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Original Research

Mitigation of Edge Fracture in Tempered Glass During Abrasive Water Jet Cutting

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Abstract

When an 8 mm-thick glass hob plate is cut in a circular shape using high-pressure abrasive water jet cutting in two distinct sizes, it leads to issues such as breakage and burr formation along the edges. As a result, a secondary grinding process becomes necessary, which not only wastes time but also drives up the cost. Additionally, this process increases the amount of scrap material produced. The goal of this research is to optimize the cutting process by experimentally determining the parameters that affect the edge quality of the 8 mm-thick glass, specifically after adjusting the diagonality of a CNC abrasive water jet cutting machine to improve the circularity of the cut. Various tests were conducted under different pressures, flow rates, nozzle types, orifice sizes, and garnet abrasives. The findings revealed that the most efficient and defect-free cutting conditions were achieved with a 2000 bar pressure, 0.4 kg/m abrasive flow rate, 0.76 mm nozzle, 0.25 mm orifice, 120 mesh garnet abrasive, and a cutting speed of 1000 mm/min.

Keywords: water jet, cutting, glass, breakage

1. Introduction

The water jet cutting method allows all artificial and natural materials to be cut efficiently without heat effects and without the need for tool changes (Akkurt, 2004; Bohez, 2001; Bohez, 2002; Chen et al. 2012; Ghobeity et al., 2009). The process is carried out by directing water, pumped at high pressure, either pure or with abrasives, onto the material to be cut. During cutting, the distance between the water jet and the material, as well as the feed rate, must be maintained. For this reason, automatic speed-controlled cutting systems are integrated into the process.

Water jet technology was first discovered and used in the mining sector in the second half of the 19th century for hydraulic washing. In the early 20th century, experiments on cutting rocks with pressurized water were carried out, reaching pressures of up to 500 bar. By the 1970s, equipment capable of generating 2750 bar was developed, and in 1972, the first industrial water jet cutting system was launched (Akkurt, 2004; Bohez, 2001). Later, by mixing abrasive materials into the pressurized water, harder materials such as glass could be cut more effectively (Ibaraki & Ota, 2014). Today, cutting systems using up to 6200 bar are available. There are two main types of water jet cutting: pure water jet cutting, in which only water is directed onto the material (suitable for softer materials), and abrasive water jet cutting, in which abrasives such as garnet are mixed with the jet, making it possible to cut harder materials such as glass (Ibaraki & Ota, 2014; Kuriyagawa et al., 1998).

Modern CNC-integrated water jet systems are capable of complex geometries such as zig-zag cuts, sharp corners, narrow angles, and very small radii (Fig. 1). Nesting software also optimizes material usage (Harničárová et al., 2013).

The greatest advantage of water jet cutting is that it is a cold cutting process. Since no mechanical or thermal stresses are generated, there is no need for post-processing stress-relief. This allows cutting without hardening, burning, deformation, molten residues, or harmful gases (Izawa, 2000; Miller, 2003).

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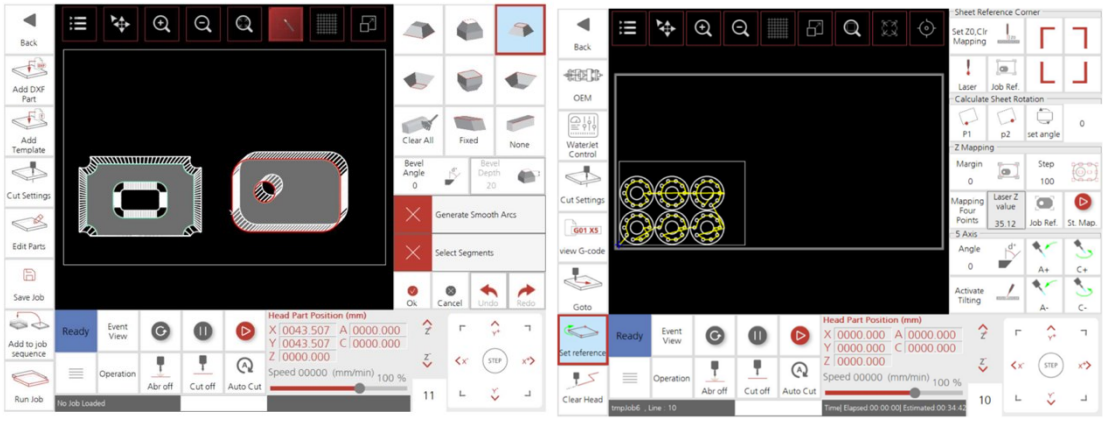

Fig. 1. Work window of waterjet cutting software.

Since the mechanical interaction during cutting occurs at the micro/molecular level, no deformation is induced on the material despite the high kinetic energy carried by the water jet. When appropriate parameters are selected and precise positioning is ensured, a burr-free cutting process can be achieved. Consequently, the cut edges obtained by water jet cutting exhibit remarkable cleanliness, eliminating the need for costly secondary deburring operations. Moreover, due to the very narrow kerf width (maximum of 1.1 mm), material losses are minimized. Depending on the jet beam diameter, very narrow and sharp corners can be cut. With the same cutting equipment, materials of different thicknesses and types can be processed simply by adjusting the cutting speed, without requiring any hardware modifications.

2. Principles and application of water jet cutting systems

A water jet cutting system operates with a high-pressure pump generating between 1500 and 6000 bar. Water is conveyed through pipes into the cutting head, where an on/off pneumatic valve controls its flow. The water is then passed through a sapphire or diamond orifice, accelerating it to nearly three times the speed of sound, and mixed with abrasives before exiting the nozzle to cut the material (Fig. 2) (Kalina, 1999; Khan & Haque, 2007; Kuriyagawa et al., 1998; Momber & Dovacevic, 1998; Rajamani et al., 2020).

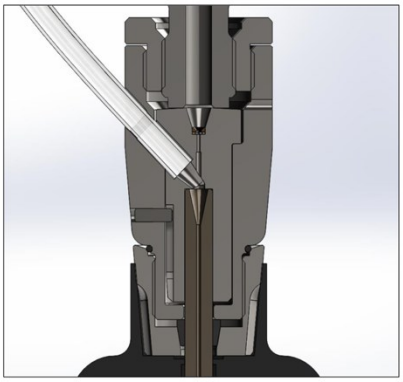

Fig. 2. Cross-sectional view of the cutting head, illustrating the abrasive jet cutting mechanism with a sapphire/diamond orifice and the nozzle assembly.

The orifice diameter is typically between 0.20 mm and 0.35 mm. The combination of orifice size, nozzle diameter (0.6–1.02 mm), abrasive grain size (80–120 mesh), and abrasive feed rate critically influence cut quality (Hashish, 1991; Hsu & Lei, 2003). On/off valve controlling the supply of pressurized water is presented in Fig. 3.

The orifice size, which is selected based on the pump capacity and the delivered water volume, is a critical parameter for achieving high-quality cutting. Figure 4 illustrates the relationship between orifice diameter and flow rate. The high-pressure water exiting the orifice is typically mixed with garnet abrasives of 80–120 mesh size inside a nozzle with an inner diameter ranging from 0.60 mm to 1.02 mm. Cutting was performed by maintaining an average stand-off distance of 2–3 mm between the nozzle tip and the workpiece. Abrasive particles can be entrained into the jet stream by vacuum suction, although dedicated abrasive feeding systems are often employed to ensure a more uniform flow (Hashish,

1991; Hsu & Lei, 2003). For consistent performance, the abrasive-laden water jet must maintain a constant traverse speed while cutting the material (Izawa, 2000; Miller, 2003).

An abrasive feeding system (Fig. 5) precisely controls garnet flow into the nozzle, ensuring a uniform jet and consistent cutting performance (Hsu & Lei, 2003). The amount of abrasive delivered is also regulated according to the voltage values provided by the water jet cutting software and the CNC system, as illustrated in Fig. 6 (Hsu & Lei, 2003).

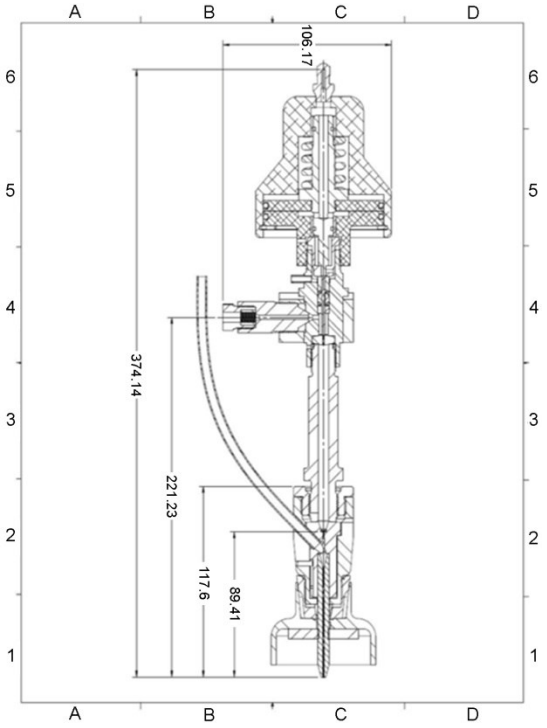

Fig. 3. On/off valve controlling the supply of pressurized water (dimensions in mm).

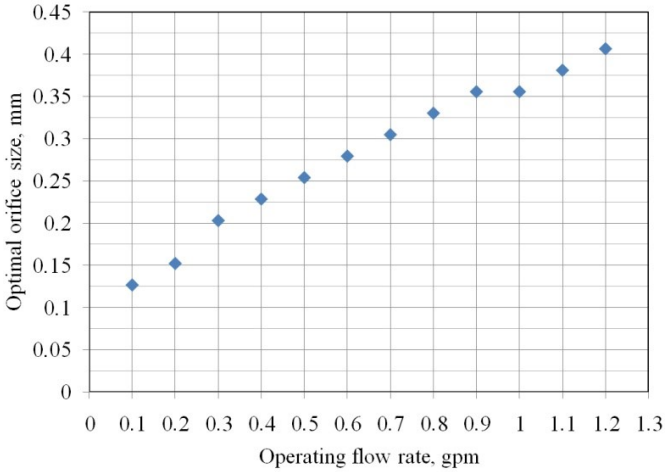

Fig. 4. Relationship between orifice diameter and flow rate.

Fig. 5 Abrasive dosing system.

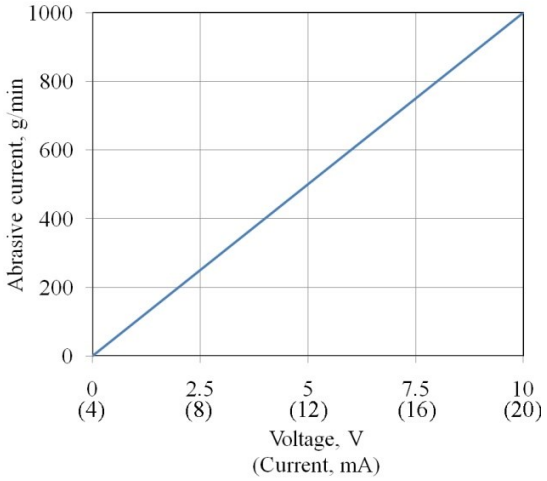

Fig. 6. Voltage/flow rate graph of the abrasive dosing system, prepared on the basis of KMT (n.d.).

3. CNC machine squareness accuracy

The squareness of the CNC machine's X and Y axes is crucial for achieving proper circular cuts and minimizing breakage or chipping along the edges. Before conducting experiments, the machine squareness was measured and corrected parametrically through the CNC control system using Y1 and Y2 motors (Figs. 7 and 8). This compensation technique is essential in minimizing circularity errors (Shanmugam et al., 2008; Şimşir 2009; Srinivasu et al., 2009; Summers, 1995; Tazibt et al., 1996).

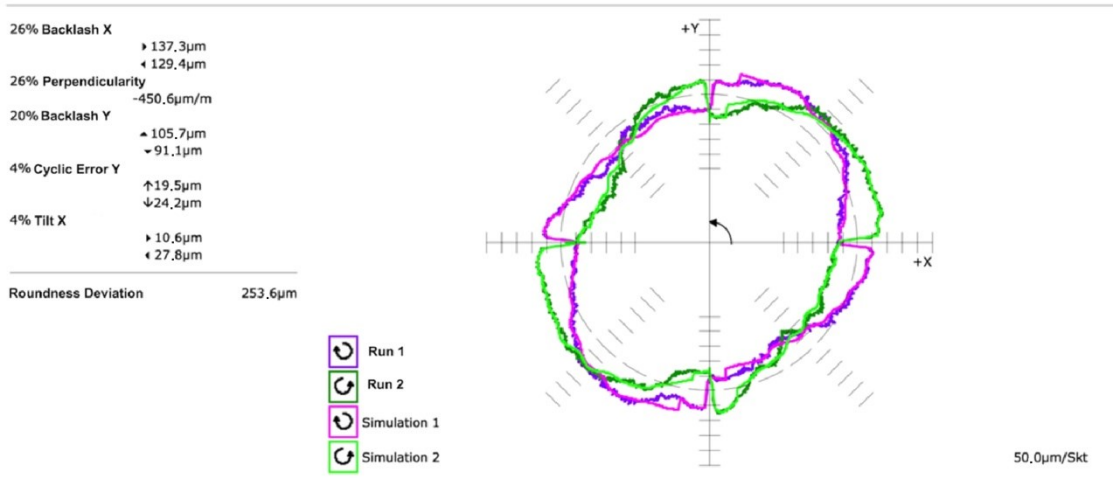

Fig. 7. Squareness before correction.

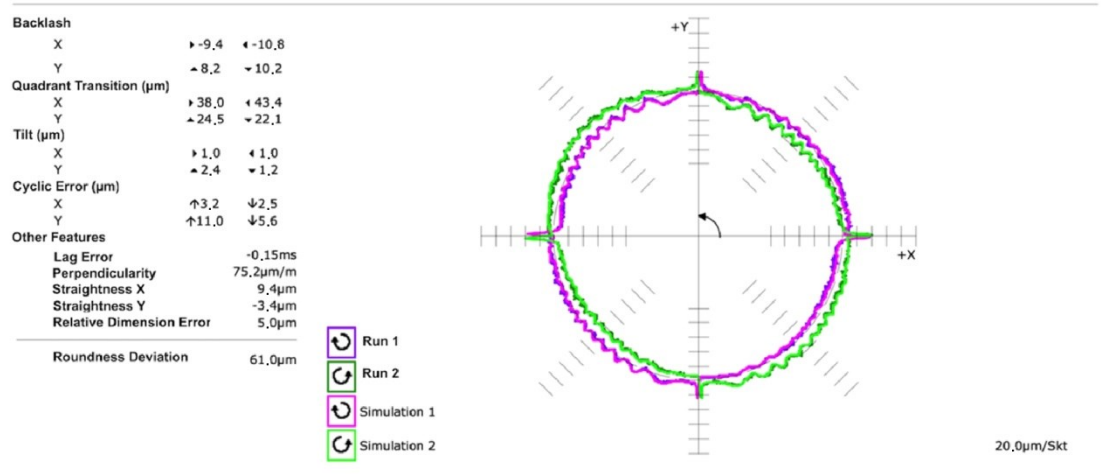

Fig. 8. Squareness after correction.

4. Experiments on the selection of cutting speed

If CNC machine positioning accuracy and squareness are insufficient, or parameters such as abrasive flow, grain size, nozzle-orifice combination, and cutting speed are improperly chosen, the cutting quality decreases (Izawa, 2000; Miller, 2003).The use of appropriate cutting parameters not only enhances cut quality but also reduces overall cost through lower abrasive consumption and decreased energy usage. Furthermore, it minimizes time losses and enables higher cutting speeds, thereby improving process efficiency.In this study, different combinations of water jet pressure, abrasive flow rate, diameter of nozzle, diameter of orifice, and abrasive mesh were tested (Table 1). Among 16 test runs, the best results were obtained in experiment no. 14, with parameters of 1000 bar, 0.4 kg/min abrasive flow, 0.76 mm nozzle, 0.25 mm orifice, 120 mesh garnet, and 1000 mm/min cutting speed.

Table 1. Test matrix.

Test no.	Water jet pressure (bar)	Abrasive flow rate (g/min)	Diameter of nozzle (mm)	Diameter of orifice (mm)	Garnet (mesh)	Cutting speed (mm/min)
1	3500	500	1.02	0.35	80	1200
2	3500	400	1.02	0.35	80	1000
3	3500	300	1.02	0.35	80	800
4	3500	200	1.02	0.35	80	600
5	3000	500	1.02	0.35	80	1200
6	3000	400	1.02	0.35	80	1000
7	3000	300	1.02	0.35	80	800
8	3000	200	1.02	0.35	80	600
9	2500	500	0.76	0.25	120	1200
10	2500	400	0.76	0.25	120	1000
11	2500	300	0.76	0.25	120	800
12	2000	200	0.76	0.25	120	600
13	2000	500	0.76	0.25	120	1200
14	**2000**	**400**	**0.76**	**0.25**	**120**	**1000**
15	2000	300	0.76	0.25	120	800
16	2000	200	0.76	0.25	120	600

The results showed that the edge quality was significantly improved, and chipping was eliminated in 8 mm-thick circular glass cuts. The best cutting results were obtained using the parameters of experiment no. 14, and it was observed that the edges of the 8 mm glass cut in a circular shape were free of chipping, resulting in a smoother edge quality. Examples of chipping observed in circular cuts with diameters of 100 mm and 30 mm, as well as clean cuts, are shown in Figure 9.

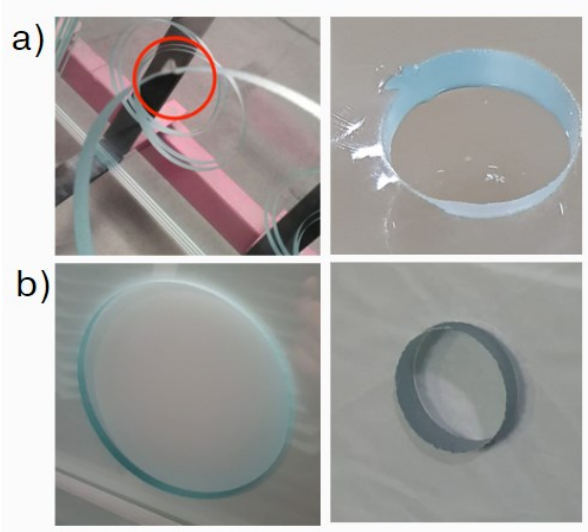

Fig. 9. Experimental results of cuts (a) performed with inappropriate parameters and (b) performed with appropriate parameters (experiment no. 14).

5. Conclusions

The experimental results presented in Table 1 clearly demonstrate the influence of each cutting parameter on edge quality and chipping during abrasive water jet cutting of 8 mm tempered glass. Higher pressures (3500 bar) combined with large abrasive flow rates (500 g/min) increased material removal but also produced more pronounced edge chipping, whereas moderate pressures (2000–2500 bar) with optimized abrasive flow rate (400 g/min) yielded smoother edges with minimal defects. Similarly, the

nozzle–orifice combination of 0.76 mm/0.25 mm, together with a 120-mesh garnet, produced a narrower kerf and cleaner cut compared with the larger 1.02 mm/0.35 mm setup and 80-mesh abrasive. Cutting speed also had a significant effect: at 1000 mm/min, edge quality improved compared to both slower (600–800 mm/min) and faster (1200 mm/min) traverses. These observations confirm that the optimized set of parameters used in experiment no. 14 is the most effective for minimizing chipping and achieving high-quality circular cuts.

Overall, the study shows that careful adjustment of pressure, abrasive feed rate, nozzle–orifice dimensions, abrasive mesh size, and cutting speed allows the process to be tailored for defect-free glass cutting, thereby reducing post-processing requirements and improving production efficiency.

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Zapobieganie Pękaniu Krawędzi Szkła Hartowanego Podczas Cięcia Strumieniem Wodno-Ściernym

Streszczenie

Cięcie szklanej płyty grzewczej o grubości 8 mm w kształcie koła za pomocą strumienia wody ze ścierniwem pod wysokim ciśnieniem w dwóch różnych rozmiarach prowadzi jest problematyczne ze względu na pękanie i powstawanie zadziorów na krawędziach. W rezultacie konieczne staje się wtórne szlifowanie, co nie tylko marnuje czas, ale również podnosi koszty. Ponadto proces ten zwiększa ilość wytwarzanego materiału odpadowego. Celem badań, których wyniki przedstawiono w niniejszym artykule, była optymalizacja procesu cięcia poprzez eksperymentalne określenie parametrów wpływających na jakość krawędzi szkła o grubości 8 mm, w szczególności po dostosowaniu ustawień maszyny CNC do cięcia strumieniem wodno-ściernym w celu poprawy okrągłości cięcia. Przeprowadzono szereg testów przy różnych ciśnieniach wody, natężeniach przepływu, typach dysz, średnicach otworów i ścierniwach granatowych. Wyniki wykazały, że najbardziej efektywne i wolne od wad warunki cięcia uzyskano przy ciśnieniu 2000 bar, przepływie ścierniwa 0,4 kg/m^3, średnicy otworu w dyszy 0,76 mm, średnicy otworu kryzy 0,25 mm, materiale ściernym z granatu o rozmiarze 120 mesh i prędkości cięcia 1000 mm/min.

Słowa kluczowe: strumień wody, cięcie, szkło, uszkodzenie