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ScienceDirect

Procedia Manufacturing 7 (2017) 240 – 245

Procedia MANUFACTURING

--International Conference on Sustainable Materials Processing and Manufacturing, SMPM 2017, 23-25 January 2017, Kruger National Park

Precision Cutting of Glass by Laser-assisted Machining

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Abstract

Precision machining of glass has been receiving attention in various applications because of the use of glass interposers in layered semiconductors or glass substrates for microfluidic chips. These applications require complicated and three-dimensional machining for further product functionality. Etching is conventionally used for precision machining of glass. However, applying etching for three-dimensional machining is difficult, and thus, a method which is applicable to three-dimensional machining of glass is needed. Cutting is a method applicable to three-dimensional machining. However, precision cutting of glass is difficult because glass is a hard and brittle material. In this research, we applied laser-assisted machining for cutting of glass. We first conducted laser-assisted milling for plane surface cutting. We then proposed laser-assisted drilling for glass drilling to perform the three-dimensional cutting of glass by laser-assisted machining. Through the experimental analyses, we demonstrated the feasibility of the precision and three-dimensional cutting of glass.

Peer-review under responsibility of the organizing committee of SMPM 2017

Keywords: Glass; Precision cutting; Laser-assisted milling; Laser-assisted drilling

1. Introduction

Precision machining of glass has been receiving attention in various fields such as optics, electronics, and chemistry. The applications include optical lenses, glass interposers in layered semiconductors or glass substrates for microfluidic chips. Etching is conventionally used for precision machining of glass. However, there is a growing demand for machining glass three-dimensionally to achieve further product functionality. Etching is a great method

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Peer-review under responsibility of the organizing committee of SMPM 2017
doi:10.1016/j.promfg.2016.12.058

for precision machining. However, applying it for the three-dimensional machining is difficult. Thus, a method, in which glass can be precisely and three-dimensionally machined, is needed.

Cutting is a method expandable to three-dimensional machining through milling and drilling. Meanwhile, precision cutting of glass is difficult to achieve because glass is a hard and brittle material, and thus, cracks can be easily generated during the cutting process. Laser-assisted machining is known as a method of machining a difficult-to-cut material. In this method, the material is heated locally by a laser beam, and the heated area is subsequently removed by a cutting tool [1]. This method has been applied to various materials. However, its application to glass cutting has not yet been reported. Furthermore, laser-assisted machining is difficult to apply to three-dimensional machining because the laser beam must be shot in front of the cutting tool. In the case of plane surface cutting, the laser beam can be shot on the surface without being blocked by anything. However, in the case of drilling, the laser beam must be shot inside the material because the front part of the cutting tool is inside the material. In this research, we applied laser-assisted machining to both the milling and drilling processes by conducting laser-assisted milling (LAM) and proposing laser-assisted drilling (LAD). We also demonstrated the feasibility of precision and three-dimensional cutting of glass.

Nomenclature

q	intensity of laser beam
x	distance between the center of the beam spot and the position on the major axis of the beam spot
y	distance between the center of the beam spot and the position on the minor axis of the beam spot
P	power of laser beam
r_0	radius of laser beam on the plane perpendicular to the light axis on the workpiece surface
θ	angle between the light axis and the workpiece surface
a	major radius of the beam spot
b	minor radius of the beam spot
d	critical depth of cut
c	constant depending on the tool geometry
K_{IC}	fracture toughness
E	Young’s modulus
H	hardness

2. Methods

We conducted LAM and LAD for glass milling and drilling, respectively, to apply the laser-assisted machining to the three-dimensional machining. Fused silica (N grade, TOSOH Quartz Corporation) was selected as a glass material because it does not contain any impurities and has various applications. An air motor spindle (HTS1501S-HSKE32, Nakanishi Inc.) mounted on a machine tool (NVD1500DCG, DMG Mori Co., Ltd.) was used for the experiments. A fiber laser (JenLas fiber cw 200, Jenoptik AG) with a wavelength of 1070 nm was used as a laser source.

2.1. LAM

Matsumura et al. previously revealed that inclining a ball-end mill toward the feed direction is effective for precision milling of glass [2]. Therefore, we conducted LAM by using inclined ball-end mills. Fig. 1(a) shows the schematic of LAM. Fig. 1(b) presents the experimental setup. The angle between the axis of the cutting tool and the workpiece surface was kept to 45 °. The light axis was inclined from the workpiece surface to avoid the absorption of the laser beam into the cutting tool. The angle between the light axis and the surface was 24 °. The angle between the light axis and the feed direction was 39 °. A two-edge ball-end mill with a diameter of 0.5 mm was used for the experiments. The tool was made of cemented carbide and covered by TiAlN coating. The beam diameter at the