Experimental Research on Engineering Ceramics Grinding Assisting with Ultrasonic Vibration

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ABSTRACT: *Engineering ceramics was machining based on grinding technology as major process method assisting with ultrasonic vibration, and the influences of grinding depth and worktable feed rate on the engineering ceramics surface roughness as well as the engineering ceramics topography was also evaluated with the help of surface rough meter and white-light interferometer. The results show that, compared with the engineering ceramics surface grinding using conventional process, the surface roughness obviously lowered and the topography improved to some extent when grinding assisting with ultrasonic vibration. Furthermore, the surface conditions was weakened as the grinding depth increases and the worktable feed rate accelerates, which highly reached to 0.332µm and 0.187µm respectively.*

Keywords: Grinding Ultrasonic Vibration Engineering Ceramics Surface Roughness Topography

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1. Introduction

With the rapid development of modern science, the requirement of material properties has been steeper and steeper. Engineering ceramics successfully wins a certain application space in current favored material applications, the aerospace, precision manufacturing, energy, chemical, and automobile and ship weapons equipment. The engineering ceramics has a serious of excellent performance in temperature resistance, wear resistance, corrosion resistance. Besides, its good stability, high mechanical strength also gain a good reputation in many other areas, such as machine tools with ceramic bearings and ceramic knives, ceramic seals hydraulic unit, ceramic rocket nozzle throat, etc. [1,2]. However, the special internal structure, such as being sensitive to internal defects and cracking easily, makes the ceramics brittle and hard. That surface micro-pits, cracks and sudden rupture often happen during the ceramic components processing and manufacturing. These shortcomings have severely restrict its performance and lead to invisible challenges for processing.

Researches show that material removal rate and cutting power problems have led to the surface micro-pits during conventional contact-type mechanical processing (such as turning, grinding, polishing, etc.) [3]. Therefore, reducing cutting force while improving the quality of the machined surface becomes important to the application of engineering ceramic components.

Researchers abroad and in have already made great achievements. Hoyle et al [4] has developed a variety of different materials tools, and appropriate way to carry out experimental studies. Results suggest that the development of new engineering tool for the brittle ceramic materials has a certain improvement effect, which will help get better surface morphology. Ramulu and Prabhakar et al [5, 6] showed the advantages of the ultrasonic vibration due to the integration with overlay. Besides, this method do not influence the inherent characteristics of the material while it can significantly reduce cutting forces and improve processing efficiency and quality. This method have shown great superiority than single processing techniques. And this result has also been confirmed by experimenters in Shandong University, Tianjin University and the Beijing Institute of Technology and so on. This paper selected this technology as the main method to improve the surface quality of engineering ceramics. We show our experiments and result analysis in this paper.

2. Experiment Design

Our platform mainly covers ultrasound equipment, energy conversion devices and horn, tools, first-class section. Specifically, the ultrasound generating device is H66MC ultrasonic generator, which is enough to provide the necessary ultrasonic vibration energy. The energy conversion device (i.e., the transducer) is used to transform the high-frequency electrical signals into ultrasonic vibration. Because the direct output amplitude is small, its applications is limited. In fact, it is often associated with the horn [7], which is to amplify the ultrasonic vibration amplitude. It should be noted that the horn design related to the overall performance of the ultrasonic vibration system. The platform becomes so involved in this experiment, so we design our own pieces. Besides, the ultrasound generating device and the associated energy conversion devices need to customize.

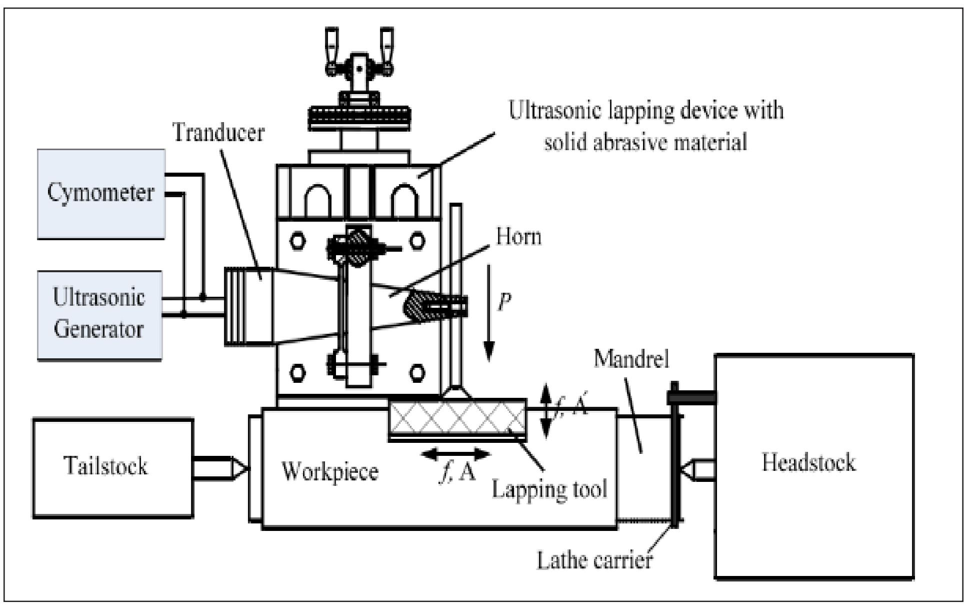

Figure 1. Ultrasound-assisted engineering ceramic grinding device schematic

2.1 Determine Parameters Value

The basic parameters of the horn are mainly the diameter, the resonant length, displacement node, the amplification factor and form factor. Some of these parameters refer to the diameter of selected energy conversion devices. We should also take into account its own rigidity and energy loss and other factors.

The principle of the pressure adjustment device is similar to that of screw nut structure. Rotate the screw handle, which will motivate the nut. A slider is connected with the screw handle and can be up and down through the dovetail rail. There exist a spring A between the slider and the screw handle and a spring B between the slider and the base. When rotate the screw to a predetermined position, the spring is balanced by the upper and lower position while being compressed until the lap. The pressure at this time is zero with the work piece. And when the screw handle is rotating, the pressure will grow. Precision grinding pressure regulator can be calculated through screw pitch, dial spring scale and bombs. The pressure p is:

$$P = kx / 1000n \tag{1}$$

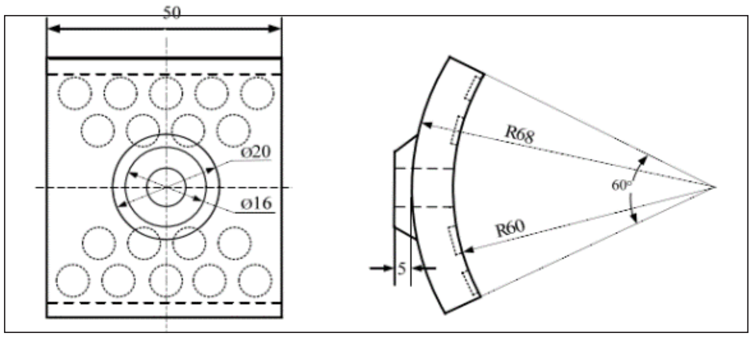

Figure 2. Sketch map of lapping tool

In this formula, n is the minimize size of the scale interval and x the screw pitch and k is the spring elasticity. According to our model, we finally determine the parameters as follows:

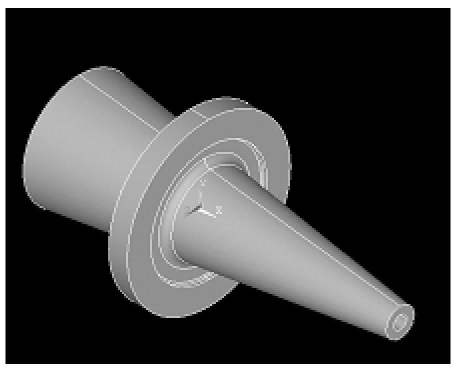

Figure 3. The horn

2.2 Create and Simulate 3D Model

Figure 3 shows the horn to create three-dimensional model. Given the design of the horn structure is more complex, for ease of modeling and subsequent simulation analysis, the model is import in Ansys. Subsequently, set corresponding essential attributes horn: material 45 # steel, density 7.8e3 kg/m3, Poisson's ratio 0.3, the elastic modulus 2.1e5 MPa. The Mechanical is used to mesh manner, as shown in Figure 4.

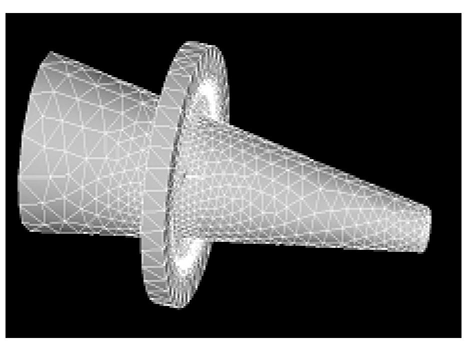

Figure 4. Meshing efficiency of the horn

Parameters	Value
Diameter of large end	60mm
Diameter of small end	15 mm
Resonance length	150mm
Amplification factor	4
Form factor	1.8

Table 1. values of the basic parameters

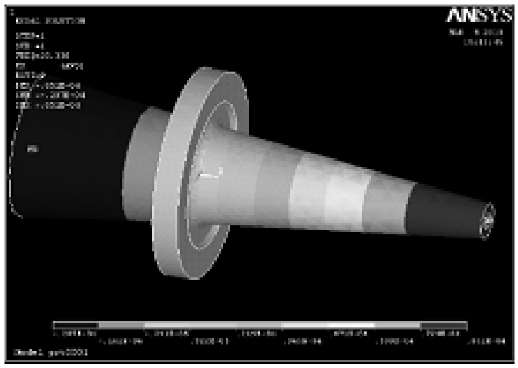

Figure 5. The horn simulation

Due to the theoretical design aspects were idealized assumption, which ignores the influence of the quality and size of the end of the threaded hole connecting both ends of the horn plate face and the resonant frequency of the horn node locations, we use Ansys software to simulate the model. Early experiments have confirmed unrealistic idealization treatment, and the disorder can cause resonant horn and node uncertain position, which can often incidentally increased system impedance, resulting in unsatisfactory results.

The simulation results obtained are shown in Figure 5. The figure shows the results of simulation analysis horn resonance frequency and frequency adjustable intervals were almost consistent with the theoretical design values, thus indicating a resonant horn to meet the requirements. Further, the proposed node displacement path from the large end and the small end of the horn, and apply the formula Analys is calculated amplification factor of about 3.8, similar to the design value and the error is 5%, within a permissible range, which also shows that the design of variable pole pieces more reasonable.

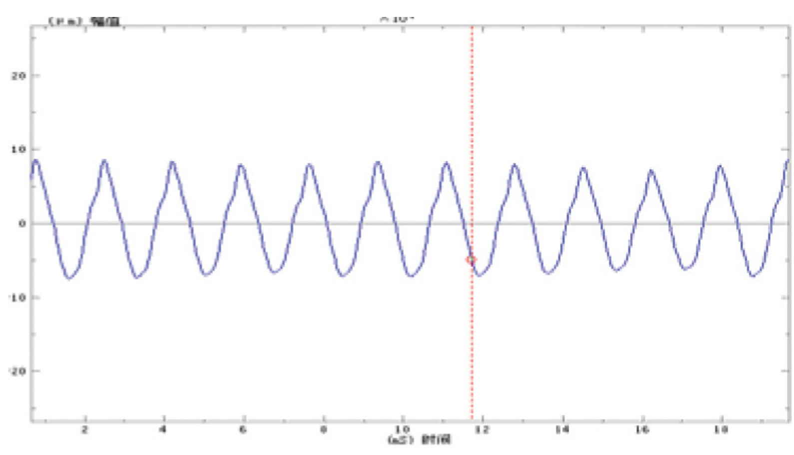

Figure 6. Evaluation of the performance

2.3 Performance Evaluate

Although the simulation results show that horn design is reasonable, performance is still unknown. To ensure optimal performance of the horn, we need the help of related instruments for performance evaluation. The performance evaluation of specific experimental procedure is as follows: according to the relevant formulas piezoelectric the acceleration sensor calibration and uniform unit of GB, which will help the calculation procedure. The calibration of piezoelectric acceleration sensors will fixed to the small end of the horn section to effectively protect the installation reliability, away from grinding off due to vibration caused by too violent. Connect the multifunctional anti-aliasing filter amplifier and a piezoelectric accelerometer output to achieve a low-pass filter and amplify the charge of double effect. Connect signal acquisition and processing platform amplifier output, and wirelessly transmit data with computers. The experimental results shown in Figure 5. There exists slight difference between the results of the experimental determination of the resonant frequency and the design value. However, there exist difference between material aspects of the theoretical design analysis software simulation and the reality is slightly different. In summary it is found that the overall design of the horn reasonable performance to meet application requirements.

Paramters	Value
Ultrasonic vibration power	40W
Ultrasonic vibration frequency	19.9Hz
Ultrasonic vibration amplitude	10ìm
Wheel speed	25m/s
Grinding depth	1~ 20 μ ìm
Table feed rate	0.08 ~ 0.25m/s

Table 2. Parameters Settings

2.4 Experiment Procedure

Before the experiment, we will refer to the standardized processes [8] and pretreat the engineering ceramics and make multiple sizes of the same specimen. Experimental parameters is shown in Table 1. In order to study its impact on the project, change only one parameter alone to get the ceramic surface roughness and morphology of the three-dimensional ultrasonic vibration assisted grinding.

After grinding the engineering ceramics, adopt methods to determine surface roughness according to average results of six time measurement. The measurement equipment is MarSurf M300C portable surface roughness tester. Talysurf CCI Taylor-type white light interferometry surface profiler is used to determine the morphology.

3. Result Analysis

3.1 Surface Roughness

Figure 7 shows the relationship between surface roughness of the engineering ceramic after grinding and grinding depth. The relationship between surface roughness of engineering ceramics and speed of table feed is in Figure .8. Comparison shows that under the same process parameters, the auxiliary ultrasonic vibration grinding surface roughness of engineering ceramics reduced compared with the conventional process significantly. For example, in Figure .7 when using the conventional process engineering ceramic the grinding surface roughness is about 0.272ìm. When the last ultrasonic vibration is applied to the secondary, the surface roughness of the grinding is only 0.16ìm with a drop of 41.2%. Similarly, as shown in Figure .8 the grinding surface roughness is about 0.24ìm with the conventional process while the latter is only 0.154ìm, with a drop of 35.8%.

Analysts believe that the main reason that surface roughness significantly reduced is because the advantages of ultrasonic vibration with a single grinding technology, which can significantly reduce the processing grinding process induced damage degree. Besides, it can be applied in a wide range of plastic cut to achieve the depth of field range of grinding, and thus improve the quality of ground surface.

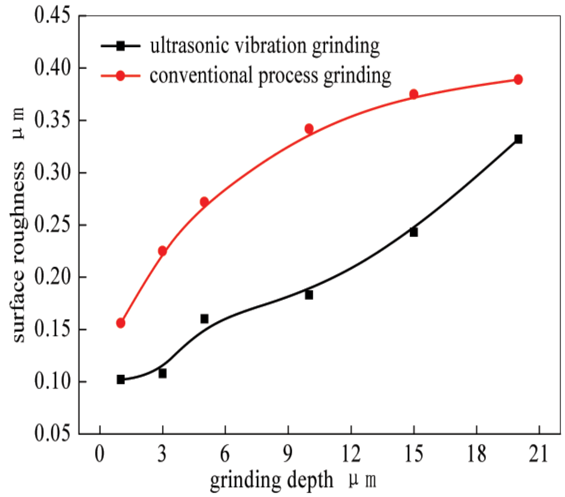

Figure 7. Relationship between grinding surface roughness of engineering ceramic and the depth of the curve

In addition, Figure .7 and Figure.8 shows that changing the grinding depth only or changing table feed rate will lead to the surface roughness changed with an increasing trend after assisted ultrasonic vibration grinding engineering ceramics with the process parameters is applied. The maximum values are 0.332ìm and 0.187ìm. For the former (Figure.7), a sharp increase raises in the trend after the first flat period, which is because in the small cutting depth, the removal of engineering ceramics achieves approximation [11, 12] in the plastic region, the electrode situation appears less massive. In the conditions of large grinding depth, although the way can still achieve removal of material, but due to the grinding depth, it is difficult to avoid the density of the material structure that will have some impact on texture. In Figure.8, the graph appear as substantially stable increasing trend, which may be attributed to the low speed condition table feed. The work piece and the abrasive grains is substantially complete separation state and the secondary grinding process is similar to the ultrasonic vibration equivalent the ultrasonic vibration cutting process. The material removal mechanism remains to remove the natural plasticity domain. But with the growth of table feed speed, the abrasive is no longer completely separated, leading to increasingly increasing in surface roughness.

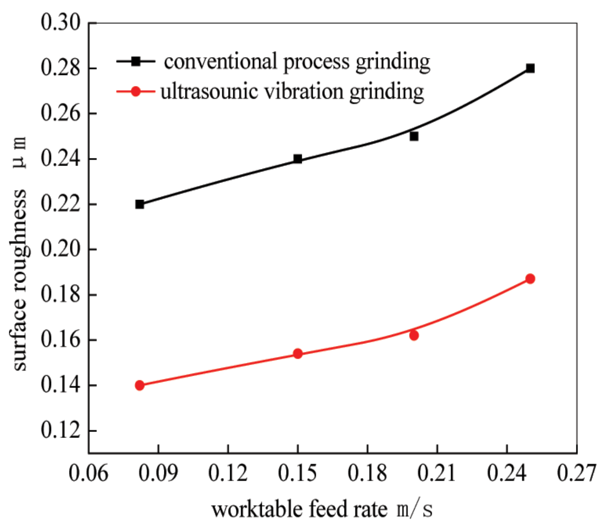

Figure 8. Relationship between grinding surface roughness of engineering ceramic and the speed of the table

In summary, by comparing the evaluation of surface roughness, the process confirmed the superiority of ultrasonic vibration assisted grinding. Nevertheless, as a description of the surface roughness after grinding engineering ceramic surface micro-roughness index and average describe the microscopic contours divide only a certain evaluation reference. It is still difficult to fully reflect the true state of intuitive surface after grinding. In view of this, to get a clear visual representation of the surface condition of engineering ceramics auxiliary rear ultrasonic vibration grinding process and further validate the advantages of ultrasonic vibration assisted grinding, a research from the surface of the three-dimensional topography level is expanded.

3.2 3D topography

Figure .9 and Figure.10 shows that when using the conventional process, the engineering ceramic surface is very unevenly distributed with large fluctuations and the surface potholes raised serious condition, showing a higher deeper gully barrow alternately like structure, which reflects the surface topography is not ideal. It is mainly because [13,14], (1) there may be a pit with a grinding wheel itself, retention pit replication makes ceramic surface after grinding works undulating, Scar evident in the grinding process and in a continuous state, similar to the appearance of cultivated pears; (2) engineering ceramic materials have more or less holes, bumps and other defects, and the defects in the grinding process prone to brittle into pieces fall off, resulting in uneven surface after grinding around the pit, forming undulating topography. However, without changing the process parameters on the basis of experiments, continuous ultrasonic vibration is applied to the secondary, the engineering plastic manner to remove the ceramic material, which is more uniform and the grinding streaks rule there was no significant loss of pits, the topography significantly improved. The situation is not serious as shown in Fig.9. Engineering ceramic surface contour curves is more uniform distribution with small fluctuations (approximately 1ìm only), and regional differences in the surface condition is relatively weak. This further confirmed the advantages of ultrasonic vibration assisted grinding process.

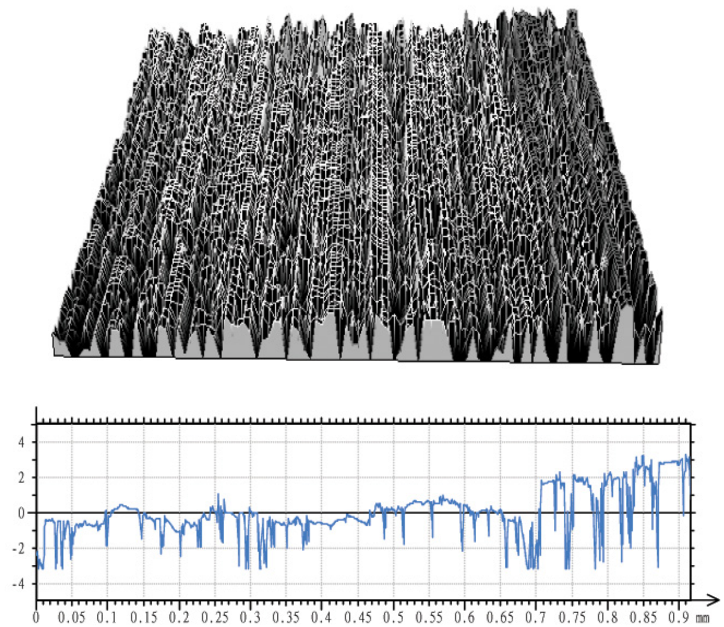

Figure 9. Surface morphology after conventional grinding process

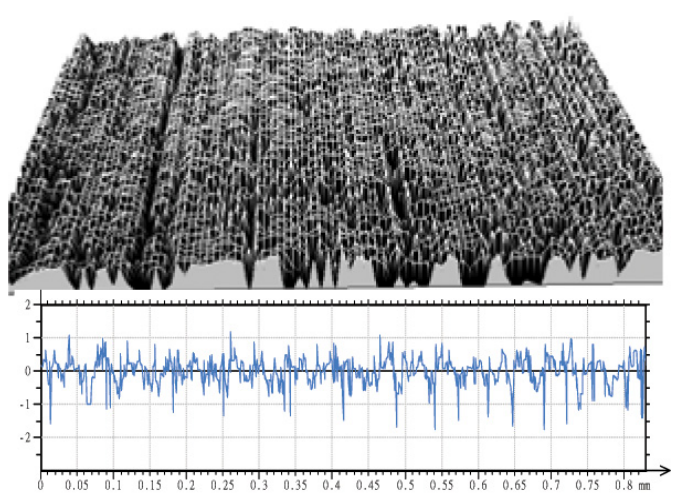

Figure 10. Surface morphology after ultrasonic vibration assisted process (depth 1um)

Figure.10 shows a 3D topography of engineering ceramics auxiliary grinding under ultrasonic vibration grinding depth 1ìm conditions. Increase the grinding depth to 3ìm, corresponding results is shown in Figure 11. As it can be seen, applying a large depth of grinding depth, the project is still relatively clear, and a smaller gap between the adjacent valleys. Compared with Fig.10, the 3D surface topography difference is not obvious. The reason is that the ultrasonic vibration abrasive grinding process occurs periodically and engineering ceramic surface separation, making the approximate trace grinding process , even in the phase separation can also be achieved abrasive grinding to plastic removal manner, the grinding process by grinding depth is not obvious . When grinding depth and even further to 5ìm 10ìm, engineering ceramic surface after grinding three-dimensional morphology and surface profile curve has changed , the former showed a slight deterioration in the trend , which has poor uniformity , and curve gap increases to some extent ,as in Figure.11 and Figure.12. Nevertheless, compared to the conventional process, three-dimensional morphology of the ultrasonic vibration assisted greatly changed, the topography is shallow and vague , reflecting the depth of the ultrasonic vibration helps to alleviate the grinding process, in a wide range of grinding depth to be achieved ductile grinding material removal , thereby improving the surface quality.

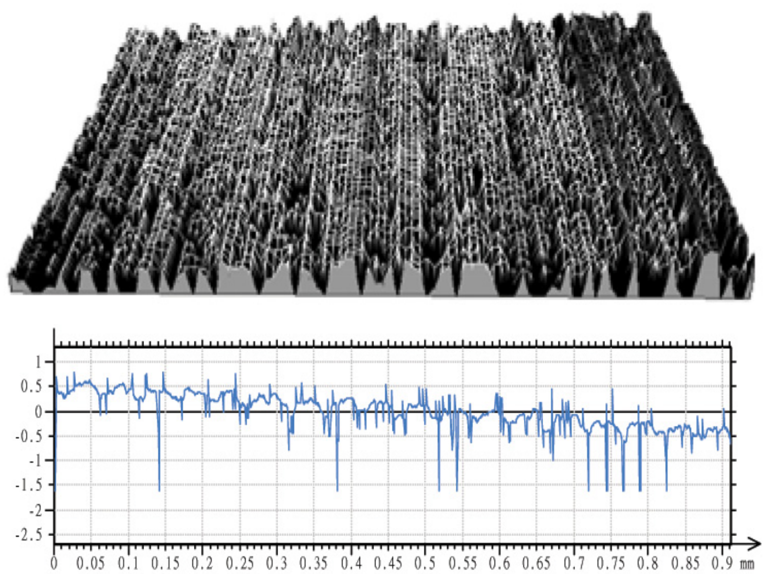

Figure 11. surface morphology after ultrasonic vibration assisted process (depth 5um)

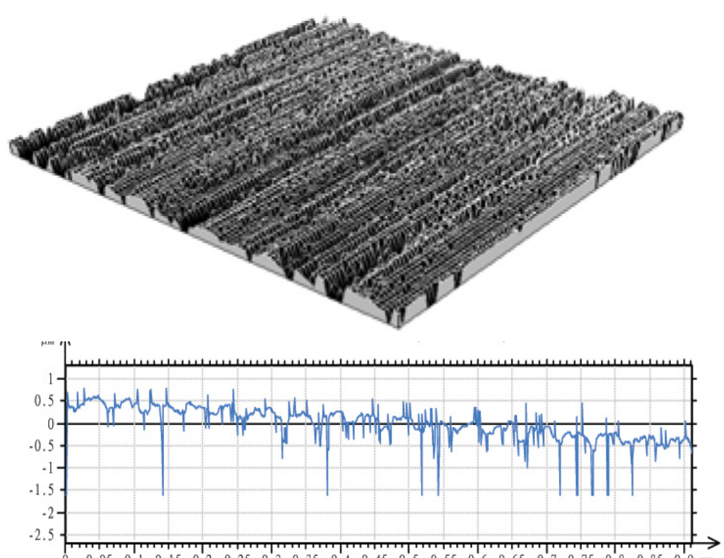

Figure 12. surface morphology after ultrasonic vibration assisted process (depth 10um)

4. Conclusion

In this paper, we mainly shows the grinding processing technology assisted with continuous ultrasonic vibration, and conducted experiment to study the engineering ceramics grinding. Experiments shows that compared with conventional processes, the auxiliary ultrasonic vibration grinding surface roughness decreased and improved three-dimensional topography. However, the grinding process parameters impacts the result with a certain effect.

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