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Waterjet cutting of cross-linked glass

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The cutting of cross-linked glasses such as silica and Corning 7059 can be difficult. We conducted an experimental study to determine the feasibility of using a high-speed waterjet to cut thin Corning 7059 glass. Cutting using either pure de-ionized high pressure water at 380 MPa (55 000 psi) or de-ionized water with entrained garnet abrasive was studied. The roughness of the cut surfaces was measured and compared. Photomicrographs were taken of glass examples cut at different traversing rates with pure water and with the abrasive entrained waterjet. Comparative studies of cutting with and without the entrained abrasive material showed that a cutting rate of 127 mm/min with abrasive could achieve a smoothness of about 9 μm rms. The abrasive waterjet can cut Corning 7059 glass into any desired shape. The process is safe, inexpensive, fast, and amenable to computer operation. © 1995 American Vacuum Society.

I. INTRODUCTION

The problem of cutting cross-linked glasses such as silica and Corning 7059 is very difficult. Soda lime, alkali borosilicate, and other common glasses normally can be cut in a fairly straightforward way using a scribe, wheel, or saw. These common glasses, however, are not suitable for certain electronic applications without the use of a barrier layer, because they contain alkali metal ions in the glass which are electrically active and act as fast diffusers.¹ In addition, these common glasses may not be useful in applications that require high-temperature processing because they contain the ingredients of low-melting materials.

High-temperature and alkali-metal-free glasses are cross-linked to a higher degree. Such glasses can break unpredictably, usually not along straight lines or scribe marks made on the glass. These cutting difficulties result in material and fabrication costs that can be expensive to users. Successful techniques for cutting heavily cross-linked Corning 7059 substrates can be very interesting to scientists and engineers using these glasses. One such method, laser scribing, has proven advantageous for many applications.² Such equipment, however, is often not readily available and does leave a heat affected zone in the glass at the edge of the cut which can produce local thermal stresses causing fracture or other undesired effects.² Scribe and break methods are used commercially to cut Corning 7059. Experience and the appropriate settings on the scribe-and-break machine for Corning 7059, however, are required to avoid random breaks and reduce waste.

Waterjet cutting has been developed for cutting a wide variety of materials and does not produce a heat affected zone in the workpiece material. Almost all the heat generated by the cutting action is carried away by the water. This article discusses the use of waterjet cutting of Corning 7059

glass for certain applications. We have found it to be a very flexible cutting process to prepare Corning 7059 glass substrates for microelectronic applications.

II. EXPERIMENT

Approximately 20 samples of 1-mm-thick Corning 7059 borosilicate glass were cut at various traversing speeds using a Flow International model 9 \times intensifier pump and Paser II abrasive mix nozzle delivery system. The nozzle was moved and positioned by a 1.2 m \times 1.8 m (4 ft \times 6 ft) gantry robot, controlled by a 80486 PC-based computer system. The machine precision was ± 0.13 mm (± 0.005 in.) in the 15 \times 15 cm (6 \times 6 in.) working area used in this experiment. The pressure and flow rate of the de-ionized waterjet stream employed for cutting were, respectively, 380 MPa (55 000 psi) and 3 ℓ /min (0.8 gal/min).

The gantry robot and the associated controller were designed and built by a team of senior mechanical and manufacturing engineering students as part of Brigham Young University's Senior Capstone program called Integrated Product and Process Design.³ The machine is also used for other research and manufacturing engineering projects. The major cost elements in the operation of abrasive-waterjet systems are the capital cost of the equipment and the cost of power, abrasive material, and the nozzles (due to wear). The operational costs per in. of cut is estimated to range from \$0.03 to \$0.10.⁴

It is useful to compare wire electrical discharge machining (EDM) to waterjet machining. Both can cut sheets of materials into any two-dimensional shapes. In the case of wire EDM, the wire has to be passed through a hole in an electrically conductive workpiece material and located properly. There are no such requirements, however, for waterjet machines. Waterjet cutting is a much more flexible cutting

process than the wire EDM process. The workpiece material does not need to be conductive, and no predrilled hole is required in the workpiece to enable the cutting operation to start.

Two variations of the waterjet cutting method were used to cut the glass in this study: abrasive and nonabrasive. In the nonabrasive mode the high-pressure de-ionized water stream was accelerated to 915 m/s (3000 ft/s) by forcing the water through a 0.35 mm (0.013 in.) diamond orifice. In the abrasive cutting mode a 50/50 mixture of 60 and 80 mesh garnet was mixed with the same high-velocity waterjet stream in a Venturi chamber and then allowed to expand and pass through a 1.0 mm (0.040 in.) mixing tube.

Specimens were placed on 5-cm-thick (2 in.) Styrofoam for support and were held in position during cutting using small (3 kg) weights to prevent movement. Both straight line cuts and holes were produced. To make the straight cuts in the samples, the nozzle was positioned 3 mm (1/8 in.) above the specimen. Various traversing speeds from 127 to 1270 mm/min (5 to 50 in./min) were used. Rectangular specimens, approximately 2×8 cm, were cut from larger pieces.

Holes also were pierced in the Corning 7059 glass by using a technique of placing a 2.4-mm-thick (0.094 in.) piece of aluminum plate over the glass to protect the glass while the hole was cut. The aluminum plate was held in place using a weight. The waterjet pressure was lowered to 82.7 MPa (12 000 psi) to lessen the impact of the jet on the workpiece,^{5,6} and the waterjet was operated in the abrasive mode using a garnet abrasive. It took approximately 20 s to pierce the aluminum cover and the glass beneath it. The resulting hole in the pierced glass measured 2.1 mm (0.084 in.) in diameter. Larger holes were produced by moving the jet in a circular path once the initial hole has been pierced.

Photomicroscopy and profilometry were used to understand the roughness of the cut surfaces. Photographs of the cut glass edges were obtained with a Zeiss dissecting binocular optical microscope, also called a stereomicroscope, using a magnification of approximately 70×. Surface measurements in this study involved the use of two kinds of instruments. One is an optical comparator made by Jones & Lamson Co. The other is a surface texture profilometer made by Mitutoyo Corporation, model SurfTest 201, series 178. The optical comparator can show height difference between peaks and valleys and average length between peaks and valleys on the surface of the cut while the profilometer gives a root mean square (rms) value over a distance of 0.8 mm.

III. RESULTS

A variety of test cuts were performed using the cutting technique described in Sec. II. It was found that the waterjet stream could easily cut the 1-mm-thick Corning 7059 glass plates into any shape with or without the addition of the garnet abrasive material. By using an abrasive waterjet stream it is also possible to pierce a relatively small hole in the glass. Comparisons between the edges cut by the waterjet stream with and without garnet are described next. Photomicroscopy and profilometry were used to understand and discuss the roughness of the cut surfaces.^{7,8}

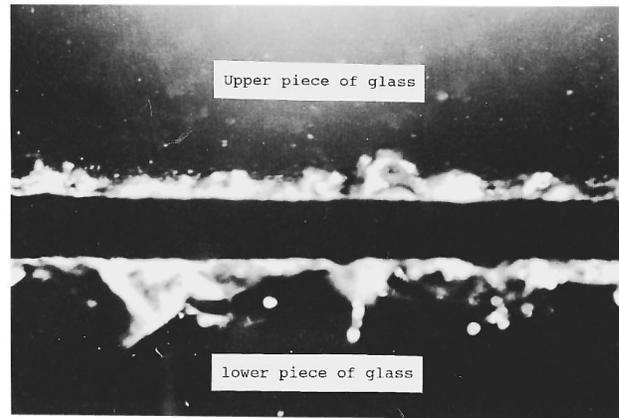


FIG. 1. Edges of the Corning 7059 glass cut at a rate of 127 mm/min by a waterjet. The upper edge is cut with a garnet abrasive material entrained in the waterjet stream and the lower edge is cut without garnet.

The high speed waterjet, with or without the addition of an abrasive material, cuts Corning 7059 glass. Figure 1 shows that, at the same cutting rate, the edge cut by the abrasive waterjet is smoother than the one cut without the



(a)



(b)

FIG. 2. (a) A section of the Corning 7059 glass cut at the rate of 127 mm/min with garnet using a waterjet. (b) A section of the Corning 7059 glass cut at the rate of 127 mm/min without garnet using a waterjet.

TABLE I. Optical comparator measurements. All the results shown are for waterjet cutting using 50%–50% mixture of 60–80 abrasive material, except those in the far right column, where only water was used.

Cutting (mm/min)	127	1270	2540	127
Height difference between peaks and valleys (μm)	25.4	25.4	25.4	127
Average length between peaks and valleys (μm)	76.2	25.4	50.8	25.4

garnet material. The workpiece shows no evidence of a heat affected zone. This is expected since the waterjet cutting process produces negligible heating.

Figure 2 shows a cut section of the Corning glass plates. Note that the cut section using abrasive material is smoother than that produced by the water stream alone as can be seen by comparing Fig. 2(a) with Fig. 2(b). Data produced by comparing the two cut surfaces using an optical comparator, shown in Table I possess a standard deviation of $\pm 0.1 \mu\text{m}$ for height difference between peaks and valleys and $\pm 0.2 \mu\text{m}$ for average length between peaks and valleys, which shows that the height differences between peaks and valleys cut at various rates with garnet are all the same, 0.025 mm (0.001 in.). However, the average lengths between peaks and valleys are different. It is evident that, for the same height difference, the longer the average length between peaks and valleys, the smoother the cut section. Table I also indicates that the height difference cut with garnet is smaller than the height difference cut without garnet which is 0.127 mm (0.005 in.). The average distance between a peak and a valley on the cut section done at a rate of 127 mm/min (5 in./min) with garnet is about 0.076 mm (0.003 in.), while the one without garnet is 0.025 mm (0.00098 in.) (see Table I). From the above data, we can see that the cutting mechanism is different with garnet than without. The cut produced with garnet has the appearance of having been broken and ground, while the cut without garnet has the appearance of having been broken or cracked without having been ground.

Table II shows the average profilometer rms surface roughness for the various cutting rates employed. For each sample we measured rms values at four test areas that were randomly chosen on the cut surfaces of the glass. From these data we established an average rms value with a standard deviation of $\pm 0.2 \mu\text{m}$.

Both surface roughness measurement methods show that, in general, the surface cut at the slowest rate of 127 mm/min (5 in./min) is the smoothest. As the cutting rate is increased, the roughness of the cut section increases. However, Table II

TABLE II. Surface texture profilometer measurements. All of the results shown are for waterjet cutting using 50%–50% mixture of 60–80 abrasive material.

Cutting rate (mm/min)	127	381	508	762	1016	1270	1524
Average rms (μm)	9.2	10.1	10.4	11.5	12.2	14.5	10.4

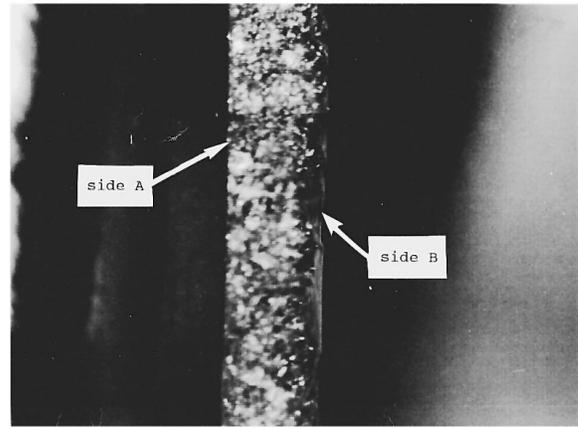


FIG. 3. A section of the Corning 7059 glass cut at the rate of 1270 mm/min with garnet, using a waterjet. Side A faces the waterjet stream; side B is away from the waterjet stream.

shows that, when the cutting rate is higher than 1270 mm/min (50 in./min), the cut section of the higher rate is smoother than the section cut at the rate of 1270 mm/min. Why this has occurred needs to be studied further. This may or may not be an anomaly.

In Fig. 3 the surface that was against the support plate is labeled “A,” and edge “B” is the side away from the plate. The waterjet stream passed from edge A to edge B. Edge A is smoother than edge B. It seems reasonable to anticipate that edge B will have a higher damage rate than edge A because there is no strong support for the backface of the glass adjacent to edge B.

As mentioned, the waterjet can also pierce holes on Corning 7059 glass plates. In our tests the smallest holes pierced on Corning 7059 glass plates were 2.1 mm in diameter. Some surface damage was noted around the small hole. It may be that this damage was caused by the garnet ricocheting off the sides of the metal plate covering the glass during piercing. This problem is not seen in larger holes where the damaged area is removed once the initially pierced hole is enlarged.

IV. CONCLUSION

The waterjet cutting process can cut cross-linked Corning glass into virtually any required two-dimensional shape. The results show that the cut edges of the glass using the waterjet process with an abrasive have a roughness of approximately $9.2 \mu\text{m}$ for a cutting rate of 127 mm/min. For some applications this cutting process can eliminate the need for secondary grinding and finishing. The entire process is relatively clean and cool with no resulting thermal or deformation stresses. The process has a high cutting speed and multidirectional cutting capabilities. Waterjet cutting as a process is amenable to computer control, ensuring accuracy and repeatability. Thus, waterjet cutting of electronic grade glasses may be of significant help when such equipment is available.

ACKNOWLEDGMENT

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