Experimental investigation of cutting temperature during drilling of float glass specimen

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Abstract. In today’s industrialization, hard and brittle material such as float glass are widely used in various applications such as micro-fluidic devices, bio-medical parts, automotive glass, and optical lenses. Due to its difficult-to-machine characteristic, drilling of float glass leads to defects related to drilled hole quality. These defects exemplify as chipping, crack and surface roughness. All these defects are directly depend upon the temperature which could affect the drilling quality. Hence, authors tried to investigate the influence of cutting temperature of float glass specimen using rotary ultrasonic drilling. The experimentation is performed at two conditions with constant value of ultrasonic amplitude (20 μm), feed rate (6 mm/min) and spindle rotation speed (5000 rpm). These conditions are without coolant and with-coolant drilling. It is noticed that maximum cutting temperature reached with coolant drilling is 50.56 °C and without coolant is 62.11°C. Consequently, it is revealed that drilling with coolant (water) should be adopted to improve the hole quality. Since, it reduced the formation of stresses during drilling operation which are induced due to rise in temperature. Microstructure images are carried out to visualize the hole quality.

1. Introduction
Continuous growth in the technology motivates the researchers to make enhance the machining and drilling quality. The demand for the efficient machining is continuously increasing especially for brittle materials i.e. float glass. Owing to high chemical and optical stability and incomparable thermo-mechanical properties, glass is widely used in optical lenses, automotive glass, reflectors, solar panels, and metrological instruments[1]. To facilitate good quality with high surface integrity during drilling, float glass should not possess any defects. But difficult to machine materials like float glass suffered numerous types of defects during drilling for instance chipping, surface roughness, and cracks which deteriorates the final hole’s quality[2-3].

At present, conventional machining process are not able to fulfill the demands of the current scenario due to generation of high temperature, low surface finish and high forces during drilling process. Therefore, hybrid machining processes has been becoming a potential candidate for hard, brittle, and tailor-made materials like float glass. The rotary ultrasonic machining (RUM) process is one of these non-conventional hybrid processes which combine the material removal mechanism of conventional drilling and vibration drilling.
Ding et al.[4] compared the results produced by conventional drilling (CD) and RUM in terms of hole quality with varying rotational speed and feed rate. The results revealed that RUM generates defect free holes with superior surface integrity. Huang et al. [5] highlighted that the use of coolant during drilling had a significant effect on the surface roughness of drilled hole on using high rotational speed and ultrasonic power during drilling with ultrasonic actuations. Zhang et al. [6] used compressed air coolant during RUM and CD of optical K9 glass and outlined that lesser cutting forces are produced on using ultrasonically actuated tool. Similarly, Cong et al.[7] investigated RUM for cutting force, surface roughness, and temperature using cutting fluid and cold air as coolant. It was found that coolant played a significant role in lowering the temperature generated during drilling. In another study [8], compared twist drilling and rotary ultrasonic drilling during machining of carbon fiber reinforced plastics. It was found that rotary ultrasonic process performed better than twist drilling in terms of better surface finish, low temperature, and high hole quality. On the same context, Kuruc et al.[9] investigated the rotary ultrasonic process during milling of polycrystalline CBN (cubic boron nitride) and outlined that RUM has the ability to machine hard material with less surface roughness. The rotational speed came out to be most influential parameter affecting the surface texture of workpiece.

In the light of above-mentioned literature, it can be stated that RUM has the ability to produce defect free high-quality surfaces. With this view, present study investigates the rotary ultrasonic machining process in terms of temperature produced during drilling of float glass ‘with coolant and ‘without coolant’ conditions. The parameters like rotational speed, feed rate, vibration power was kept constant. Further, microstructure analysis has been carried out to determine the effect of coolant on hole’s surface quality.

2. Material and methods
A rotary ultrasonic machining (RUM) set up are used to make holes in float glass material. A complete experimental set up includes ultrasonic generator, horn tool assembly, thermal camera, fixture, coolant nozzle, personal computer and float glass specimen as shown in figure 1. RUM has been working with 20 KHz of vibration frequency and 20 µm of vibration amplitude.

![Figure 1. Complete RUM experimental set up.](image_url)
In this study, diamond coated hollow abrasive tool is used to perform whole experimentation. The abrasive mesh size is in range of 100-150. Tool’s dimension as tool length (50.75 mm), tool outer diameter and inner diameter are 7.86 mm and 5.89 mm, respectively and abrasive coated lateral face is around 3.15 mm. The float glass specimen is composite of silica sand, salt cake, soda ash, limestone, dolomite and small broken glass pieces. It has a compressive strength of 212 MPa, poison’s ratio of 0.23, tensile strength of 50 MPa and Density (ρ) of 2500 Kg/m³. Fixed designed experimental factors are illustrated as shown in table 1.

| S. no. | Parameters                        | Unit   |
|-------|-----------------------------------|--------|
| 1     | Spindle rotation speed (N)        | 5000 rpm |
| 2     | Feed rate (fr)                   | 6 mm/min |
| 3     | Coolant type                     | Water  |
| 4     | Depth of cut or W/P thickness (T) | 5 mm   |
| 5     | Vibration amplitude              | 20 µm  |
| 6     | Glass specimen size (L*B*T)      | 148*84*5 mm³ |
| 7     | Tool type                        | Diamond coated hollow abrasive tool |

After completing all the drilling aspects while considering experimental setup capacity, the designed experimentation is performed at two conditions. These are (a) without coolant drilling, (b) With coolant drilling. In this study, overall 10 holes are created in which 5 holes are drilled at without coolant condition and remaining 5 holes are drilled with coolant condition. Water is acquired as a coolant which is widely used in glass drilling based industries. For the study, machining time is constant for both the drilling condition. Consequently, machining time (Tm) is estimated as 50 sec using Tm= T/fr. Where, Hole depth (T) is 5 mm, feed rate (fr) is 0.1 mm/sec.

Here, the cutting temperature at both the conditions is noticed using infrared camera (Keysight Technologies-U5855A) as shown in figure 1. ‘Keysight true IR analysis software’ is used further to collect thermo-graphic images. The temperature recording is performed by focusing the camera light on drilling zone (contact region between tool and workpiece). The value of emissivity and humidity during observation are 0.90 and 50 %, respectively. The range of temperature quantification is 0 to 350ºc. In each second, 8 frames are taken place. As, the total machining time is 50 sec, in total 400 frames are has been carried out.

3. Results and discussion

Figure 2 illustrates the thermo-graphic images at various stages during rotary ultrasonic drilling. Figure 2 (a) depicts the thermo-graphic images showing the initial drilling temperature (29.75ºc) at without coolant condition. Figure 2 (b) shows the image of maximum drilling temperature (62.11ºc) at without coolant condition. Figure 2 (c) and figure 2(d) illustrate the images of initial drilling temperature (29.70ºc) at with-coolant condition and maximum drilling temperature (50.56ºc) at with-coolant condition.
Figure 2. Illustration of thermo-graphic images at various stages during rotary ultrasonic drilling: (a) Initial drilling temperature at without coolant condition, (b) Maximum drilling temperature at without coolant condition, (c) Initial drilling temperature at with coolant condition, (d) Maximum drilling temperature at with coolant condition.

After visualizing the thermo-graphic images, it is noticed that as compare to ‘without coolant condition’, at ‘with coolant condition’ the temperature is reduced by 11.55 °C. Figure 3 shows the comparison of drilling/cutting temperature with respect to time for without coolant and with coolant conditions.

Figure 3. Comparison of drilling temperature with respect to time for without coolant and with coolant conditions.

This reduction in temperature is because of heat dissipation in case of ‘with coolant condition’ is far superior to other case. It is cleared that from the initiation of drilling till conclusion of drilling, there is a drastic effect of presence of coolant is visualized which leads to decrease in thermal energy caused by friction produced between the tool face and float glass periphery. This friction could also
affect the quality of the hole specifically at the corners [10]. Figure 4 shows the microscopic image at two drilling conditions (without coolant and with-coolant).

![Microscopic image at two drilling conditions](image)

**Figure 4.** Microscopic image at two drilling conditions (without coolant and with-coolant) with 50x and 150x magnification.

As shown in microscopic images, it is noticed that use of coolant could also aid in reducing the hole quality. More chipping amount is occurred seen nearby float glass edges at ‘without coolant condition’. It means the reduction in cutting temperature would be the prime concern that can also raise the float glass application. It can be visualize that the surface corner damages would ultimately effected by the cutting temperature. Thus, the implementation of cutting fluid, which acts as a coolant, is very crucial during drilling of brittle materials. Consequently, it is revealed that drilling with coolant (water) should be adopted to improve the hole quality. Since, it reduced the formation of stresses during drilling operation which are induced due to rise in temperature.

4. **Conclusion**
An experimental investigation has been performed to confirm the influence of cutting temperature of float glass specimen using rotary ultrasonic drilling. The key conclusion has been drawn as:

- Drastic effect of coolant is visualized which leads to decrease in thermal energy caused by friction produced between the tool face and float glass periphery.
- Maximum cutting temperature reached with coolant drilling is 50.56 °c and without coolant is 62.11°C.
- Cutting temperature is reduced by 11.55 °c by using ‘with coolant condition’ drilling.
- It is affirmed that the damages occurred at the drilled corner ultimately affected by the cutting temperature.

5. **Future scope**
A study could happen to quantify the optimum amount and flow rate of coolant required during drilling. A study on effect of ‘without coolant and with-coolant’ conditions on tool wear can also consider.
References

[1] P. D. Gaudio, H. Behrens, J. Deubener, Viscosity and glass transition temperature of hydrous float glass, J Non Cryst Solids 353, 223–236 (2007). doi: 10.1016/j.jnoncrysol.2006.11.009

[2] A. Sharma, V. Jain, D. Gupta, Multi-shaped tool wear study during rotary ultrasonic drilling and conventional drilling for amorphous solid 0,1–10 (2018). doi: 10.1177/0954408918776724

[3] A. Sharma, V. Jain, D. Gupta, Characterization of Chipping and Tool wear during drilling of Float glass using rotary ultrasonic machining, Measurement 128, 254–263 (2018). doi: 10.1016/j.measurement.2018.06.040

[4] K. Ding, Y. Fu, H. Su, Experimental studies on drilling tool load and machining quality of C/SiC composites in rotary ultrasonic machining, J Material Process Technol 214, 2900–2907, (2014). doi: 10.1016/j.jmatprotec.2014.06.015

[5] D. Lv, Y. Huang, Y. Tang, H. Wang, Relationship between subsurface damage and surface roughness of glass BK7 in rotary ultrasonic machining and conventional grinding processes, Int J Adv Manuf Technol 67, 613–622, (2013). doi: 10.1007/s00170-012-4509-1

[6] C. Zhang, W. Cong, P. Feng, Z. Pei, Rotary ultrasonic machining of optical K9 glass using compressed air as coolant: A feasibility study, Proc Inst Mech Eng Part B J Eng Manuf 228, 504–514, (2014). doi: 10.1177/0954405413506195

[7] Q. Feng, W. L. Cong, Z. J. Pei, C. Z. Ren, Rotary ultrasonic machining of carbon fiber-reinforced polymer: Feasibility study, Mach Sci Technol 16, 380-398, (2012). doi: 10.1080/10910344.2012.698962

[8] F. D. Ning, W. L. Cong, Z. J. Pei, C. Treadwell, Rotary ultrasonic machining of CFRP: A comparison with grinding, Ultrasonics 66, 125–132, (2016). doi: 10.1016/j.ultras.2015.11.002

[9] Kuruc M, Vopat T, Peterka J Surface roughness of poly-crystalline cubic boron nitride after rotary ultrasonic machining. In: Energy Procedia 100, 877-884, (2015).

[10] G. Deng, Z. Lu, G. Yao, J. Liu, Z. Li, D. Zhang, Cutting temperature and resulting influence on machining performance in rotary ultrasonic elliptical machining of thick CFRP, International Journal of Machine Tools and Manufacture 123, 160–170, (2017).