Finishing of Advanced Ceramics and Glasses

Edited by

Robert Sabia
Victor A. Greenhut
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Finishing of Advanced Ceramics and Glasses

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COVER PHOTO: "Secondary electron images and the EDS composition of the surface of yttria doped AlN," is courtesy of Sadanori Shimura, Tsuneaki Ohashi, and Keiichiro Watanabe, and appears as figure 7(a) in their paper "Fluorination of AlN Ceramics, Silicon, and Silica in an Inductively Coupled NF_3 Plasma," which begins on page 341.

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Preface

Over the past decade, an enormous expansion of both industrial and academic research has occurred in developing improved finishing methods for ceramics. From advanced ceramics designed for structural applications to the use of deposited ceramics in the microelectronics field, the need for understanding the fundamentals behind bulk processing and final finishing for these materials continues to grow. Current state-of-the-art, ultraprecision processing includes the use of computer numeric controlled (CNC) grinding and polishing equipment and the application of chemical-mechanical polishing techniques.

This volume is the proceedings for the symposium held at the 101st Annual Meeting of The American Ceramic Society. The objective for this symposium was to bring together researchers from ceramics, glass, and microelectronics to present on all stages of materials finishing and discuss how techniques from this rapidly growing field can be further developed. Included in this volume are sections on "Machining and Fixed Abrasive Grinding," "Loose Abrasive Grinding and Polishing," "Chemical-Mechanical Polishing," and "Material Characterization and Surface Metrology."

The editors would like to thank the invited speakers for preparing detailed reviews of the history of grinding and polishing, and on state-of-the-art finishing technologies. Also appreciated are session chairs Dana Zagari of Ferro Electronic Materials, Rodney Ridley of Harris Semiconductors, Andrew D'Souza of 3M, and Otto Wilson of the University of Maryland for their diligence in maintaining a smooth-running program. Finally, we would like to thank The American Ceramic Society for sponsoring this symposium and proceedings, especially Sarah Godby and Mary Cassells, who made the preparations so enjoyable.

Robert Sabia
Victor A. Greenhut
Carlo G. Pantano

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Machining and Fixed Abrasive Grinding

PRECISION GRINDING PROCESS DEVELOPMENT FOR BRITTLE MATERIALS*

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ABSTRACT

High performance, brittle materials are the materials of choice for many of today's engineering applications. This paper describes three separate precision grinding processes developed at Lawrence Livermore National Laboratory to machine precision ceramic components. Included in the discussion of the precision processes is a variety of grinding wheel dressing, truing and profiling techniques.

INTRODUCTION

Precision ground brittle materials, such as ceramics and silicon, are steadily finding their way into an increasing number of engineering applications including engine components, medical equipment, defense systems, electrical insulators and thermal heat sinks [1,2]. Although the manufacturing processes are as varied as the applications, many utilize precision grinding in at least part of the manufacturing technique. These processes require strict control over mechanical positioning of the grinding wheel and workpiece, thermal effects, spindle motions, grinding fluid delivery, and grinding wheel properties and conditioning.

A number of processes with the aforementioned characteristics were developed at Lawrence Livermore National Laboratory (LLNL) to precision grind components with micrometer tolerances in materials such as beryllium-oxide (BeO), alumina (Al_2O_3), zirconia (ZrO_2), silicon nitride (Si_3N_4) and aluminum-titanium carbide (AlTiC). The various component geometries require different machine tool configurations, which includes cylindrical grinding, creep feed grinding and cup wheel surface grinding. Among the list of ground component geometries presented here are slotted BeO heat sinks, cylindrical and contoured ceramic

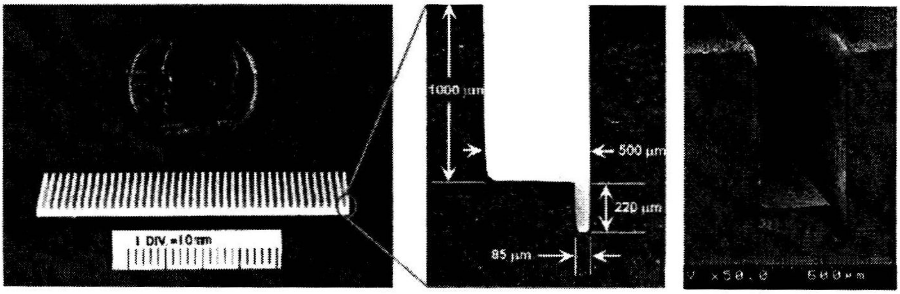
* This work was performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract No. W-7405-ENG-48.

components. In addition to the required machine and process control, a few process-enabling techniques are employed to improve process flexibility, robustness and efficiency. The techniques include electrical discharge machining (EDM) to profile and true metal bond grinding wheels and electrolytic in-process dressing (ELID) [3, 4, 5] to dress the grinding wheel surface. All of these processes were designed to be eventually transferred to outside vendors for higher production levels of manufacturing and therefore, the precision fabrication techniques required compatibility with manufacturing economics.

CREEP FEED GRINDING

This precision grinding application incorporates EDM profiling and truing with creep feed grinding to fabricate micrometer tolerance, slotted heat sink components in BeO. A typical heat sink has 40 of these multifeatured grooves with tolerances ranging between ± 1 μm and ± 5 μm. Among the critical dimensions are vertical wall flatness, 980 μm groove depth, and a maximum bottom notch width of less than 100 μm. Figure 1 shows a completed part with overall dimensions of 4 cm x 1 cm x 2 mm and a magnified view of one of the grooves. In addition to meeting the geometric challenges, this process requires safe containment of the resultant BeO dust, which is considered toxic.

As the final geometric design was evolving, a flexible creep feed grinding process was needed to accommodate rapidly changing part specifications. The flexibility of this process stems from the use of an EDM process to impart detailed profiles corresponding to various part geometries on to the periphery of a metal bond grinding wheel. An on-machine, single-point turning tool is used to profile a rotating graphite electrode. The electrode is used to EDM profile the grinding wheels mounted on a two-wheel arbor. Mercury wetted slip rings and carefully insulated arbor assemblies provide the necessary EDM electrical paths,



(a) (b) (c)

Figure 1 – Heatsink groove geometry (a) finished part, (b) groove side profile, and (c) SEM micrograph of a typical groove.

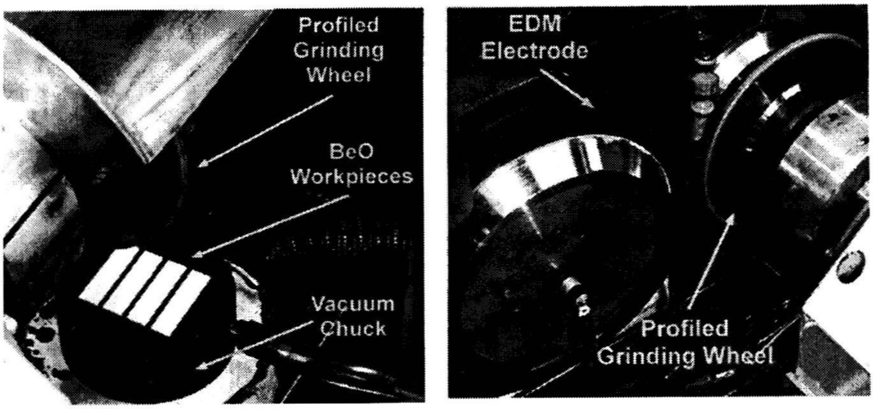


Figure 2 – (a) Grinding BeO with profiled grinding wheel and (b) EDM profile of the grinding wheel with the on-machine rotating electrode.

without risking damage to the air bearing surfaces of the spindles. Figure 2(a) shows the profiled grinding wheel addressing the BeO workpieces and Figure 2(b) shows the rotating EDM electrode used to profile the grinding wheels. The next generation of this process replaced the larger grinding wheels with two commercial slicing blades with thicknesses of 85 µm and 470 µm. In this application, the EDM rotating electrode is used to remove wheel radial runout and to generate square edges on the wheels. Figure 3 shows this configuration implemented on the machine tool and Table I shows the parameters used in both configurations.

Table I - Creep feed parameters

	EDM Profiling Process	EDM Truing Process
Diamond grit grinding wheels	4/8 µm; cast iron bond; 20 cm Ø	10/20 µm; electroplated nickel bond; 11.4 cm Ø 30/40 µm; sintered bronze bond; 11.4 cm Ø
Material	BeO	BeO
Wheel speed	39 m/sec	45 m/sec
Feed rate	5 cm/min	5 cm/min
Coolant flowrate	15 l/min	15 l/min

This next generation process has been transferred to outside vendors for higher production rate manufacturing. Because of the initial capital investment, some of the vendors have chosen not to use EDM truing and instead are using strictly mechanical methods to condition the grinding wheels.

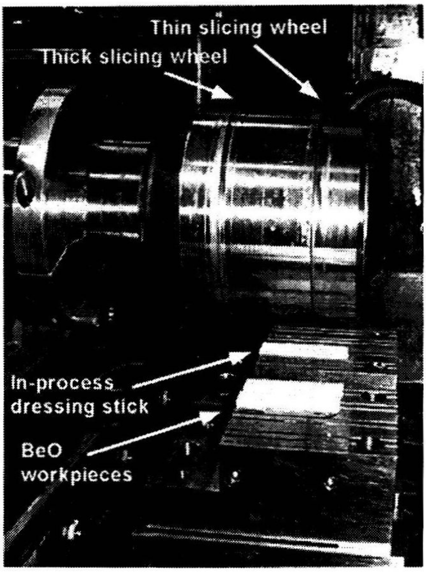


Figure 3 – Double arbor slicing wheel configuration

CYLINDRICAL GRINDING

Another process that is conceptually similar to the creep feed grinding process described above was developed to cylindrically grind ceramics for engine components. Figure 4(a) shows a photograph of one of the components and Figure 4(b) is a close-up image of the ground shoulder feature. Some of the critical features to note regarding this geometry are cylindricity to within 1.0 µm, a specified radius of curvature on the right end of the component, a chamfer edge on the left shoulder and a specific radius of curvature for the internal corner of the shoulder.

In this process the workpiece is rotated using a collet in a rolling-element spindle. The grinding wheel is driven under CNC control to produce the required features on the workpieces and grinding fluid is applied using a low pressure, flood cooling method. Figure 5 shows a photograph of the machine tool, on which this process is applied. Shown in the photograph are the grinding wheel spindle and the workpiece spindle that rotates the workpiece and the EDM electrode.

Figure 4(a) – Ground ZrO_2-Al_2O_3 component

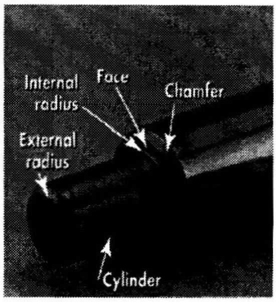


Figure 4(b) - Close up view of shoulder feature

Figure 6 shows a top and side view (SEM micrographs) of a diamond grit in a metal bond grinding wheel that was EDM trued and used to grind a ceramic part. The side view shows the diamond has a large wear flat on it and the protrusion from the bond is approximately 3 µm.

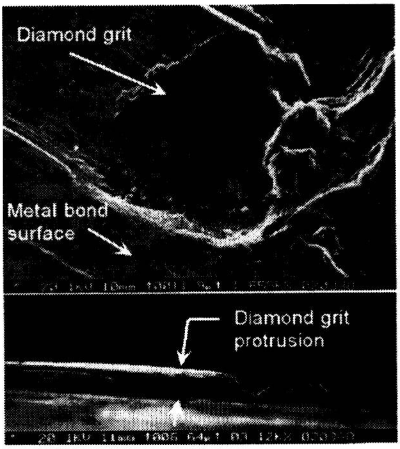


Figure 6 – Diamond grit protrusion

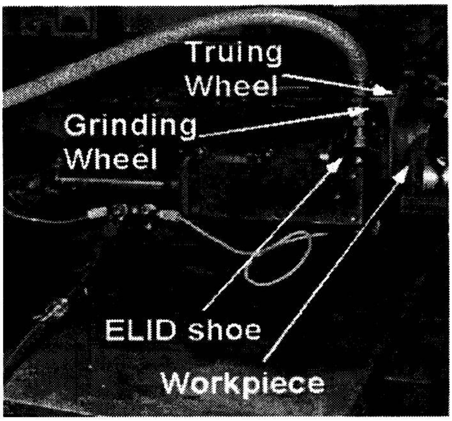


Figure 7 – Surface grinding

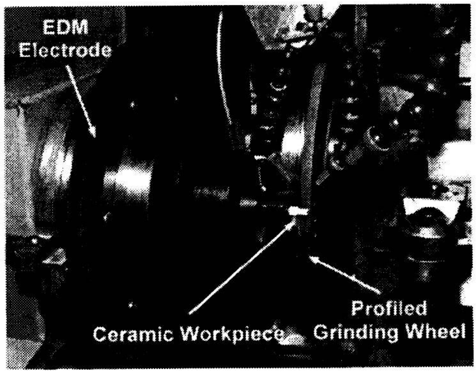


Figure 5 – Cylindrical grinding

SURFACE GRINDING

The objective of the final process to be described here is to investigate the influence of machining parameters on precision surface grinding of alumina/titanium carbide workpieces. Final design specifications require roughness values of 2.5 nm Ra or less and profile deviations of less than 25 nm. This process utilized an off-line EDM wheel figuring operation, followed by on-machine, ELID assisted truing and dressing. Figure 7 shows a photograph of the machine tool used for the initial phase of this project.

Figure 8 is a photograph of the ELID 'shoe' used for the in-process dressing of the 1-2 µm diamond, metal bond grinding wheels. Note that the grinding configuration is face grinding with a 125 mm diameter grinding wheel and the ELID shoe provides the electrical path for truing and dressing the face of the metal bond wheel.

This configuration was also used to study the effects of using resin versus metal bond grinding wheels. Note that ELID is not applicable to conventional resin bond wheels and the differences in dressing may account for the variability in grinding data. Figure 9 shows a plot of average normal grinding force versus the surface feed rate. Both curves are fairly linear and the metal bond wheels generated considerably less force than the resin wheels. Figure 10 is related to Figure 9 by the compliance of the machining system. In this figure, the average depth of cut versus feed rate was plotted for the resin and metal bond wheels. Note, that if the machining system was infinitely stiff, then these curves would be horizontal lines. If the machine system was perfectly compliant, then the force versus feedrate curves would be horizontal lines and in this 'constant force' grinding mode the depth of cut curves would fall off much more radically than those shown in Figure 10. The stiffness of the machining system was obtained by acquiring displacement versus force data after wheel-to-workpiece contact was made and then slowly increasing the commanded in-feed. A non-rotating, resin bond grinding wheel against a ceramic workpiece was used in this test with about a

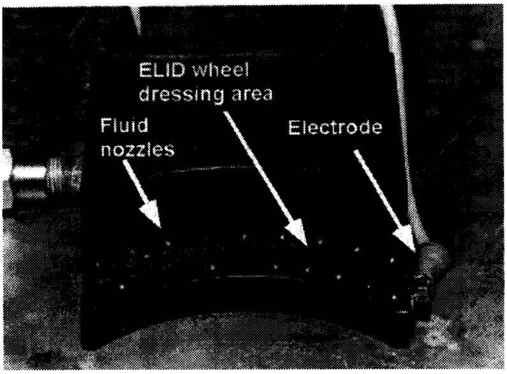


Figure 8 – ELID shoe

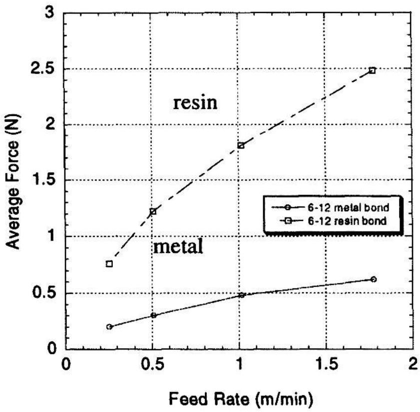


Figure 9 – Normal force

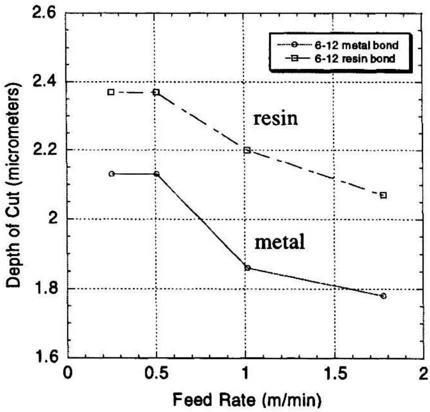


Figure 10 – Depth of cut