Available online at www.sciencedirect.com

ScienceDirect

International Journal of Machine Tools & Manufacture 47 (2007) 2091–2097

INTERNATIONAL JOURNAL OF MACHINE TOOLS & MANUFACTURE DESIGN, RESEARCH AND APPLICATION

www.elsevier.com/locate/ijmactool

Surface and subsurface integrity in diamond grinding of optical glasses on Tetraform ‘C’

Qingliang Zhao[a,*], Yingchun Liang[a], David Stephenson[b], John Corbett[b]

[a]School of Mechatronics Engineering, Harbin Institute of Technology, P.O. Box 413, 150001 Harbin, China
[b]School of Applied Sciences, Cranfield University, Cranfield, Bedford MK43 0AL, UK

Received 31 July 2006; received in revised form 14 May 2007; accepted 17 May 2007
Available online 2 June 2007

Abstract

In order to investigate the surface and subsurface integrity of diamond-ground optical glasses, a Tetraform ‘C’ machine tool featuring high close-loop stiffness was used to conduct the ultra-precision machining of fused silica and fused quartz assisted with electrolytic in-process dressing (ELID). An acoustic emission (AE) sensor and a piezoelectric dynamometer were used to monitor the grinding process to correlate the processing characteristics with the generated surface and subsurface integrities, which were characterized by atomic force microscope (AFM), scanning electronic microscope (SEM), and nano-indentation technique. Experimental results showed that for optical glasses the fracture toughness value can be used to predict the machinability while its bigger value always means a better surface and subsurface integrity. During the grinding process of optical glasses, the smaller amplitude and RMS values of AE signal, as well as the smaller grinding forces and the ratio of normal force to tangential force, correspond to a better surface and subsurface integrity. With selected machining parameters and a 6–12 μm grain-sized diamond-grinding wheel, nanometric quality surfaces (Ra < 5 nm) with minimal subsurface damage depth (< 0.5 μm) can be generated for fused quartz on Tetraform ‘C’.

Keywords: Surface and subsurface integrity; Tetraform ‘C’; Optical glass; Diamond grinding; ELID

1. Introduction

During diamond grinding of optical glasses, material removal mode of brittle or a combination of brittle and ductile inevitably introduces damage into the machined surface and subsurface, and loose abrasive lapping or polishing is therefore required, which entails extra manufacturing cost and lower the geometry accuracy of machined surfaces.

In order to obtain a better surface and subsurface integrity of optical glasses, ductile material removal mode must take place during the machining process instead of brittle mode. Usually to realize this a super fine abrasive metal-bonded diamond-grinding wheel must be used together with electrolytic in-process dressing (ELID), and also, an ultra-precision machine tool with high loop stiffness is a must for ductile machining of optical glasses to guarantee the minimized surface and subsurface damages [1]. In addition, grinding parameters must also be optimized to generate good surface and subsurface integrity so that lapping or polishing time can be largely shortened to reduce deterioration of surface form accuracy.

Previous research work was mainly focused on how to optimize machining parameters in generating very “smoothed” surfaces [2–10]. However, we think in order to produce high-quality optical glass, it is more important for us to see what happened below the machined surfaces so that we can comprehensively evaluate the surface and subsurface integrity in diamond grinding of optical glasses.

To realize this, a series tests were conducted on Tetraform ‘C’ with ELID, to correlate the machining parameters and processing signals with the corresponded diamond grinding results of fused silica and fused quartz.

---

*Corresponding author. Tel.: +86 451 86402683; fax: +86 451 86415244.
E-mail address: zhaoqlyx@yahoo.com (Q. Zhao).

0890-6955/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ijmachtools.2007.05.005

2. Experimental conditions

The machine tool used was Tetraform 'C' which features very high static stiffness and exceptionally high dynamic stiffness thanks to its unique pin-jointed tetrahedral structure, as shown in Fig. 1(a) [11]. A well-conditioned metal-bonded cup diamond-grinding wheel with grain size of 6–12 μm and a 75% concentration was used with a constant peripheral speed of 40 m/s (6000 rpm). The ELID device was home made in Precision Engineering Lab at Cranfield University.

Micro-indentation tests were conducted by MHT-1 (Matsuzawa Seiki Co. Ltd.), to generate vents with radial cracks. NanoTest 600, a nano-indentation tester was used to measure the hardness and elastic modulus of optical glasses.

An acoustic emission (AE) sensor (Dittle M5000) and a piezoelectric dynamometer (Kistler 9257A) were used to acquire AE signals and grinding force components, respectively.

Atomic force microscope (AFM) (Nanoscope III, Dimension 3000) was used to characterize the morphologies of ground surfaces while scanning electronic microscope (SEM) (Philips Inc.) was used to characterize cross-sectioned and then polished surfaces, as well as the micro-indentation vents on polished glass surfaces.

The specimens ($25 \times 25 \times 12$ mm) are fused silica and fused quartz whose high purity can ensure minimum contamination in the grinding process.

3. Experimental results and discussions

3.1. Determination of fracture toughness

Generally the machinability of an optical glass is determined by its plastic deformation resistance (hardness, H) and its elastic deformation resistance (elastic modulus, E). However, the fracture toughness K_c of optical glass indicates its fracture resistance, and it is therefore more appropriate to evaluate the machinability. Its value can be calculated by Lawn's method [12,13]:

$$K_c = (E/H)^{0.5} P/c^{1.5}, \tag{1}$$

where P is indentation load (N), c is radial crack radius (m), H is hardness (GPa) and E is elastic modulus (GPa).

The hardness and elastic modulus can be measured through nano-indentation tests by NanoTest 600. The measured results at ambient temperature are: fused silica:

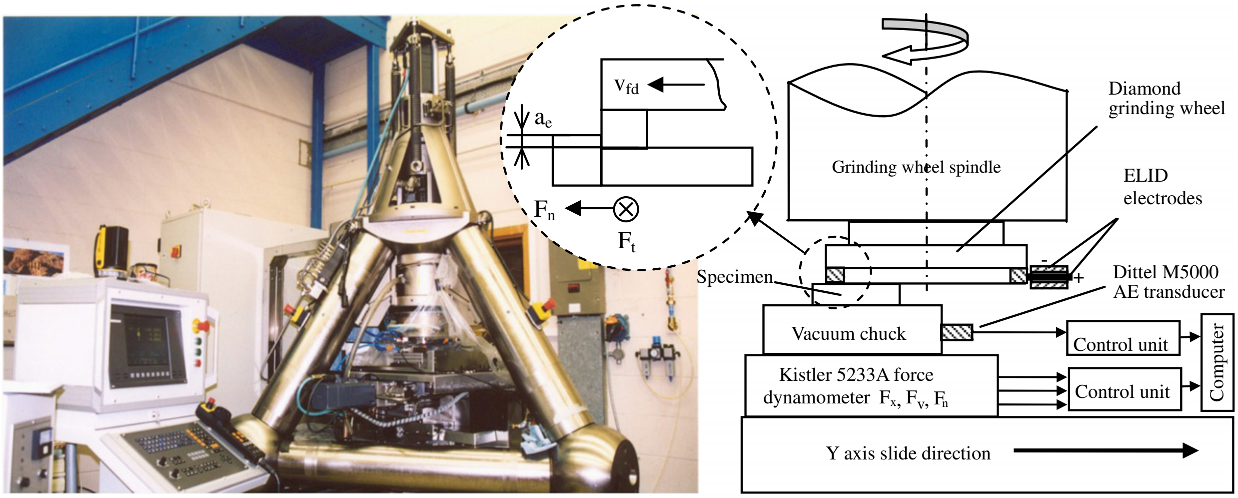

Fig. 1. Experimental setup for diamond grinding of optical glasses: (a) Tetraform 'C' ultra-precision grinder, whose unique structure guarantees high close-loop stiffness, (b) schematic diagram of grinding setup.

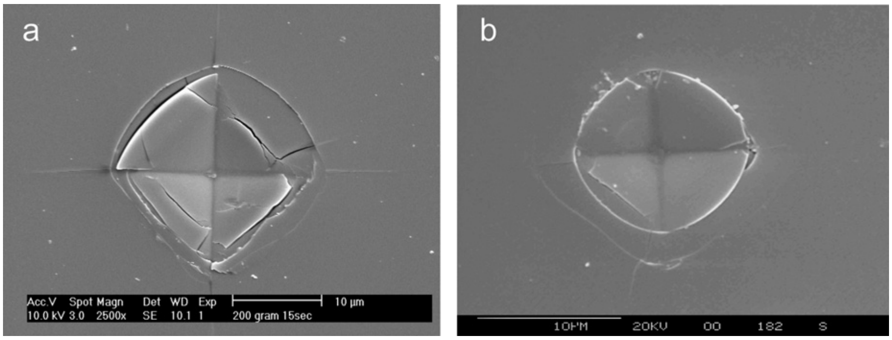

Fig. 2. SEM images of micro-indentation vents of two glasses under 200 g indenting load: (a) fused silica, (b) fused quartz.