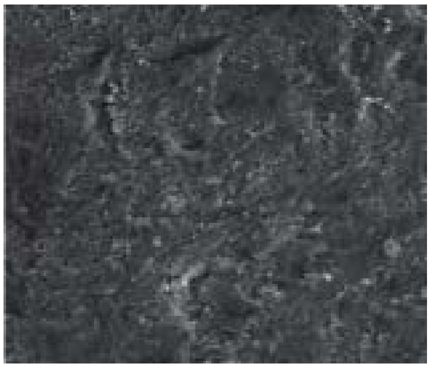
m=350, r=0.05

Figure 5. The relation between the ultrasonic amplitude and the cutting force

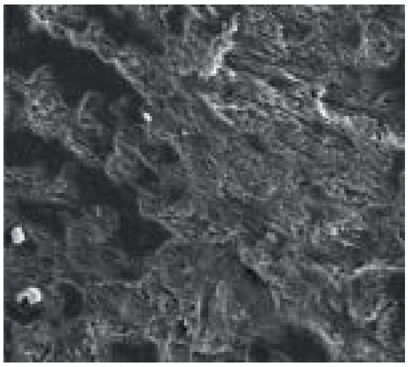
5.4. Detection to quality of the processed jade

Fig. 6(a) shows the processed jade, a figure of Buddha as a pendant whose shape meets technological requirements. Fig. 5(b) shows the surface quality of the jade scanned by an electron microscope when the experiment is conducted at the optimum level (m=350, r=0.05, A=0.015). Under a electron microscope (1000×), we see a fine processing result, except some uniform micro indentations on the surface of the jade specimen. Fig. 5(c) shows the image by the electron microscope (1000×) when both the size and the number of diamond girts are maximum (m=450, r=0.075). From the image we see some micro cracks on the jade surface, indicating that the integrated impact of diamond grids becomes powerful when the processing parameters increase, which enlarges the cutting force on the surface and gives rise to micro cracks if the parameters are too large, and, as a result, the processing quality degrades.

(a) The Hetian jade after grinding



(b) the surface quality of the jade scanned by an electron microscope



(c) Local crack on the surface of the jade

Figure 6. Detection to quality of the processed jade

6. Conclusion

(1)This indicates that both the number and the size of diamond grits have significant effect on the cutting force. The cutting force becomes larger with increasing the number and the size of diamond grits. The amplitude of ultrasonic vibration does not show a significant effect.

(2)As a result, more volume of the specimen is cut, which enlarges the cutting force and, therefore, raises the processing efficiency.

(3)When the number of diamond grits increases, the volume of the specimen cut by diamond grits under the ultrasonic vibration also increases, namely, the processing efficiency is raised.

(4)When cutting force is overlarge, the force on the surface of the jade, lead to the micro cracks on the jade surface, integrated machining efficiency and machining quality, determine the optimal process parameters of ultrasonic vibration machining for m = 350, r = 0.05, A = 0.035, at this time for good processing effect.

Acknowledgment

The work was supported by the National Natural Science Foundation of China under Grant No. 51265048.

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Effect of Attenuation on Thin Sand Bed AVO

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Abstract
Thickness prediction of thin bed is one of most important research objectives of fine reservoirs characterizations in seismic exploration. AVO research on thin bed is one of its important applications. Usually, only primary reflections are produced in AVO modeling by the convolution method, in addition, no attenuation is considered within such modeling. Modeling algorithm based on reflectivity method can simulate the whole responses to thin bed, and consequently the modeling results are closer to real seismic waves. Reflectivity method was used to model