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Experimental stress analysis of glass cutting using a non-rigid cutting mechanism

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Abstract

A non-rigid cutting mechanism was developed to apply a technique to control the normal cutting force during the fabrication of micro-grooves. Although this mechanism has been mainly used for ductile materials, several experiments on glass were performed; as result the fabrication of crack-free micro-scale grooves was achieved. The photoelastic analysis was applied to observe the internal stress field on the material during the cutting process comparing the non-rigid mechanism and a rigid tool-holder. The critical cutting depth using this mechanism was determined in approximately 2.5 μm and some of the cutting conditions were defined in order to achieve ductile mode cutting.

Keywords: Ductile mode cutting; Micro-groove fabrication; Diamond cutting; Micro-machining

1. Introduction

A non-rigid cutting mechanism has been introduced in [1–4], which is based on the nano-cutting method using an atomic force microscope (AFM) [5–6]. In this mechanism, a single-crystal diamond tool mounted on a cantilever beam is used to remove material. During the cutting process, the cantilever beam exhibits deformation that is measured by a displacement sensor, and is used to implement a force feedback control (FFBC) system to control the normal cutting force applied to the tool. Fig. 1 shows the cutting mechanism developed and a schematic illustration of the control principle of this technique, which has been called as Constant Load Cutting (CLC) process.

It is known that the machining of brittle materials under conventional cutting conditions will induce fracture rather than chip formation because of the large stress concentrations in the cutting zone. The conditions that allows the machining of brittle materials in ductile mode have been investigated [7–9]; however, in most cases, plastic deformation can only be achieved prior to fracture when the cutting depth is extremely small (under 200 nm) [7]. Other researches indicate that it is possible to not only achieve ductile mode cutting, but also to increase the magnitude of the cutting depth, by applying an external pressure to the material during the cutting process. This will contribute to reduce the stress intensity factor at the tip of the pre-existing cracks and flaws in the workpiece until it become less than the fracture toughness [8]. In any case, from the energetic point of view of the material-removal process, the main consideration to achieve ductile mode cutting of brittle materials is the reduction of the stress concentration in the cutting zone.

In this paper, several cutting experiments on glass performed by the CLC mechanism are described. The fabrication of micro-scale grooves in ductile mode was

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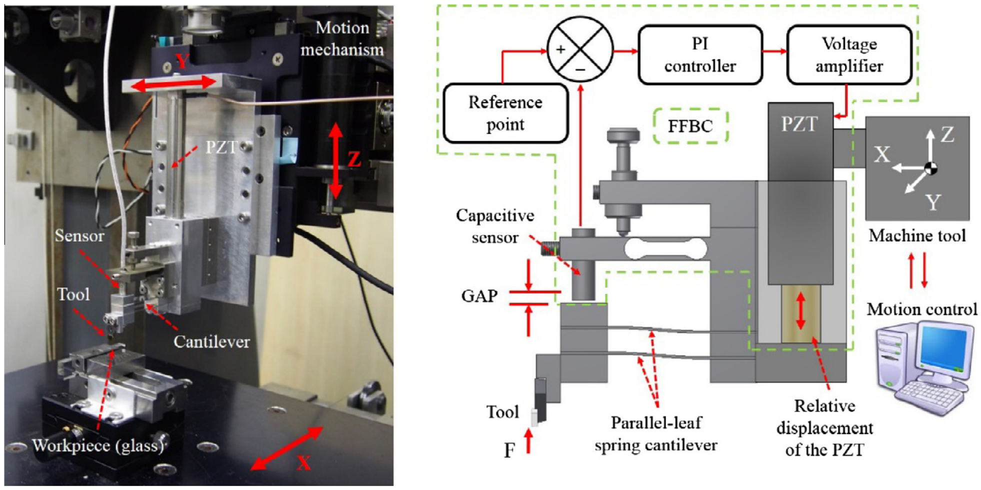

Fig. 1. CLC mechanism and its control principle.

achieved, the critical cutting depth was determined in approximately 2.5 μm. The results suggest that this mechanism contributes to the reduction in the stress in the cutting zone. Finally, a photoelastic analysis was performed to compare the CLC mechanism with a conventional rigid system, and to observe the stress field inside the material for both cases.

2. Cutting experiments of glass using the CLC mechanism

The experiments conducted to observe the performance of this mechanism and its effects on the machining of glass are briefly described below. Experimental results are presented on Fig. 2. In this image, d_C represents the cutting depth of the fabricated micro-grooves.

(1) *Experiments on inclined surfaces with the FFBC non-active*. To observe whether it was possible to achieve ductile mode cutting and to estimate the critical cutting depth allowed by this mechanism. Initially, the tool is positioned in close proximity to the workpiece surface (without contact); then the workpiece moves in the direction where eventually the tool tip will create the micro groove in the workpiece surface. The inclination of the material causes the cutting depth and the deformation of the cantilever beam to increase gradually. As result, ductile mode cutting was achieved at a cutting depth range of 2–3 μm; after this value, cracks can be easily developed, although occasionally crack-free grooves with a larger cutting depth were fabricated [4].

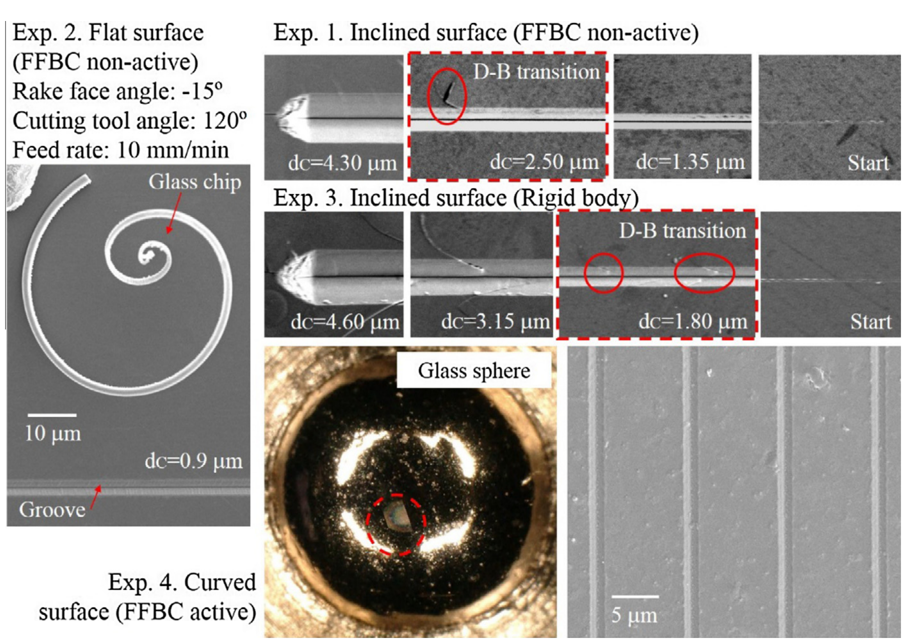

Fig. 2. SEM images of the experiments on glass using the CLC cutting mechanism.