Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 42 (2016) 460 – 463

www.elsevier.com/locate/procedia

18th CIRP Conference on Electro Physical and Chemical Machining (ISEM XVIII)

Study on thermal stress cleavage of chemically strengthened glass by CO_2 laser beam

Hisashi OGI[a,]*, Tatsuaki FURUMOTO[b,]*, Tomohiro KOYANO[b,]*, Akira HOSOKAWA[b,]*

[a]*Graduate school of National Science and Engineering, Kanazawa University, Kakuma-machi, Kanazawa, Ishikawa 920-1192, Japan*
[b]*Institute of Science and Engineering, Kanazawa University, Kakuma-machi, Kanazawa, Ishikawa 920-1192, Japan*

* Corresponding author. Tel.: +81-76-234-4723. *E-mail address:* h.ougi@stu.kanazawa-u.ac.jp

Abstract

This study deals with the thermal stress cleavage of chemically strengthened glass by CO_2 laser beam irradiation. In order to prevent breakage from external stress, the surface of chemically strengthened glass is load with compressive stress by ion-exchanging methods. Generally, thermal stress cleavage occurs because of tensile stress on the brittle material. This stress is induced by laser beam irradiation. Therefore, the compressive stress on the surface of chemically strengthened glass renders the thermal stress cleavage difficult to create. It is also difficult to introduce an initial crack on the surface. In this study, cleavage characteristics of chemically strengthened glass with a thickness of 0.7 mm are investigated experimentally. The depth of compressive stress from the surface is 33 μm. The laser used is a continuous CO_2 laser beam with a wavelength of 10.6 μm. This laser is also applied to the introduction of the initial crack at the edge of the chemically strengthened glass. Additionally, the influence of laser power and energy density on the introduction of the initial crack and the thermal stress cleavage are evaluated. From these results, in order to propagate the initial crack, the depth of the initial crack needs to exceed the depth of the compressive stress layer from the surface. The depth of the initial crack tends to increase with increasing energy density. When an initial crack is introduced along the cleaving line, the quality of the cleaved surface is poor. The quality of cleavage was improved by the introduction of an initial crack at the edge of the glass.

Peer-review under responsibility of the organizing committee of 18th CIRP Conference on Electro Physical and Chemical Machining (ISEM XVIII)

Keywords: laser processing, laser cleaving, chemically strengthened glass, thermal stress, CO_2 laser ;

1. Introduction

Chemically strengthened glass is loaded with compressive stress on the surface by an ion-exchanging method in order to prevent breakage from external stress. The compressive stress on the surface makes it difficult to cut the material with a blade saw and to mechanically trim the edge of material by using a cutting tool. It is also difficult to introduce an initial crack on the surface.

This study deals with thermal stress cleavage in chemically strengthened glass by CO_2 laser beam irradiation. The thermal stress cleavage caused by laser beam irradiation was first proposed by Garibotti [1]. Lumley also reported that the CO_2 laser had a high potential for separating brittle materials such as alumina ceramics and glass [2]. Wang et al. used a line-shape laser as the heat source to create thermal cleavage on glass [3]. Many other studies of thermal stress cleavage on glass have been carried out [4–7]. Thermal stress cleavage is a process that is applied to separate brittle materials such as glass and ceramics by irradiating a laser beam onto a small area of the substrate and controlling the crack propagation inside the thermal gradient area. The laser energy irradiated to the substrate creates a compressive stress at the laser spot area, and also induces a tensile stress at the circumferential area. The crack on the substrate propagates toward the center of the laser-irradiated area by the tensile stress that occurs at the circumferential area, and the substrate can then be separated mechanically. Thermal stress cleavage by laser beam irradiation has many advantages. The cutting tools are not used to create the thermal stress cleavage; therefore, the substrate is not contaminated by the coolant and chips [8]. In

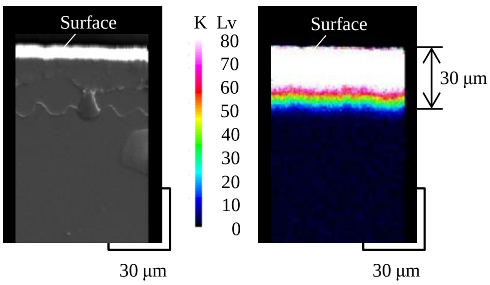
Peer-review under responsibility of the organizing committee of 18th CIRP Conference on Electro Physical and Chemical Machining (ISEM XVIII)
doi:10.1016/j.procir.2016.02.232

addition, this method has the capability of producing a smooth surface by cleaving the cleavage plane of the substrate [9].

In the present study, the thermal stress cleavage by laser beam irradiation is applied to chemically strengthened glass with a thickness of 0.7 mm. The depth of the compressive stress from the surface is 33 μm. The laser used is a continuous CO_2 laser with a wavelength of 10.6 μm. This laser is applied to induce the initial crack and also to cleave the chemically strengthened glass. It is well known that a CO_2 laser can be used to cut various types of glass with a high absorption to the glass. Lee et al. improved the mechanical separation of chemically strengthened glass with a conventional wheel by irradiating a variable-frequency microwave [10]. However, the median crack was caused on the scribed surface. The application of a laser beam makes it possible to separate the glass without causing cracks on the surface. The influence of laser conditions such as energy density and scanning speed on cleavage characteristics are investigated experimentally. The introduction of the initial crack is also evaluated.

2. Chemically strengthened glass

The substrate used is a chemically strengthened glass with a thickness of 0.7 mm. The compressive stress is generated on the substrate surface by an ion-exchanging method that is induced by changing from smaller sodium ions to larger potassium ions. **Fig. 1** shows an SEM image of the surface of the chemically strengthened glass and a mapping image of potassium ion on the surface of chemically strengthened glass measured by wavelength dispersive X-ray spectroscopy (JEOL Ltd.: JXA-8100). As was obvious from the image, the potassium ion was replaced by the sodium ions at the glass surface with a depth of 30 μm. **Table 1** shows the measurement results obtained by a glass-surface stress measuring system (ORIHARA Industrial Co., Ltd.: FSM-6000LE), and **Fig. 2** shows the stress distribution inside the chemically strengthened glass. The maximum compressive stress on the surface was 887 MPa, and the compressive stress layer was from the surface to a depth of 33 μm. A tensile stress with a value of 44 MPa also existed inside the glass. From these results, it was shown that the compressive stress layer was generated by the ion-exchanging method with a depth of 33 μm.



(a) SEM image (b) Mapping image of potassium ion by wavelength dispersive X-ray spectroscopy

Fig. 1 Analyzed images at the surface of chemically strengthened glass

3. Experimental setup

3.1. Inducing initial crack

To investigate the characteristics of inducing an initial crack on the substrate surface, two methods are used. Experimental conditions are shown in **Table 2**. The size of the specimen is 10 × 10 mm, and all samples were prepared with thermal stress cleavage using CO_2 laser beam irradiation. It was confirmed by microscope that the crack was not generated in the process of sample preparation.

One method is the indentation of a Vickers indenter at the glass surface. The Vickers indenter is loaded at five points with an interval of 100 μm and the load is 9.8 N. Soda lime glass with a thickness of 0.55 mm is also used for comparison. The loaded point is observed by a microscope (Nikon Co., Ltd.: ECLIPSE ME600L).

Another method is the irradiation of a CO_2 laser beam to the glass surface. The laser beam used is a continuous CO_2 laser [SYNRAD Inc.: 48-1(s)] with a wavelength of 10.6 μm. The spot diameter on the glass surface is kept constant at 60 μm, which is the minimum focused spot diameter. The laser beam is irradiated to the glass surface, and the influence of energy density on the introduction of the initial crack is evaluated. Energy density is calculated from laser power, scanning speed, and beam diameter. The initial crack in each condition is observed with the microscope.

Table 1 Specification of the chemically strengthened glass

Material		Chemically strengthened glass
Thickness	[mm]	0.7
Compressive stress	[MPa]	887
Depth of compressive stress layer	[μm]	33
Tensile stress	[MPa]	44

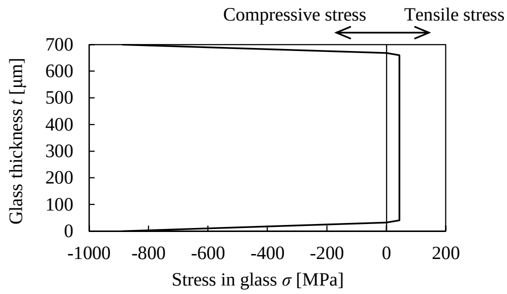


Fig. 2 Stress distribution in cross-sectional direction for the chemically strengthened glass

Table 2 Experimental conditions of inducing initial crack

Laser beam			CO_2 laser
Wavelength	λ	[μm]	10.6
Irradiation mode			Continuous wave
Laser power	Q	[W]	4 ~ 9.5
Feed speed	V	[mm/s]	5 ~ 60
Beam diameter	D	[μm]	60
Energy density	P	[J/mm^2]	1.1 ~ 23.3