

Current Global Advanced Research Projects in Fixed Abrasive Grinding

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Abstract

A 500-page report has been written, reviewing the fixed abrasive grinding research being done at universities around the world. The project was initiated by the Association for Manufacturing Technology (AMT), to inform their members of the current state-of-the-art. The report is based on the completion of one-page summaries obtained from 200 researchers during a 2-month period (November-December 2004). From these summaries, key words were categorized that helped to structure the report by: material investigated; fluid application used; tool design, modeling method used, etc. The appropriate summaries are referenced in each section, using country code pre-fixed letters, with full summaries included in the Appendix. An additional 50 technical references and books are also cited in the report.

The summaries contain full contact details for the researcher, an abstract of the research topic, details of any key issues that arose during the research, and a list of recent publications for further reading. In most cases, the researchers will generally be pleased to receive communication on the topic outside of the confidential aspects. Although the initial objective was to identify projects which have been active within the last 5 years, the majority of summaries show much more recent research.

A total of 198 research institutions from 32 different countries were contacted, after being identified from an extensive literature search. From these 198 institutions, 14 did not do 'fixed-abrasive' grinding research and only 10 did not respond to the request and reminders. In many cases, multiple summaries were provided by institutions, with Aachen WZL having the greatest number at 16. The total number of summaries received by the cut-off date was close to 360. This report can therefore be considered as an accurate account of the status of fixed-abrasive grinding research around the world. A sample chapter on 'externally-assisted grinding processes' is included at the end of this article.

Structure of the Report

The report includes an initial description of fixed abrasive grinding, in an easy to read style, followed by 15 technical sections of research areas covered by the university projects. These sections include:

1. the processing of new and traditional materials
2. use of external energy to aid the grinding process
3. fluid application methods, including minimum quantity techniques
4. grinding machine design and dynamics
5. abrasive tool design and new developments
6. high speed and high efficiency grinding
7. analysis, simulation and modeling methods used
8. novel control strategies being developed for grinding
9. in-process and post-process monitoring techniques
10. instabilities of grinding, including chatter, vibration, lobing, etc
11. quality of the ground surface, including residual stresses, phase transformations, etc

12. novel truing and dressing techniques for preparing grinding wheels
13. ultra-precision grinding
14. economic and environmentally driven projects
15. optimization methods, experimental design, and grindability assessment

Approximately 1000 grinding references are cited in the report, with a list of 43 scientific journals and technical conferences where these papers are published

Why the Report is Useful to the Grinding Community

The report can be considered as a snap-shot of current global fixed-abrasive grinding research at the beginning of 2005. The benefits of the document include the following:

- a. Faster literature searching in most grinding technology areas, saving time developing keywords, and the cost of obtaining documents through search engines and databases
- b. Statistical data of grinding research by country, technology, or by institution
- c. Easier contact with 184 universities around the world
- d. Identification of research areas that are inadequately researched
- e. Definitions of grinding terms and technologies

Institutions and individuals that would benefit from the report include the following:

- a. University and industrial researchers
- b. University and industrial libraries
- c. Grinding wheel manufacturers
- d. Dressing and truing tool manufacturers
- e. Grinding process end-users, such as manufacturers of bearings, automotive components, gas turbines, cutting tools, etc
- f. Machine tool, machine controls, and sub-system manufacturers
- g. Grinding fluid manufacturers and pumping/filtration suppliers

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Sample Section on Externally Assisted Grinding Processes

Externally-assisted grinding processes are those that are enhanced by electrical energy, dynamic motion, chemical activity or thermal input. The follow processes often overlap with externally assisted dressing techniques if the role of the assistance helps keep the grinding wheel sharp and clean from loading.

Several externally-assisted grinding, or truing/dressing systems, have been developed in the last decade. The systems have been developed for diamond tool grinding, diamond wheel preparation, ceramic grinding, and others. The following acronyms describe a few of the electrically-assisted systems:

- Electro-Chemical Discharge Machining (ECDM)
- Contact Discharge Truing and Dressing (CTTD)
- Electro-Contact Discharge Dressing (ECDD)
- Electro-Discharge Machining and Grinding (EDMG)
- Electrochemical in-process Controlled Dressing (ECD)
- Electro-Discharge Diamond Grinding (EDDG)
- Rotary Electro-Discharge Machining by grinding wheel (REDM)
- Abrasive Electro-Discharge Grinding (AEDG)
- Electrolytic In-process Dressing (ELID)

Some of the above systems will work with standard metal-bond superabrasive wheels, although in some cases, specially developed electrically-conductive bonds and coatings have been developed to enhance the process. A selection of these systems, identified by the one-page summaries covering recent work, are as follows:

1. Electro-discharge [IN2, IN4]

Electro-Discharge Diamond Grinding (EDDG) has been developed for grinding PCD cutting tool inserts. The process has primarily been developed empirically up to now, however some modeling of the process is now being done, including FEM and parametric studies. The surface integrity of the tool material after EDDG is also being examined through FEM and experimental verification.

2. Electrolytic [C5, C12, G14, J31, GB29, GB21, GB22, U47]

A variation of the ECDM technique is ELID [J31], where the grinding wheel is the anode and the electrolyte is supplied into the inter-electrode gap. The aim is to eliminate wheel loading and ensure permanent dressing. Using this technique on an ultra-stiff precision grinding machine, surface finish values of less than 10 nm Ra, have been achieved [GB21].

ELID usually employs a cast-iron fiber-bonded grinding wheel. An oxide layer (expensive rust) is produced on the wheel surface, during the electro-chemical reaction between bond and fluid, shedding worn diamond grains (see Fig 1). ELID enables the use of nano-order diamond grain sizes to be used, and can be applied to most modes of precision grinding.

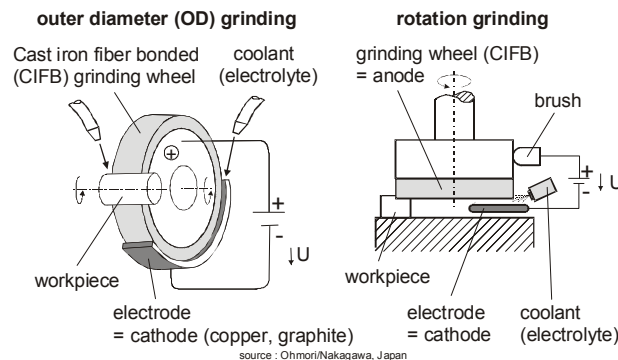


Figure 1. Principle of ELID [J31]

3. Vibration-assisted [G10, G38, J1, J12, U9, U12, U13, U14, G74]

Ultrasonic Assisted Grinding has appeared during the last 5 years for the grinding of ceramics and other brittle materials, giving relatively high material removal rates and low process temperatures. Both empirical and kinematic simulation studies have been investigated, especially on damage depth, surface finish and chip-size distribution [U13, G10]. The process is said to change the nature of the removal behavior of ceramic grinding by leaving a smoothed-over appearance to the surface that is less prone to particle detachment and therefore is superior for tribo-mechanically loaded surfaces [G38]. UAG can also be used for precision grinding of small holes in ceramic materials, decreasing grinding forces by up to 70% and improving surface finish by up to 30%.

In silicon dicing applications, UAG has also shown benefit, although the study is relatively young. Rotary Ultrasonic Machining and Grinding (RUMG) combines the virtues of diamond grinding and ultrasonic machining, resulting in higher material removal rates and lower cost than some of the alternatives (EDM and laser-assisted) [U9]. A simple example of vibration assistance can be a segmented wheel giving rise to intermittent cutting action [U14].

4. Thermally assisted [J3, U53]

Experimental research has been done to fabricate electro-formed diamond tools which are used in conjunction with laser-assistance. The thermal softening of the otherwise brittle ceramic material aids chip removal and lowers grinding forces, as with EDM-G.

5. Electro-chemical [GB8, SD2]

Titanium poses difficulties for conventional manufacturing owing to its low thermal conductivity, which can cause high thermal tool loads, and its high reaction affinity with atmospheric oxygen. An alternative technique, Electro-Chemical Grinding ECG, has been developed, in which mechanical and electro-chemical removal mechanisms occur [GB8]. Optimization of the process to secure appropriate machining variables for acceptable surface quality and rate of metal removal has been carried out, and also the development of artificial intelligence techniques for a knowledge-based system arising from these results. The electrical conductivity of the grinding wheel, from arbor to abrasive, is critical to the process.

6. Particle assisted [J10]

The combination of grinding in the presence of a slurry is not new, however, recent work has been done using an alumina fiber brush and peach powder slurry for the polishing of mirrors.

7. Chemo-mechanical [J8, C7, J36, J40]

Although it is likely that Chemo-mechanical polishing will be the topic of a separate Technology Assessment, chemo-mechanical grinding is also being developed, which uses fixed abrasives instead of loose abrasive.

8. Combinations of above [CA2, SD2]

ECDM combines ECM and EDM. The ECM action is assisted by the thermal erosive effects of the discharges. The grinding wheel must have a conducting metal bond, preferably bronze or copper. The ECM and EDM time periods need to be balanced. In the first stage ECM occurs and anodic dissolution of the outer layer of the workpiece takes place. In parallel, mechanical

grinding also occurs. On increasing the voltage in the second stage of the process, the concentration of the ions increases until electrical discharges occur. A plasma channel is created and material removed by evaporation. The technique has also been applied to truing and dressing of grinding wheels [SD2], which are then used for high precision grinding of cylindrical workpieces. Grinding wheel surface quality and roundness error are claimed to be superior to those obtained by conventional grinding.

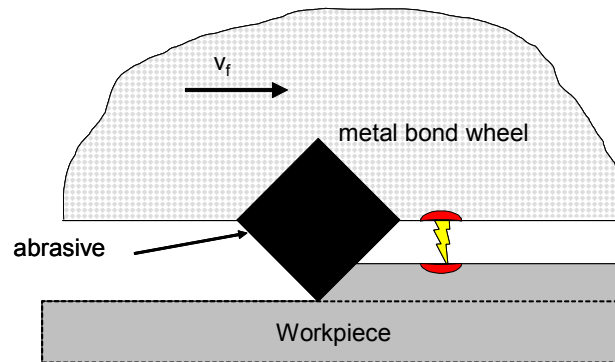


Figure 2. Principle of EDM-G (CA2)

Electro-Discharge Machining-Grinding, shown in Figure 2, is a hybrid machining process that integrates EDM with grinding [CA2]. The electrical spark discharges in the grinding zone, thermally softening the work material and reducing the grinding forces. The method is also very effective in preventing the wheel from loading during grinding. A suitable workpiece material would also be poly-crystalline diamond (PCD).

Acknowledgements

The Author acknowledges the tremendous response from the contributors, to the initial request for information. Very little of the cited work is by the Author, and significant effort has been made to credit the contributors in the appropriate sections.

Summaries Cited in Above Section

- C4 ***Truing and Dressing of Superabrasive Grinding***, Professor R.K. Kang, Key Laboratory for Precision & Non-traditional Machining Technology of Ministry of Education, School of Mechanical Engineering, Dalian University of Technology, China.
- C7 ***Belt Grinding of Brittle Materials***, Professor Wang Chengyong, Institute of Manufacturing Technology, School of Mechanical Engineering, Guangdong University of Technology, China.
- C12 ***ELID Grinding***, Professor Feihu Zhang, Dept. of Mechanical Manufacturing and Automation, School of Mechanical and Electrical Engineering, Harbin Institute of Technology, China.
- G10 ***Ultrasonic Assisted Grinding***, Professor Dr.-Ing. Eckart Uhlmann, Institute for Machine Tools and Factory Management, Berlin University of Technology, Germany
- G14 ***Precision Contour Grinding of Optical Glasses Using Coarse-Grained Diamond Wheels***, Dr. Qingliang Zhao, LFM (Laboratory for Precision Machining), Bremen University, Germany.

- G38 ***Ultrasonic Superimposed Grinding of Advanced Ceramics***, Professor Jan C. Aurich, Institute for Manufacturing Engineering and Production Management – FBK, University of Technology Kaiserslautern, Germany.
- G74 ***Ultrasonic Grinding***, Professor Berend Denkena, Institute of Production Engineering and Machine Tools, Hannover University, Germany.
- GB8 ***Optimization of Electrochemical Grinding Process for Titanium Alloys***, Joseph McGeough, Regius Professor of Engineering, University of Edinburgh, Division of Engineering (Mechanical), United Kingdom.
- GB21 ***Optimisation of Process Chains for the Superfinishing of Bearing Materials***, Professor David Stephenson, School of Industrial & Manuf. Science, Cranfield University, UK.
- GB22 ***High Efficiency Precision Grinding of Hard Materials***, Professor David Stephenson, School of Industrial & Manufacturing Science, Cranfield University, UK.
- GB29 ***Intelligent and Adaptive Control for Grinding***, Dr Michael Morgan, Manager, Advanced Manufacturing Technology Research Laboratory, Liverpool John Moores University, UK.
- J1 ***Internal Machining of Small Hole by Ultrasonically Assisted Grinding (UAG)***, Associate Prof. Dr. Yongbo Wu, Dept. of Machine Intelligence and Systems Engineering, Akita Prefectural University, Japan.
- J3 ***Combined Micro Fabrication System using Both Laser and Microgrinding***, Professor Takuya Senba, Fukuoka Institute of Technology, Japan.
- J10 ***Abrasive Characteristics on Mirror Finishing by Alumina Fiber Brush***, Associate Professor Hitoshi Suwabe, Department of Mechanical Engineering, College of Engineering, Kanazawa Institute of Technology, Japan.
- J8 ***Chemo-Mechanical Grinding Technology***, Professor Zhou Libo, System Engineering Department, Ibaraki University, Japan.
- J12 ***Study on Dicing Saw using Ultrasonic Vibration***, Associate Professor Hitoshi Suwabe, Department of Mechanical Engineering, College of Engineering, Kanazawa Institute of Technology, Japan
- J31 ***Nanoprecision Micro-mechanical Fabrication***, Hitoshi Ohmori, RIKEN, Japan
- J36 ***Influence of Machine Tool Stiffness on Fixed-abrasive Planarization***, Professor Zhou Libo, System Engineering Department, Ibaraki University, Japan.
- J40 ***Mechanical-Chemical Finishing Using a Grinding Stone Including Microcapsules***, Associate Professor Toshiyuki Enomoto, Department of Computer-Controlled Mechanical Systems, Osaka University, Japan.
- IN2 ***Parametric Study Of Temperature Distribution In Electro-Discharge Diamond Grinding***, Prof. V. K. Jain, Department of Mechanical Engineering, Indian Institute of Technology, Kanpur, India
- IN4 ***Theoretical Analysis Of Thermal Residual Stresses In Electro-Discharge Diamond Grinding***, Prof. V. K. Jain, Department of Mechanical Engineering, Indian Institute of Technology, Kanpur, India.
- SD2 ***Electro-chemical Truing and Dressing of Grinding Wheels***, Professor Konrad Wegener, Institute of Machine Tools and Manufacturing, Swiss Federal Institute of Technology, Switzerland.
- U9 ***Rotary Ultrasonic Machining and Grinding***, ZJ Pei, Ph.D., Assistant Professor, Kansas State University, Dept of Industrial and Manufacturing Systems Engineering, USA

- U12 ***Wheel Loading Causes and Solutions***, John W. Sutherland, Ph.D., Chair Professor, Dept. of Mechanical Engineering-Engineering Mechanics, Michigan Technological University, USA.
- U13 ***Geometric Modeling of Ground Surface Generation***, John W. Sutherland, Ph.D., Chair Professor, Dept. of Mechanical Engineering-Engineering Mechanics, Michigan Technological University, USA.
- U14 ***Intermittent Grinding Processes for Hard Steels and Ceramics***, John W. Sutherland, Ph.D., Chair Professor, Dept. of Mechanical Engineering-Engineering Mechanics, Michigan Technological University, USA.
- U47 ***HELID (High-speed Electrolytic In-process Dressing) - An Efficient Method for In-process Dressing of High-speed Grinding Wheels***, Professor Zhenqi Zhu, Stevens Institute of Technology, USA.
- U53 ***Laser Assisted Grinding of Ceramics***, Professor Ioan D. Marinescu, Precision Micro-Machining Center, College of Engineering, University of Toledo, USA.