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Cutting Performance Improvement Through a Hybrid Assisted Machining Technique on Quartz Glass Milling

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Keywords：Quartz glass, biaxial ultrasonically assisted, laser-assisted, hybrid assisted, cutting performance

ABSTRACT

The four stage experiments including without assistance, laser-assisted, biaxial ultrasonically assisted and hybrid assisted machining systems on quartz glass milling were constructed in this study in order to verify the assisted effects on cutting performance among them. The milling experiment without assistance was firstly performed to investigate the variations of cutting performance and the results were used for the suitable process parameter planning in the subsequent stage experiments. Next, laser assisted system, biaxial ultrasonically assisted system, and combination of laser assisted system and biaxial ultrasonically assisted system with two-axis simultaneous oscillations (x and y directions) were subsequently introduced at the second to the fourth stage experiments, respectively. At each stage experiment, the effects of process parameters on the variations of surface roughness, side surface morphology and cutting-tool wear are thus investigated. Also, a hybrid assisted machining system may be established through the integration of this biaxial ultrasonically assisted system and laser assisted system. Under these assistances, milling experiments of quartz glass by a cutting-tool of extra-fine particle tungsten carbide with nACo® coating were conducted. And the full factorial experiments of process parameter combinations such as feed rate, cutting velocity and radial depth of cut were also planned.

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The results show that the milling experiments through the combination of laser assisted system and ultrasonically assisted system with two-axis simultaneous oscillations have the better results than those experiments without assistance, with laser assisted and biaxial ultrasonically assisted systems only. Because the use of this hybrid assisted machining system, the cutting performance of tool wear and surface roughness are improved significantly.

INTRODUCTION

Hardened and brittle material such as quartz glass has gradually become the important materials for light source, electronic, optical communication, laser and aerospace technology industry applications in recent years. In which electro-optical system and semiconductor applications are particularly active. As its demand is increased constantly, various requests on machining qualities of quartz glass are also more stringent. At present, the main machining ways on quartz glass are almost with engraving milling, grinding lapping or polishing and these machining processes are too complicated and too much wasted. Therefore, seeking a breakthrough way for shortening the process and saving the cost effectively is an important issue for the machining workers. Chen and Jiang (2015) presented a force controlled grinding-milling technique to micromachining of quartz glass. In order to achieve a ductile-mode of material removal, an intellectualized machine which may support grinding-milling at nanometer-scale cut depth was designed and constructed. The rigidity of the developed machine-tool was also validated by FEA. A micro-edged grinding-tool with a double-negative back rake angle was proposed and employed to create a compressive stress grinding-milling, which is made from boron-doped polycrystalline composite diamond. Zhou et al. (2009) applied a chemo-mechanical grinding technique to machining of large-size quartz glass substrates and optimizing the machining conditions that achieves surface quality and geometrical accuracy simultaneously. The process parameters were first optimized to improve material removal rate. The surface quality including surface roughness, flatness and optical transmittance were analyzed and evaluated subsequently. Yuan et al. (2003) adopted soft material polisher (pitch K3), fine abrasive powder (SiO_2), and proper working environments to realize the lapping and polishing processes for obtaining the damage-free and super-smooth surfaces of quartz crystal. The obtained results show that both rolling and micro-cutting are the main mechanical actions of abrasives in lapping process, and the optimum scopes of lapping parameters of quartz crystal were determined by experiments. Jain and Adhikary (2008) applied an electrochemical spark machining technique for quartz cutting by use of a controlled feed and a wedge edged tool. Experiments of quartz plate cutting by sinking operations were conducted independently for both direct polarity and reverse polarity under the same machining conditions. Material removal rate, penetration rate, surface roughness of the machined surface and tool wear were measured for the evaluation of process performance. The obtained result of the machined surface shows a difference in the mechanism of material removal between direct and reverse polarities. Guzzo et al. (2003) investigated the wear mechanisms of synthetic quartz and natural quartz under different ultrasonic abrasion conditions. Material removal rate and surface roughness were investigated and regarded as a function of both abrasive particle size and crystallographic orientation of quartz specimen. They employed the skewness and kurtosis coefficients to characterize the variations in wear mechanisms appearing in the abraded surface topography. Brittle micro-cracking due to hammering and impact actions of abrasive particles on the workpiece material was found as the main wear mechanism involved in the material removal. Kim and Lee (2014) investigated cutting force and preheating temperature prediction for laser-assisted milling of Inconel 718 and AISI 1045 steel. A high power diode laser was used for preheating experiments to determine the absorptivity of Inconel 718. They proposed the equations for determining cutting force and preheating temperature in laser-assisted milling through statistical and regression analyses, and these equations were also validated experimentally under a wide range of milling conditions. Farahnakian and Raxfar (2014) applied a hybrid system for the assisted turning of AISI 4140 hardened steel to investigate the cutting force and surface roughness. The hybrid system consists of ultrasonic and plasma aided machining. The turning process parameters in that study are cutting speed, feed rate, depth of cut, tool material, and the related parameters of plasma and ultrasonic assisted. A model was developed the relationship between plasma current and the material removal temperature, and Taguchi method was used for turning experiment design. Results showed the reduction of cutting forces in hybrid machining in comparison with conventional turning, plasma enhanced turning and ultrasonic-assisted turning. While finished surface roughness depending on cutting conditions can be improved in hybrid machining in comparison with the above single assisted technique.

Because quartz glass has the properties of high hardness, large brittleness, less malleability, low thermal conductivity and hence low machinability, it causes the cutting-tool wear quickly during the machining processes. Also, the crack and damage, and edge-indentation are easily generated on the machined surface and around the outer edge, respectively. In order to solve the above problems, this study applies the diamond cutting tool to conduct quartz glass machining through a combination of ultrasonically assisted and laser-assisted machining under different combinations of process parameters. It is expected to handle the material removal process corresponding to different ductile-brittle transition modes properly for quartz glass machining and enhance the processing efficiency, surface quality improvement and reduction of production cost consequently. Furthermore, the machinability of such high hardened and brittle materials can also be promoted resulting in good cutting performance and smaller cutting-tool wear.

THEORETICAL FOUNDATION

Characteristics of quartz glass

Quartz glass is a very popular kind of hard-brittle material. It is made from natural crystal quartz (crystal or pure silica) or synthetic silane through high temperature melting. Because of its high compactness of crystal structure and high bonding strength between atoms, it owns high hardness, good properties of light transmission, temperature endurance, thermal shock resistance, corrosion resistance, dielectric, low density, low thermal expansion, etc. It also owns an exceptional transmission ability in both ultraviolet and infrared spectra. This excellent comprehensive performance is the basis of its application in the field of high technology such as the production of semiconductors, electric light source, semiconductor communication devices, laser devices, optical instruments, laboratory equipment, electrical equipment, medical equipment, chemical corrosion equipment and fire-resistant building materials, etc. As just mentioned above, quartz glass all has a wide range of applications. It is also one of the indispensable excellent materials in the modern advanced technology such as space technology, nuclear energy industry, defense equipment, automation system, semiconductor, metallurgy, chemical industry and light industries.

The property of piezoelectric effect in quartz crystal makes it being used to manufacture electronic components with high-precision oscillation frequency, which are frequently appeared in watches and color TV carrier frequency devices. In the era of scientific and technological progress, quartz glass in the light source, electronics, optical communications, laser, aerospace and nuclear energy technology fields have a growing application trend.

Ultrasonic assisted cutting system

In the quartz glass cutting processes, high temperature is promptly accumulated around the cutting edge due to the contact between the workpiece material and cutting-tool, and the very poor thermal conductivity of the workpiece material itself. In order to improve this phenomenon, cutting fluid should be used for cooling and lubrication to ensure good cutting performance. But if the cutting fluid is simply applied for high temperature cooling, the actual improvement results are limited. By introducing an ultrasonic assisted cutting technique, a vacuum region may be constituted around the primary cutting zone and the pumping effect is formed in this area, which may enhance the cutting fluid penetrating into the cutting zone accelerating high temperature cooling at the tool-tip. Furthermore, ultrasonic assisted cutting technique may convert the engagement type of cutting tool-chip into an interaction manner of a small amount of vibration. The results obtained from the literature have also reported that the following effects may be induced if the ultrasonic assisted machining technique is properly introduced in the cutting process, i.e., to improve the bur generation around the machined side surface, reducing cutting forces and thus improve the vibration effects arising from the cutting, to improve the quality of the surface roughness, to reduce friction at tool-workpiece interface, increasing tool life and reducing the geometrical accuracy error. Thus, appropriate application of ultrasonic assisted technique in cutting process can actually improve the cutting performance. A model combines ultrasonic assisted cutting technique and cutting fluid is schematically shown in Fig. 1.

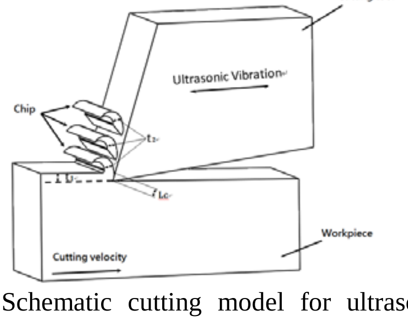


Fig. 1 Schematic cutting model for ultrasonically assisted machining.

Laser-assisted cutting system

Thermally assisted machining (TAM) offers an effective way for achieving a cost-efficient production of high-quality parts when machining difficult-to-cut materials such as titanium alloys, super-alloys, structural ceramics, etc. As a result, the material removal rate and dimensional control can be promoted, and the cutting forces and surface defects can be reduced. For TAM of brittle workpiece, an intense heat source such as laser, plasma, electric arc is used to heat the workpiece material locally above a threshold temperature without evaporating or melting the material. It can not only reduce the material's yield strength below the fracture strength but also enable a quasi-plastic material removal by a cutting tool, rather than brittle fracture.

Laser-assisted machining (LAM) is a kind of thermally assisted machining, in which the material is preheated by a laser spot prior to the workpiece material removal, and the material is subsequently removed plastically by a cutting-tool as shown in Fig. 2. LAM has been well known as a noncontact machining method and has been applied to various difficult-to-machine materials such as hardened and brittle material, i.e., titanium alloys, super-alloys, structural ceramics, etc. The laser absorptivity of ceramics in the infrared is better than metals generally. Thus, when ceramic workpiece is sufficiently preheated and then is cut by a cutting tool, the cutting load will be lower than that without laser assistance. Local heating of LAM may enhance the machinability of workpiece material, change the type of chips produced from fragmented to continuous, reduce the specific cutting energy, improve the machining characteristics and suppress the cutting-tool wear, etc. Furthermore, a precise control of deposited energy and preheated region can change the brittle material deformation behavior from brittle to ductile modes before the material is removed, which also reduces the yield strength of the brittle material to a value below the fracture strength, thereby avoiding any undesirable heating of the finished surface or destruction of the subsurface.

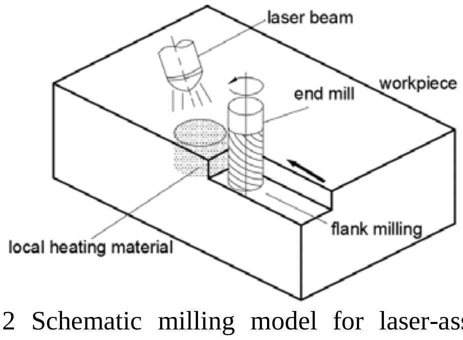
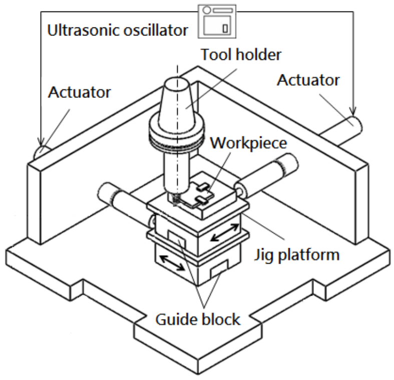


Fig. 2 Schematic milling model for laser-assisted machining

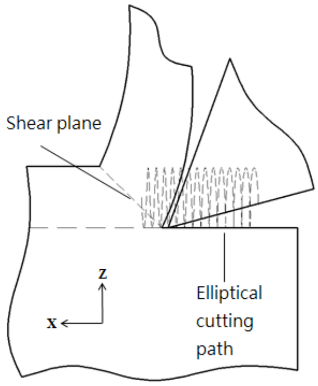
EXPERIMENTAL METHODS AND PROCEDURE

Before the use of laser assistance, the laser preheating time related to the workpiece surface fragmentation should be tested in advance for a proper setting of spacing distance between laser-spot and cutting-tool edge. A biaxial ultrasonically assisted machining system is also designed, fabricated and mounted on a machine-tool worktable. At the meantime, a long-term oscillation test including calibration and detailed adjustment was conducted repeatedly until the whole normal manipulation of the system is assured. Under each machining technique, a side-milling experiment on quartz glass workpiece is performed by an extra-fine particle tungsten carbide with nACo® coating in this study. The cutting performances are thus investigated under various milling manners such as without assistance, laser-assisted, biaxial ultrasonically assisted and hybrid assisted machining systems. During the experiments, dynamometer is used to monitor the variation of cutting force. Tool wear, edge-indentation and side surface morphology of the machined quartz glass will be measured by tool-microscope off-line. Surface roughness measurement through a probe contact type instrument is also performed. After the milling processes, machined surface morphology at the central area and around the outer-edge, surface roughness and cutting-tool wear were sampled or measured through a tool-microscope. The experimental set-up for a biaxial ultrasonically assisted machining system and the corresponding elliptical cutting path are shown in Fig. 3, in which vacuum chuck was used to clamp the thin quartz glass substrate on jig platform. While the experimental set-up for a hybrid assisted machining system is shown in Fig. 4.

The process parameter planned for side-milling experiments is shown in Table 1. In this study, the full-factorial experiments are conducted with the variables and conditions of three levels of spindle speed, three levels of worktable feed rate and three levels of radial depth of cut, totally 27 combinations were constituted in each stage experiment shown in Table 2. The axial depth of cut of 2mm is the thickness of the quartz glass workpiece. Thus, through a series of analyses on the experimental results mentioned above, the investigation of cutting performance of quartz glass may be completed consequently. The experimental results are not only used for studying the effects of different combinations of process parameter on cutting performance of quartz glass in each assisted milling case but also used for comparing the merit, drawback, limitations and processing behaviors among these four stage machining techniques.



(a) biaxial ultrasonically assisted system



(b) elliptical cutting path

Fig. 3 The experimental set-up for a biaxial ultrasonically assisted machining system and the corresponding elliptical cutting path.

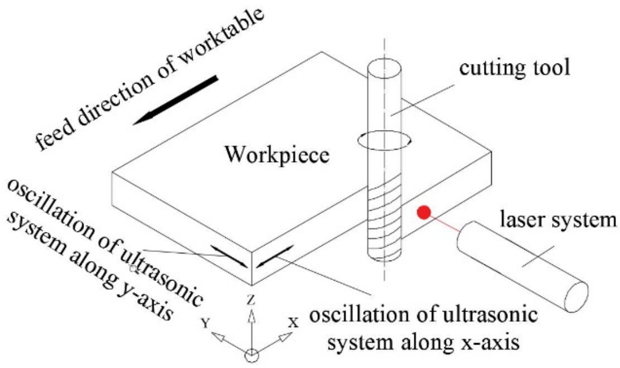


Fig. 4 The experimental set-up for a hybrid assisted machining system.

Table 1 Process parameter planning for side-milling experiments

Process parameter	Level (1-3)
Diameter of mill, d(mm)	Φ6 (four cutting-edge flute)
Spindle speed, n(rpm)	3000, 5300, 7800
Feed rate, f(mm/min)	150, 300, 450
Radial depth, a_e (μm)	3, 6, 9
Axial depth, a_p (mm)	2, i.e. workpiece thickness

Table 2 27 sets of process combination for each stage assisted cutting

set	n	f	a_e	set	n	f	a_e
1	3000	150	3	15	5300	300	9
2	3000	150	6	16	5300	450	3
3	3000	150	9	17	5300	450	6
4	3000	300	3	18	5300	450	9
5	3000	300	6	19	7800	150	3
6	3000	300	9	20	7800	150	6
7	3000	450	3	21	7800	150	9
8	3000	450	6	22	7800	300	3
9	3000	450	9	23	7800	300	6
10	5300	150	3	24	7800	300	9
11	5300	150	6	25	7800	450	3
12	5300	150	9	26	7800	450	6
13	5300	300	3	27	7800	450	9
14	5300	300	6				

RESULTS AND DISCUSSION

There are totally 108 set experiments are executed in this study, in which every 27 set side-milling experiments are conducted for each machining manner individually such as without assistance, laser-assisted, biaxial ultrasonically assisted and hybrid assisted machining systems. The effects of various assisted machining technique applications on cutting performance of quartz glass milling may be compared crossly. Also, the effects of different process parameters such as spindle speed, feed rate and radial depth of cut on machined surface roughness, surface morphology and cutting-tool wear in each assisted manner are investigated accordingly.

Fig. 5 shows the comparisons of machined surface roughness among various assisted machining techniques. The assisted effect can be validated evidently from the obtained results, i.e., the machined surface roughness with a hybrid assisted system is better than that of the other assisted manners used in this study. And the overall results from the laser-assisted machining are also better than those without assistance although the results pertaining to some process parameter combinations are worse than that without assistance due to a faster feed rate of worktable and larger rotational speed of spindle, which owns the smaller preheating time on the workpiece. The surface roughness produced between the biaxial ultrasonically and a hybrid assisted milling is very close to each other. The larger is the rotational speed of spindle, the better is the surface roughness in a hybrid assisted milling, which prevails to biaxial ultrasonically assisted milling. However, both of them the level of surface roughness is almost below 1μm which indicates that at least 50% improvement has emerged as compared to that produced in that without assistance. Hence, the merit and limitations in the assisted machining technique are pointed out obviously.

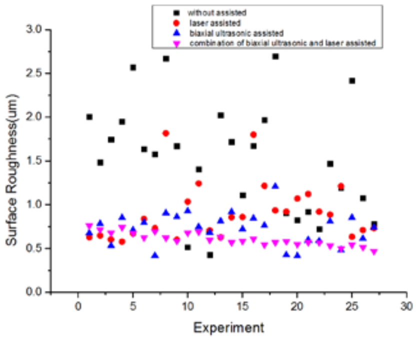


Fig. 5 Comparison of machined surface roughness for every 27 experiment sets among various machining techniques.

Fig. 6 shows the comparisons of maximum cutting-tool wear on the flank face among various machining techniques. Under the two sources of energy integration from ultrasonic oscillation and laser preheating, the maximum cutting-tool wear with a hybrid assisted system is better than that of the other assisted manners used in this study. Due to the back and forth engagement manner between the workpiece and cutting-tool in ultrasonic assisted situations, the amount of cutting-tool wear in ultrasonic assisted machining are greater than that without assistance. This is because high frequency friction force generated at the tool-workpiece, which abraded the cutting edge intensively during the ultrasonic assisted machining processes. While a continuous tool-workpiece engagement is exhibited in the cases of without assistance, which relatively reduces the abrasive action. However, the overall cutting-tool wear from the biaxial ultrasonically assisted manner is better than that with laser-assisted because the ultrasonic oscillation excites the workpiece along x and y-axis directions simultaneously and harmonically resulting in a slightly improper oscillation force acted on the cutting-tool wear land as compare with the non-steady state preheating time due to the unequal feed rate of worktable. Hence, the merit and limitations in the assisted machining technique may also be investigated clearly.

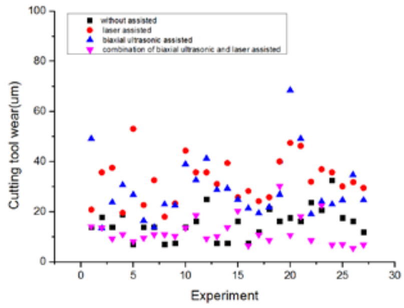
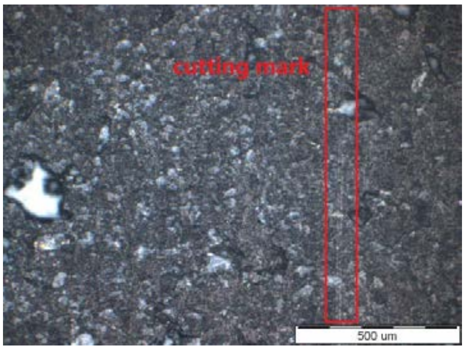
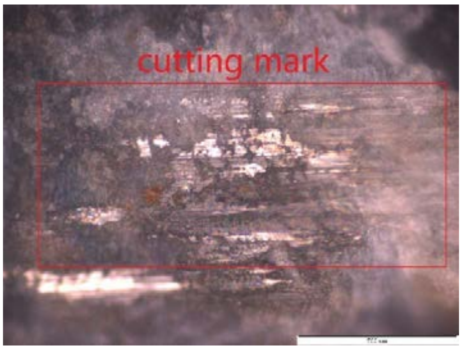


Fig. 6 Comparison of cutting tool wear for every 27 experiment sets among various machining techniques.

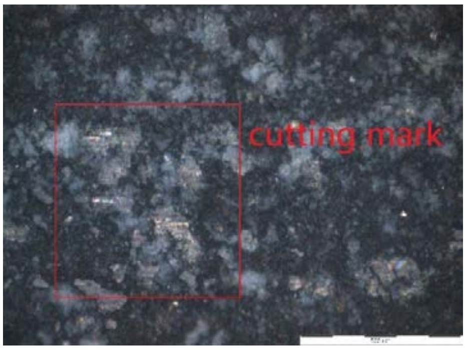
Fig. 7 and Fig. 8 show the comparisons of the best and worst surface morphology at the central area and around the outer edge, respectively, among various machining techniques. Where, the letters of w, l, b and h represent the without, with laser, biaxial ultrasonic and hybrid assistances, respectively. Figs. 7(a) to (d) and Figs. 8(a) to (d) show the best surface morphology photos while Figs. 7(e) to (h) and Figs. 8(e) to (h) show the worst surface morphology photos among various techniques. Here, the obvious damage, crater or indentations are marked by red lines. A larger damage, crater or indentation area is distributed on the machined surface without assistance or for the other assisted systems under a larger feed rate condition. But the surface quality states in biaxial ultrasonically assisted machining are relatively moderate which has been validated in Fig.5. A common phenomenon of the cutting mark obviously exists on machined surface shown in Figs. 7(a) to (d) indicating the best surface morphology at the central area among various machining techniques. The surface flaw of edge indentation is frequently occurred around the outer edge as indicated in Figs. 8(e) to (h) which is under the larger feed rate and radial cutting depth conditions.



(a) $w/f_1/n_2/a_{e3}$

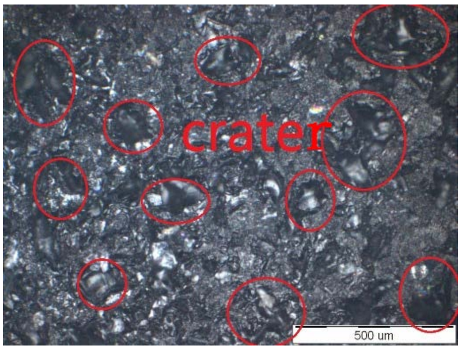


(b) $l/f_2/n_3/a_{e2}$

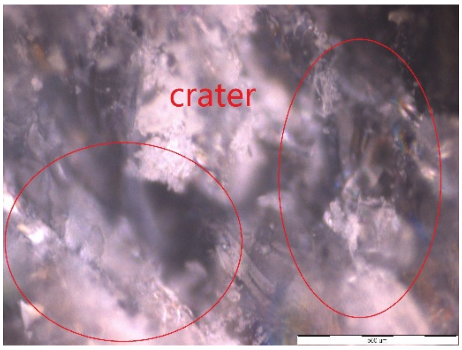


(c) $b/f_1/n_3/a_{e1}$

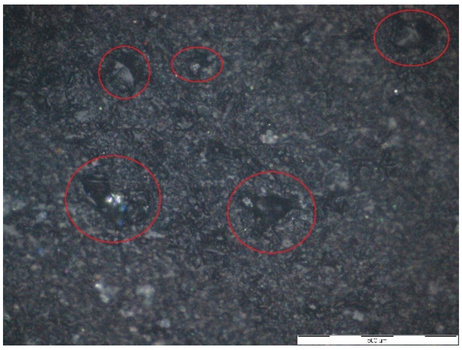
(d) $h/f_2/n_1/a_{e2}$



(e) $w/f_3/n_1/a_{e2}$



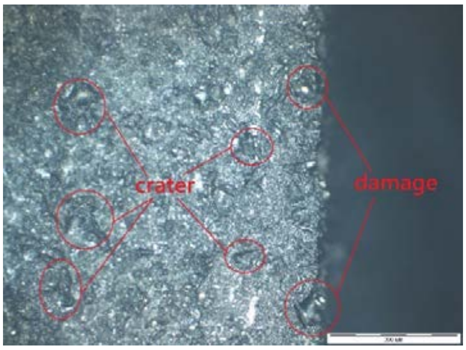
(f) $l/f_2/n_2/a_{e2}$



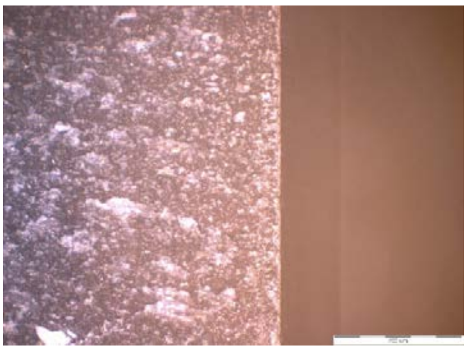
(g) $b/f_3/n_1/a_{e1}$

(h) $h/f_3/n_3/a_{e1}$

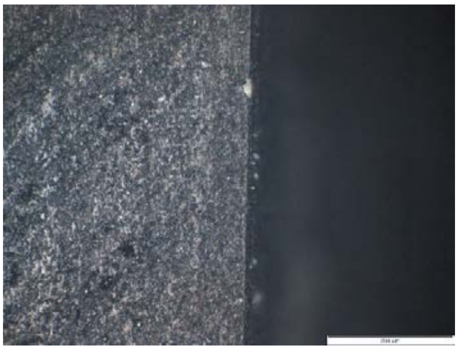
Fig. 7 The best (a-d) and worst (e-h) surface morphology at the central area among various machining techniques.



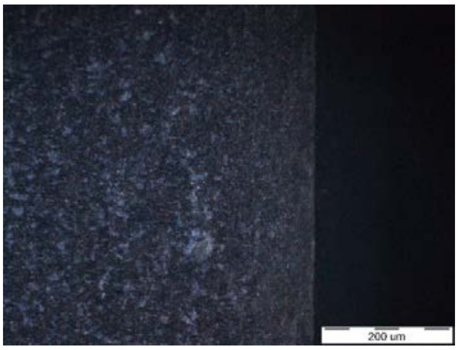
(a) $w/f_3/n_1/a_{e1}$



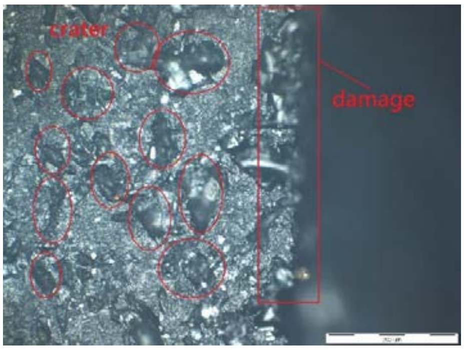
(b) $l/f_1/n_1/a_{e1}$



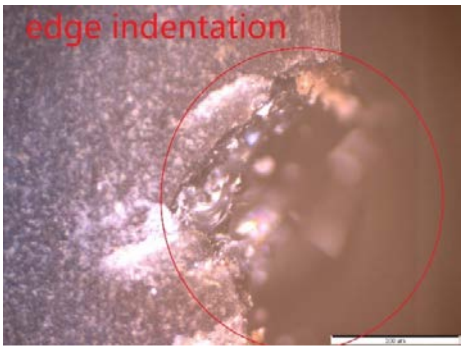
(c) $b/f_3/n_1/a_{e1}$



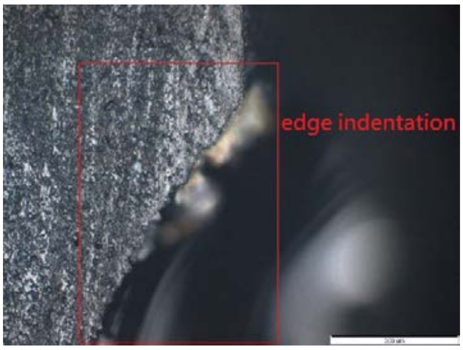
(d) $h/f_1/n_3/a_{e1}$



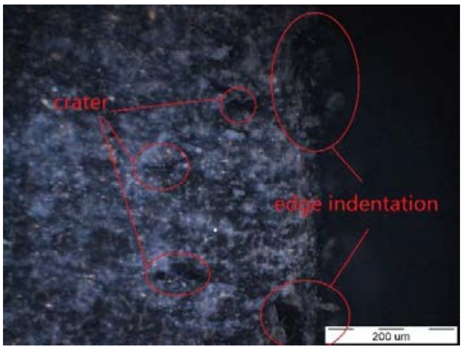
(e) $w/f_3/n_1/a_{e2}$



(f) $l/f_2/n_2/a_{e2}$



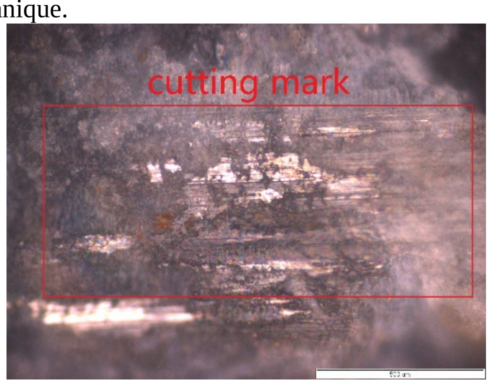
(g) $b/f_2/n_2/a_{e3}$



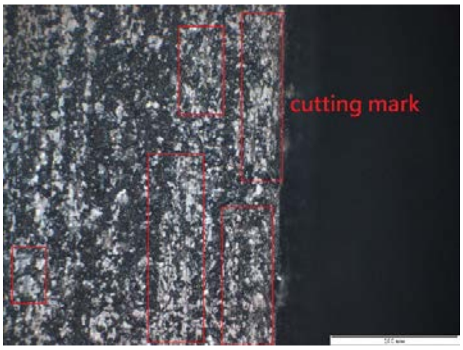
(h) $h/f_3/n_1/a_{e1}$

Fig. 8 The best (a-d) and worst (e-h) surface morphology around the outer edge among various assisted machining techniques.

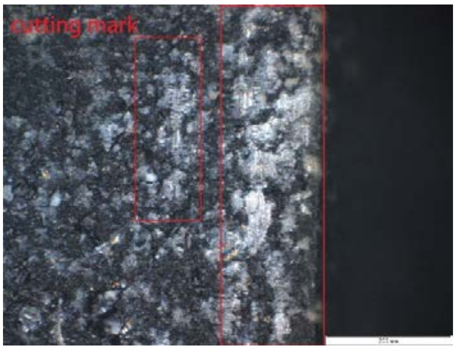
Fig.9 shows the cutting path marks left on the machined surface as indicated by red lines. The results show that the surface brightness has a better improvement and the cutting marks tend to be uniform as the biaxial ultrasonically assisted technique and a hybrid assisted system were applied. This result is also related to surface roughness promotion in quartz glass milling as shown in Fig.5. The obvious cutting marks may reflect a ductile-brittle transition mode machining in some process parameter combination and more frequently appeared in biaxial ultrasonically assisted machining situations. Furthermore, the cutting marks have more opportunity left on machined surface when the larger level of process parameter is utilized for each assisted technique.



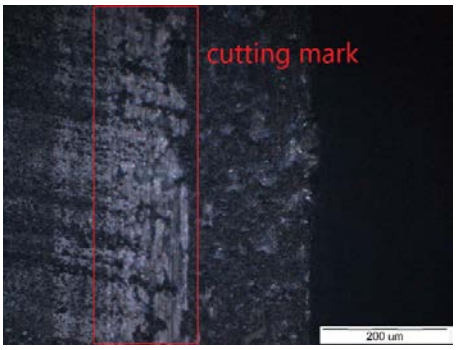
(a) $l/f_2/n_3/a_{e2}$



(b) $b/f_2/n_3/a_{e1}$



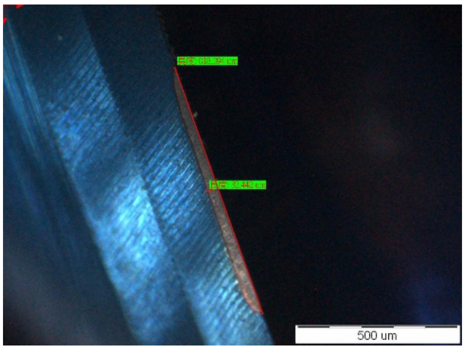
(c) $b/f_3/n_2/a_{e3}$



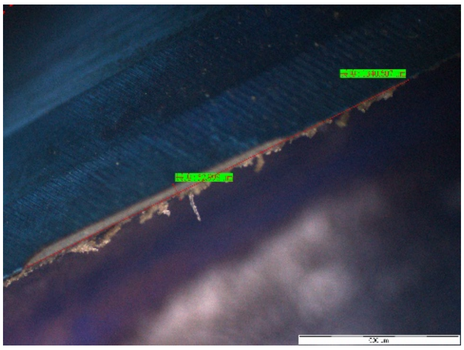
(d) $h/f_3/n_3/a_{e3}$

Fig. 9 Cutting path mark left on the machined surface for the illustrations of ductile-brittle transition mode machining.

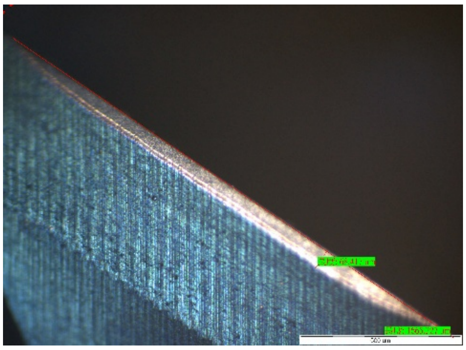
Fig. 10 shows the cutting tool wear pattern among various machining techniques. For cutting-tool flank wear, the cutting depth, feed rate and cutting depth, rotational speed, and rotational speed are the main influential factors in without assistance, laser-assisted, biaxial ultrasonically assisted and hybrid assisted systems, respectively. While for surface morphology quality as shown in Figs. 7 and 8, the cutting depth, rotational speed and thermal energy, oscillation force, and oscillation force and thermal energy are the main influential factors in without assistance, laser-assisted, biaxial ultrasonically assisted and hybrid assisted systems, respectively.



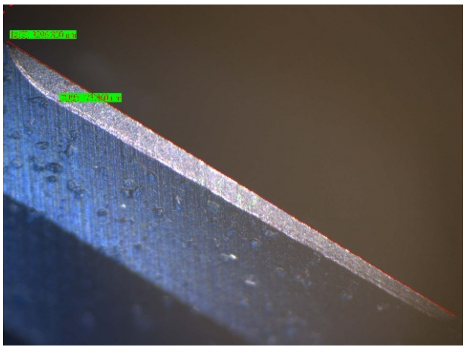
(a) $w/f_2/n_3/a_{e3}$



(b) $l/f_2/n_1/a_{e2}$



(c) $b/f_1/n_3/a_{e2}$



(d) $h/f_1/n_3/a_{e3}$

Fig. 10 Cutting-tool flank wear pattern for the illustrations of process parameter combination effects among various machining techniques.

Fig.11 to Fig.13 show the relationship between the surface roughness and feed rate for different spindle speeds under a_e=3μ, 6μ and 9μm, respectively, with a hybrid assisted machining. The surface roughness is decreased as the feed rate is increased, which is quite different from those milling situations for conventional metal cutting. However, the surface roughness is decreased as the spindle speed is increased.

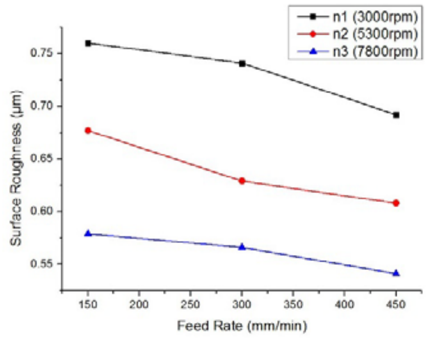


Fig.11 The relationship between surface roughness and feed rate for different spindle speeds under a_e=3μm with a hybrid assisted machining.

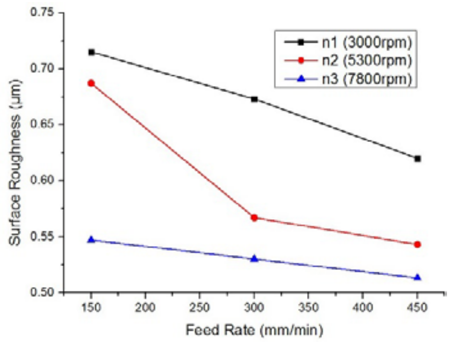


Fig.12 The relationship between surface roughness and feed rate for different spindle speeds under a_e=6μm with a hybrid assisted machining.

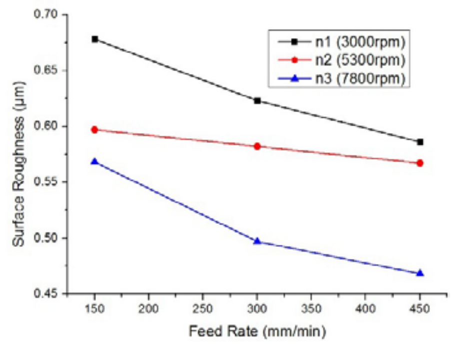


Fig.13 The relationship between surface roughness and feed rate for different spindle speeds under a_e=9μm with a hybrid assisted machining.

Fig.14 to Fig.16 show the relationship between surface roughness and spindle speed for different radial cutting depths under f=150, 300 and 450mm/min, respectively, with a hybrid assisted machining. As mentioned above, the surface roughness is decreased as the spindle speed is increased. While the surface roughness is almost decreased as the radial cutting depth is increased except at the spindle speed of 5300rpm, which is also quite different from those milling situations for conventional metal cutting.

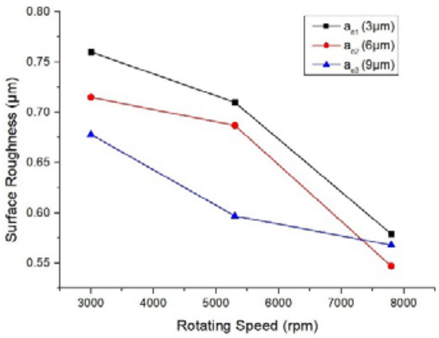


Fig.14 The relationship between surface roughness and rotating speed for different radial cutting depths under f=150mm/min with a hybrid assisted machining.

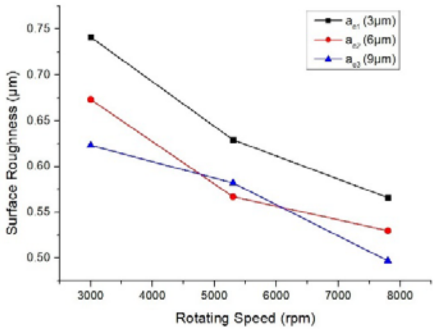


Fig.15 The relationship between surface roughness and rotating speed for different radial cutting depths under f=300mm/min with a hybrid assisted machining.

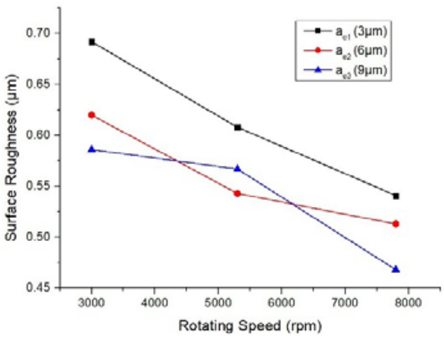


Fig.16 The relationship between surface roughness and rotating speed for different radial cutting depths under f=450mm/min with a hybrid assisted machining.

Fig.17 to Fig.19 show the relationship between surface roughness and radial cutting depth for different feed rates under n=3000, 5300 and 7800rpm, respectively, with a hybrid assisted machining. As mentioned above, the surface roughness is decreased as the feed arte and radial cutting depth is increased generally, which is also quite different from those milling situations for conventional metal cutting.

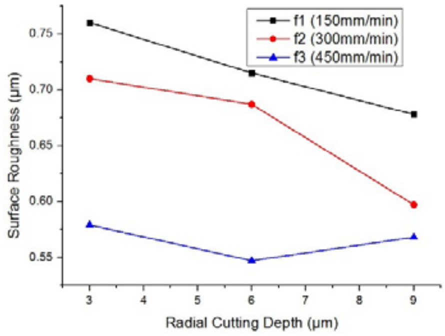


Fig.17 The relationship between surface roughness and radial cutting depth for different feed rates under n=3000rpm with a hybrid assisted machining.

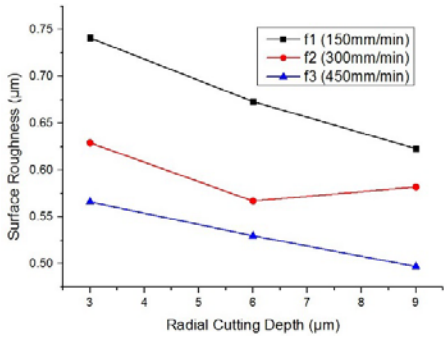


Fig.18 The relationship between surface roughness and radial cutting depth for different feed rates under n=5300rpm with a hybrid assisted machining

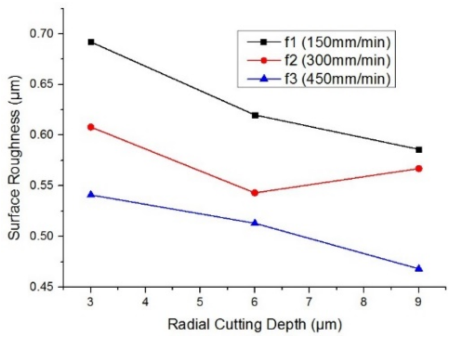


Fig.19 The relationship between surface roughness and radial cutting depth for different feed rates under n=7800rpm with a hybrid assisted machining

CONCLUSION

The four stage experiments including without assistance, laser-assisted, biaxial ultrasonically assisted and hybrid assisted machining systems on quartz glass milling have been performed in this study. The effects of various assisted machining technique applications on cutting performance of quartz glass milling are compared crossly. Also, the effects of different process parameter combinations on cutting performance in each assisted manner are investigated. From the above analyses, the following conclusions are thus drawn.

1. The assisted effect can be validated evidently from the obtained results, i.e., the machined surface roughness with a hybrid assisted system is better than that of the other assisted manners used in this study.
2. Under the conditions of spindle speed of 5300 and 7800rpm with a hybrid assisted milling, a larger area of cutting-tool path mark pattern is appeared on the machined surface. The material removal behavior from brittle to ductile transition mode may be validated in this hybrid assisted system since two energies have been integrated from biaxial ultrasonically assisted and laser assisted machining techniques.
3. Under the conditions of spindle speed from 5300 to 7800rpm and radial cutting depth from 6 to 9μm with a hybrid assisted milling, the sharpness of the cutting-tool may be kept for a long period and material removal behavior is fall into a ductile mode.
4. The optimum process parameter combinations are Set 24 and Set 27 as indicated in Table 2 under the assisted manner of a hybrid system. The corresponding roughness are 0.497μm and 0.468μm, respectively, which accompanied by a cutting-tool flank wear of 44.187μm and 133.986μm, respectively.

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混合輔助切削技術於石英玻璃銑削切削性改善之研究

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摘 要

本文建構一四階段石英玻璃銑削實驗，包含無輔助、雷射輔助、雙軸向超音波輔助及混合輔助系統以驗證它們切削性能的輔助效果。首先，第一階段進行無輔助銑削以研究切削性能之變化並將成果用於其他階段適當製程參數之規劃。接著，第二至第四階段分別依序導入雷射輔助、雙軸超音波輔助及雙軸超音波雙軸振盪與雷射系統結合之混合輔助銑削。於每一階段實驗，研究各加工製程參數對表面粗糙度、邊緣形貌及刀具磨耗之變化影響趨勢。再者，整合雙軸向超音波輔助系統與雷射輔助系統以建構一混合式輔助切削加工系統。本文採用耐磨耗且導熱係數較高的 nACo®極細微粒碳化鎢鍍層刀具，透過加工製程參數（切削速度、徑向銑削深度、進給速度）全因子組合的調變規劃，針對石英玻璃進行上述四階段之銑削加工實驗。結果顯示，雙軸超音波雙軸振盪與雷射系統的混合輔助銑削，不僅優於上述各單項輔助系統，且明顯地大幅度改善刀具磨耗與表面粗糙度。