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New Technique of Applying Ultrasonic Frequency on Drilling Chemical Treated Glass

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Abstract*: *The usage of chemical treated toughened glass has steadily increased especially for electronic panel display devices. Due to the ion-exchange process throughout the surface treatment phase has create six to eight times tougher and crack resistance as compare to normal float glass. Owing to these, the subsequent manufacturing process such as conventional drilling is almost impossible for this toughened glass. Considering these fact, in this paper feasibility study on the effectiveness of applying ultrasonic frequency during the drilling process toward holes' quality were investigated. Sets of experimental investigation of ultrasonic assisted drilling with varying speed and feed rate were performed to evaluate the burr formation and the generated thrust force magnitude. From the experimental results, it was found that the areas of burr formation and the thrust force magnitude were dependent with the drilling parameter. It also can be noted that the present of the ultrasonic vibration show significant improvement on the holes' performance. By incorporating the drilling process with an ultrasonic vibration able to decreases the magnitude of thrust force and increases the effectiveness of chip evacuation process due to the intermittent cutting process. The outcome from this work serve as a basis for advancing the technology related to micro machining of chemical treated toughened glass.

Keywords* : *Precision machining, Ultrasonic assisted drilling, Chemical treated glass.

I. INTRODUCTION

Chemical treated toughened glass offered a great strength as a result of a post-production chemical process by means of an ion-exchange process. Chemical treated toughened glass offers an improved scratching, impact and bending strength, as well as an increased temperature stability which make it as preferred material for electronic panel display devices application such as mobile phone and tablet PCs screen, camera lens, optical component, etc. [1]. In such aforementioned applications, micro holes drilling is required as to serve for the particular purposes such as camera lenses, speakers and proximity sensors as shown in Figure 1. However, due to the inherent properties of chemical treated toughened glass in which stronger under compressive stress and weak under tension make it as a challenge for conventional drilling process. Conventional drilling process tends to generate high tensile stress due to the thrust forces that results in poor holes' quality and rapid cracks propagation.

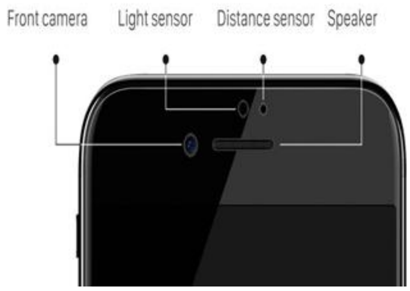

Figure 1: Micro holes' positions at mobile phone screen

In current industry practices, drilling of micro holes for glass can be achieved using several techniques, namely mechanical methods (mechanical drilling, powder blasting, abrasive slurry jet micromachining, abrasive waterjet micromachining and ultrasonic drilling) [2-4], thermal methods (laser drilling i.e. carbon dioxide (CO2) laser, excimer laser, liquid-assisted laser processing, ultra-short pulse (pico/femtosecond) laser, and focused electrical discharge), [5-6] chemical methods (wet etching and deep reactive ion etching) and hybrid methods (vibration-assisted micromachining, laser-assisted micro-cutting/milling, laser-induced plasma micromachining, water-assisted micromachining, chemical-assisted micromachining, chemical-assisted ultrasonic machining, electrorheological fluid-assisted ultrasonic machining, electrical discharge machining (edm) with an assisted electrode and hot embossing) [7-10].

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Among all of the glass drilling methods, vibration assisted micromachining has shown great potential in drilling brittle material such as glass. Few of reported works on drilling float glass proved that by employing the ultrasonic vibration frequency on the rotating diamond tool results in lower thrust force, improved tool wear and reduction in chip generation [11-12].

It is therefore, in this paper, feasibility study on the effectiveness of employing rotary ultrasonic micro drilling (RUMD) toward chemical treated toughened glass were investigated. The experimental investigation will evaluate the burr formation and the generated thrust force magnitude. various aspects on drilling chemical treated toughened glass includes drilling parameters, clamping jig design, cutting condition and drilling strategy. The outcome from this work serve as a basis for advancing the technology related to micro machining of chemical treated toughened glass.

II. METHODOLOGY

A. Experimental Setup, Material and Tool

A three axis vertical machining center (VF1, HAAS milling machine Co., Ltd) were used for the drilling test. An ultrasonic BT40 tool holder was employed to the HAAS milling machine spindle with ultrasonic frequency of 20,000 Hz that generate an amplitude vibration of 3 µm. Figure 2 shows the rotary ultrasonic assisted machining device and experimental setup used in the experiment. An alumina oxide abrasive grit with the concentration of 15 % was used throughout the experiment. In addition, since the glass has superior strength and crack resistance properties a special design jig and fixturing was fabricated to hold the sample. The design of the work holding device need to be rigid to cater the compressive stress occur during the RUAD process in both entry and exit surfaces as shown in Figure 3.

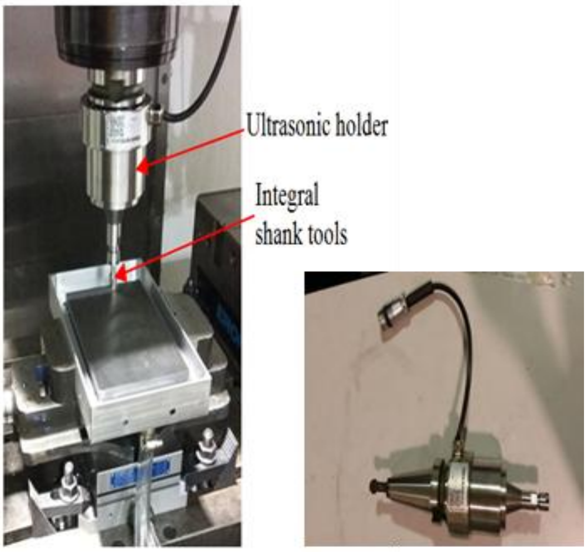

Figure 2: Rotary ultrasonic drilling setup and tool holder

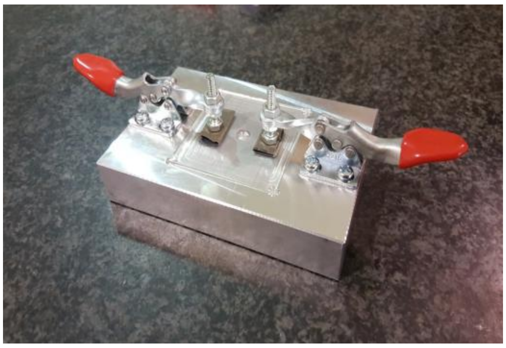

Figure 2: Clamping jig for holding the workpiece

Chemical treated toughened glass plate type Corning® Gorilla® Glass 3 with Native Damage Resistance™ with the geometry of 50×50×1 mm was used as the workpiece. Gorilla® Glass 3 with Native Damage Resistance™ are six to eight times the strength of soda lime as shown in Figure 3 and 4.

Central Composite Design (CCD) matrix of Response Surface Methodology (RSM) technique was used as DoE to evaluate the RUAD parameters input to the output responses. The independent variables and levels value namely spindle speed (A) and feed rate (B) were tabulated in Table I and Table II. The upper and lower limit value for the input variables were based from cutting tool's manufacturer recommendations and from past literature [2].

Table- I: Factors and levels

Factor	Range	Unit
Cutting speed, *N*	6000-7000	(rpm)
Feed rate, f	0.25-0.75	(mm/min)
Frequency, *f*	20	(kHz)
Amplitude, a	3	(µm)

Table- II: Experimental run

Run no.	Speed (rpm)	Feed rate (mm/min)
1	6000	0.5
2	6500	0.5
3	6000	1.5
4	6500	1.5
5	5896.45	1
6	6603.55	1
7	6250	0.29
8	6250	1.71
9	6250	1
10	6250	1
11	6250	1
12	6250	1
13	6250	1

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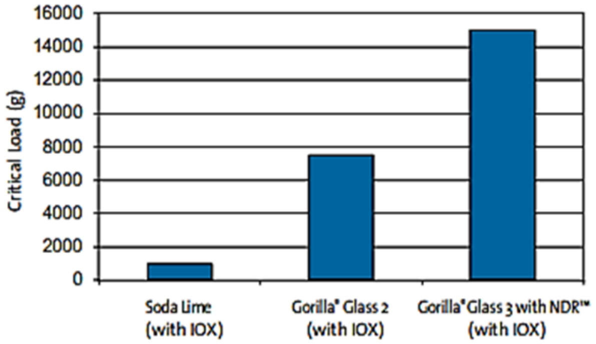

Figure 3: Comparison of damage resistance performance between glass type

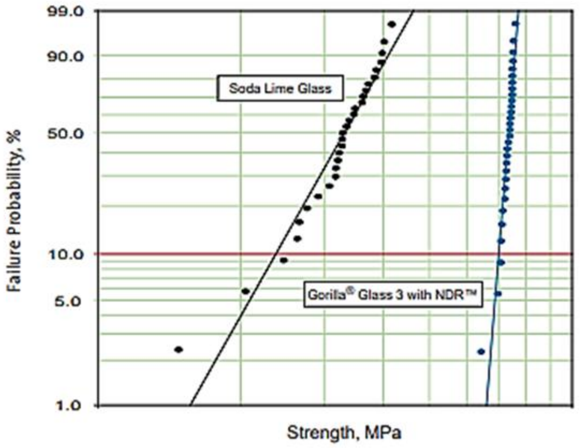

Figure 4: Failure load between glass type

A 0.5 mm diameter electroplated diamond tool with diamond abrasive grains (#600 size 25 – 35 µm) was used in performing the ultrasonic drilling process. The tool is constructed by a 3 mm diameter carbon steel (JIS SK5) shaft with two straight plane design for chips discharge purposes as depicted in Figure 5 and Figure 6.

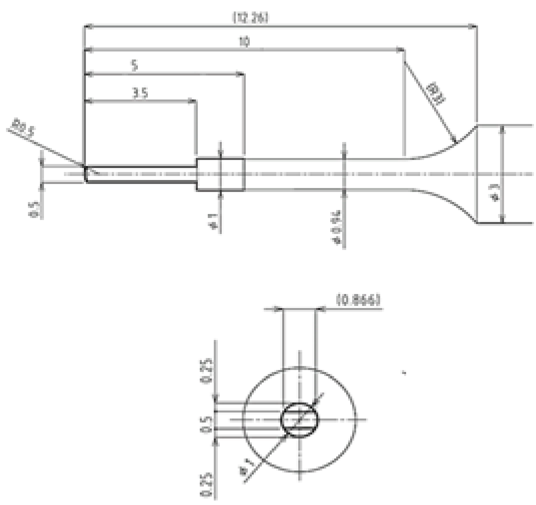

Figure 5: Details dimension of the electroplated diamond tool

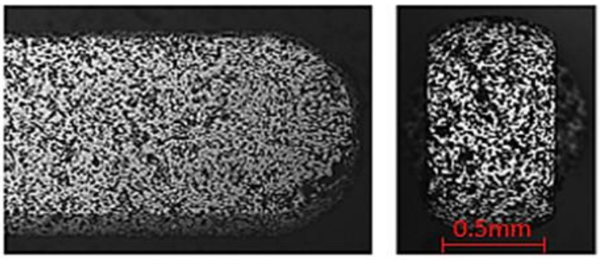

Figure 6: Electroplated diamond tool tip images

The drilling force was measured using Kistler Dynamometer place at the bottom of the glass. Optical microscope was used to captured the drilled holes images for the analysis. Subsequently, the image to be process by the ImageJ® software for measuring the chipping area at both entry and exit surface. Figure 7 illustrated the step taken for calculating the total chipping area i.e. entry and exit surfaces. To ensure the accuracy of the reading, the measurements were done five times.

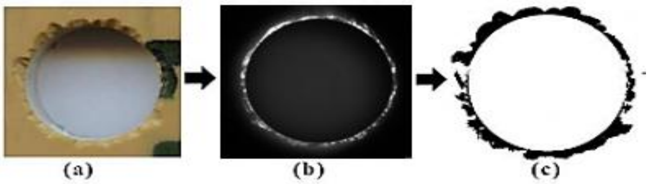

Figure 7: Image processing operations to determine the burr area (a) digital image (b) intermediate processed image (c) final processed image

III. RESULT AND DISCUSSION

A. Hole Performance - Burr Area Formation

Table 2 tabulated the holes' performances namely burr area and drilling force of run no 1-13. The observed burr area value varied between 0.0762 mm^2 to 0.16545 mm^2. The variations on the observed values indicate that the RUAD drilling parameters has significant effects on the hole's quality. Figure 8 shows the burr area formation for the experimental runs.

Statistical ANOVA of burr surface areas (Table IV) was performed to further investigated the effects of RUAD parameters namely cutting speed and feed rate towards burr surface areas. Based on the ANOVA, a quadratic model was selected to exemplify the cutting parameters effects towards the burr surface areas.

In addition, from the analysis if the P-values of the cutting parameters are less than 0.05 indicate that these model terms significantly affect the response in the design space [9-10]. Based on the P-value the most significant factor was factor A^2 i.e. cutting speed. The results revealed that, as the cutting speed increases the burr area became smaller.

Table- III: Experimental result

Run no.	Burr area (mm^2)	Drilling force (Newton)
1	0.15855	1.62
2	0.15845	1.54

3	0.14945	1.79
4	0.16545	2.23
5	0.13125	1.81
6	0.1373	1.72
7	0.1012	1.37
8	0.09285	2.32
9	0.07845	1.71
10	0.0762	1.68
11	0.07915	1.69
12	0.0771	1.73
13	0.0767	1.76

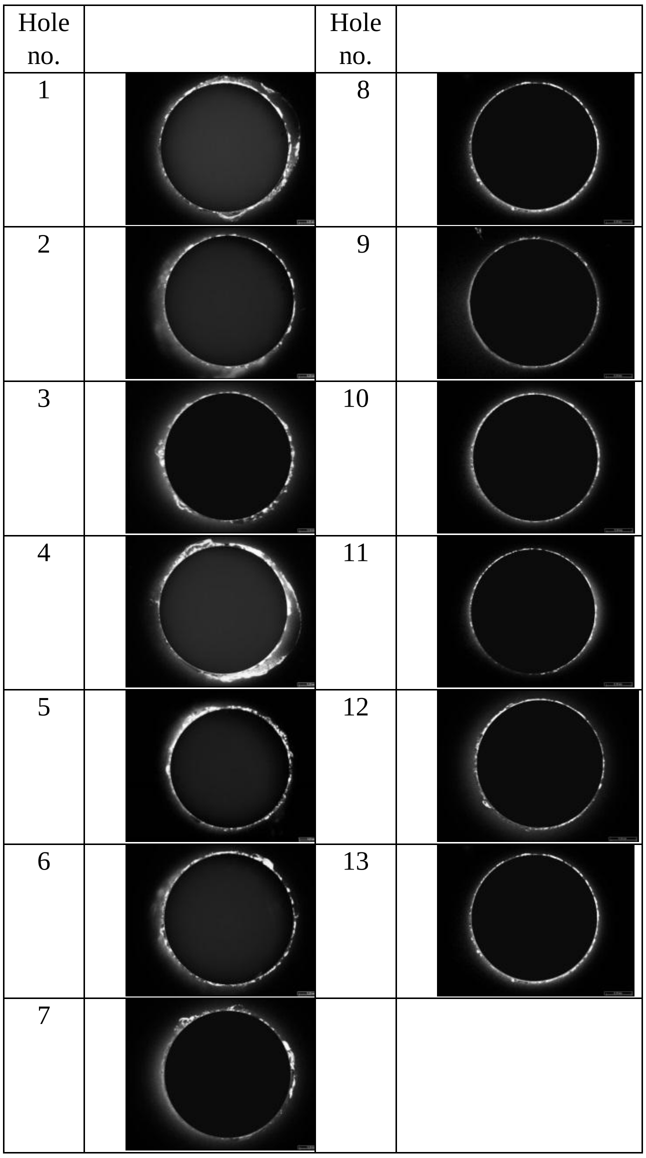

Figure 8. Burr surface area results

Table- IV: ANOVA result for burr area

Source	Sum of Square	DF	Mean Square	F	Prob > F
Model	0.012	5	2.47E-03	4.8	0.0318
A	7.48E-05	1	7.48E-05	0.15	0.7146
B	2.42E-05	1	2.42E-05	0.047	0.8347
A^2	0.011	1	0.011	20.49	0.0027
B^2	2.88E-03	1	2.88E-03	5.58	0.0502
AB	6.48E-05	1	6.48E-05	0.13	0.7333
Residual	3.61E-03	7	5.15E-04		
Lack of Fit	3.60E-03	3	1.20E-03	785.5	< 0.0001
Pure Error	6.11E-06	4	1.53E-06		
Cor. Total	0.016	12			

Figure 9 shows a 3d response surface plot on the burr area with regards to the speed and feed rate. Based on the produced holes it was observed that the burr formation started to occurred at almost two-third of the penetration depth which show webbing formation at the glass surface. In addition, the present of the ultrasonic vibration helps to improve the grinding process and chip evacuation as depicted in Figure 10.

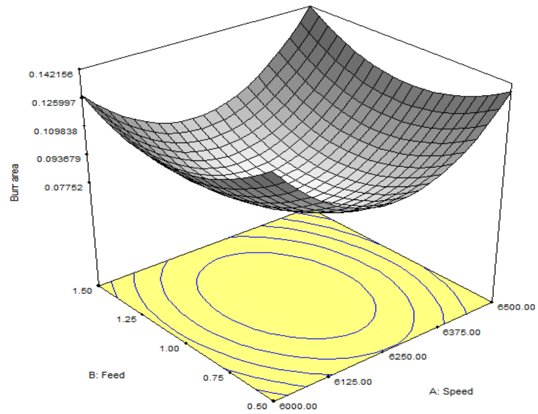

Figure 9: 3D response plot for burr area

B. Hole Performance – Drilling Force

Referring to Table 2 the drilling force value varied between 1.37 Newton to 2.32 Newton. The variations on the observed values indicate that the RUAD drilling parameters has significant effects on the hole's quality. Statistical ANOVA of drilling force (Table V) characterize a linear model between the cutting parameters effects towards the drilling force. Furthermore, from the analysis it was found that the most significant factor that affect the model was factor B i.e. feed rate. The finding show that as the feed rate increased the drilling force will also increase as agreed with other literatures [11-12].

Table- V: ANOVA result for drilling force

Source	Sum of Square	DF	Mean Square	F	Prob > F
Model	0.68	3	0.23	22.13	0.0002
A	6.77E-03	1	6.77E-03	0.66	0.4377
B	0.61	1	0.61	59.13	< 0.0001
AB	0.068	1	0.068	6.59	0.0304
Residual	0.092	9	0.01		
Lack of Fit	0.088	5	0.018	17.14	0.0083
Pure Error	4.12E-03	4	1.03E-03		
Cor. Total	0.77	12			

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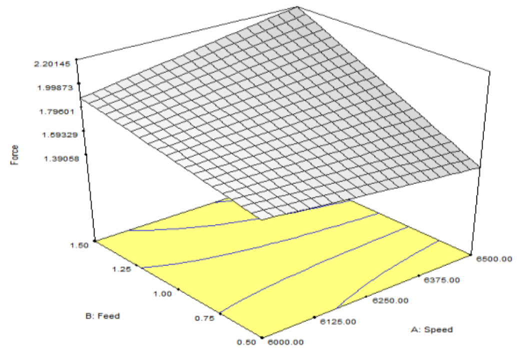

Figure 10: 3D response plot for force.

Figure 10 shows a 3d response surface plot on the drilling force towards speed and feed rate. Based on the graph, it shows that the maximum drilling force occurred at both high spindle speed and feed rate respectively.

IV. CONCLUSION

This paper has comprehensively performed a feasibility study on applying ultrasonic frequency on drilling chemically strengthened glass using electroplated diamond tool. The added feature of Native Damage Resistance^{TM} on chemically strengthened glass plate Corning® Gorilla® Glass 3 enhances the glass retained strength and creating high resistance to scratch and sharp contact damage. The experimental work proved that through ultrasonic drilling technique can be used to drill micro size hole at chemically strengthen glass surface with acceptable tolerance. It showed that through ultrasonic drilling technique, the material are removes via micro chipping and hammering of abrasive slurry to the glass surface. By employing this technique has causes the cutter to shear whilst periodically vibrate perpendicular to the work surface creating an intermittent cut at a constant feed that substantially improved the hole surface.

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