Surface generation with engineered diamond grinding wheels: Insights from simulation

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Introduction
- Response variability in grinding
- Engineered grinding wheels
- Objective of present research

Simulation methodology
- Stochastic simulation
- Technique validation

Surface generation with engineered wheels
- Protrusion height distribution
- Spatial array parameters
- Grain shape

Summary & outlook
Introduction

- Fine grinding
  - Stringent surface quality & tolerance requirements
  - Often engaged at the limits of process capability
  - Imperative to realize repeatable process performance

- Process response variability
  - Cutting
    - Work material inhomogeneities, machine tool characteristics, cutting fluid, measurement scheme, etc.
  - Grinding
    - Time-dependent, stochastic geometry of abrasives, and random three-dimensional abrasive spatial location
Variability in grinding

- Significant process variability in grinding
  - Intriguing in terms of academic pursuit!
  - Industrial implementation: Art vs. science
  - Imperative to develop a scientific approach

- Models for grinding process variability
  - Quantify variability inherent to the process
  - Benchmarking wheel performance
  - Devise strategies for minimizing process variability
Control of grinding variability

- Process variability depends on (table speed / wheel speed)
  - Improved repeatability in creep-feed & high-speed processes

- Truncate the range of abrasive grit size in standard mesh
Concept of engineered grinding wheels

- An innovative approach to minimizing variability
- Abrasive grains are arranged in a predetermined spatial array

Characteristics:
- Devoid of grain clustering
- Facilitate accommodation of grinding debris & ingress of grinding fluid
- Effective heat transfer
- Consistent performance
- Improved wheel life

Manufacture of engineered grinding wheels

- **Microreplication**
  - Copying of three-dimensional microscopic structures in a continuous repeating pattern

- **Brazing/galvanizing technologies in conjunction with novel grain placement strategies**

Objective of present work

- Formulation of a theoretical framework for the design of engineered wheels
  - Guidelines for wheel manufacture
  - Impractical experimental characterization
- Maximize performance with respect to surface generation characteristics
- Comparison of the performance of engineered wheels vis-à-vis conventional diamond wheels
- Accomplished through an experimentally validated surface generation model
Simulation of grinding processes

- Surface generation models for grinding
  - Vast majority of models relate to conventional abrasives
  - Material response to kinematic mapping of wheel topography
  - 3-D wheel topography models
    - Digital representation of wheel surface through profilometry
  - Stochastic simulation methodology
Stochastic simulation: Assumptions

- Considers size distribution of abrasive grains
- Does not entail any experimental input
- Spherical abrasives
  - Symmetric normal distribution
  - Size range = 6 times standard deviation
  - Grains distributed uniformly in wheel volume
  - Critical bonding ratio = 0.2
- Geometric wheel-work interaction
- Estimates process inherent variability
  - The minimum and maximum among 100 profile indices represent 95% tolerance limits @ 95% confidence level [Natrella, Experimental Statistics, 1963].
Stochastic simulation of diamond grinding

Simulation of wheel structure

Grit size; Concentration

3-D wheel topography

Simulation of material removal

Synthesized ground surface

Process kinematics

Simulation of material removal

Wheel

Work

11
Simulation validation

Simulated transverse profile

Expt. (silicon nitride)

Upper and lower bounds correspond to 95% tolerance limits at 95% confidence level
Simulation results:
Role of protrusion height distribution

Peripheral surface grinding
Concentration 100; \(v_s\) 30m/s
\(v_{ft}\) 120mm/s; \(a_e\) 10µm

<table>
<thead>
<tr>
<th>Mesh</th>
<th>Ra (µm)</th>
<th>Active Grains</th>
<th>Max Chip Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>320/400</td>
<td>0.39</td>
<td>1507</td>
<td>53 µm²</td>
</tr>
<tr>
<td>140/170</td>
<td>1.03</td>
<td>178</td>
<td>252 µm²</td>
</tr>
</tbody>
</table>

Radial distance from outermost point (µm)

Probability density

Chip cross-sectional area (µm²)

Number of occurrences
Simulation results: Effect of altering protrusion height distribution

Peripheral surface grinding
320/400 mesh; concentration 100
\(v_s\) 30m/s; \(v_{ft}\) 100mm/s; \(a_e\) 10\(\mu\)m

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53\textsuperscript{rd} CIRP General Assembly
August 2003, Montreal, Canada
Simulation results: Effect of altering protrusion height

Peripheral surface grinding
320/400 mesh; concentration 100
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Need for technology to control protrusion height distribution

- Uniformly distributed
- Normally distributed

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Simulation results: Role of spatial arrangement

- For the lowest roughness, the maximum axial offset is to be less than 25-40% of average grain diameter.
- Roughness corresponding to the best spatial arrangement only on the order of that due to a conventional diamond wheel.

Peripheral surface grinding
320/400 mesh; concentration 100
\( v_s \) 30m/s; \( v_{ft} \) 100mm/s; \( a_e \) 10\( \mu \)m;
Average grain diameter 42 \( \mu \)m

5mm x 0.4mm

Bounds due to conventional diamond wheels
Simulation results: Role of grit shape

The effect of grain shape on roughness is on the order of the inherent process variability.

Peripheral surface grinding 320/400 mesh; concentration 100

Peripheral surface grinding 320/400 mesh; concentration 100
v_s 30m/s; v_f 100 mm/s; a_e 10 μm

Bounds due to conventional diamond wheels
Summary & outlook

- **Kinematic simulation is a valuable tool in the development of engineered wheels.**
  - The roughness and the associated variability are controlled by the protrusion height distribution and is independent of the maximum value.
  - Surface quality can be significantly improved by controlling the protrusion height distribution.
  - For spatially ordered arrays, the axial offset need be 25-40% of the average grain diameter for achieving the best finish.
  - The effect of grain shape on roughness is only on the order of the process inherent variability.

- **There is a need to develop technologies for tailoring abrasive protrusion height distribution.**
For more information please see: