Magnetic Abrasive Finishing with Hybrid Magnetic Tools

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Abstract

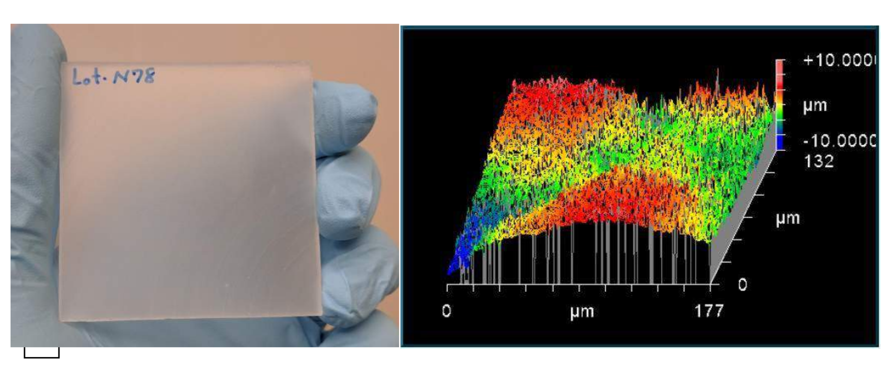
In manufacturing, finishing of components may require multiple processes to achieve desired surface characteristics or function. One process may be used to achieve desired form accuracy, but must be followed by another to achieve desired roughness. Implementing multiple processes may require multiple costly machine tools, and may add significant amounts of time to the manufacturing process. A single process capable of achieving both goals is desired. This research explores the use of hybrid magnetic tools to alter both form accuracy and roughness on ceramic workpieces. Hybrid magnetic tools consist of magnetic particles bonded together with water-soluble glue. The tool acts in two phases: a bonded particle phase and a brush phase. The toll begins finishing in the bonded particle phase, removing material to flatten and smooth the target surface. As the applied lubricant dissolves the glue, the tool gradually transitions to the brush phase, allowing it to deform to the workpiece surface and smooth it without altering form accuracy. It was found that the transition behavior and finishing characteristics of hybrid magnetic tools are influenced by the tools' glue content. Increasing the amount of glue was found to prolong the bonded particle phase. The bonded particle phase was found to affect the ceramic's form accuracy by grinding a profile into the surface the width of the un-dissolved portion of the tool. Reducing the amount of glue was found to accelerate the tools' transition to the brush phase, which had little effect on the ceramic's form accuracy while reducing roughness. Although each hybrid magnetic tool spent a different amount of time in each phase due to the varying glue content, each tool reduced the ceramic's average roughness Sa from approximately 1.00 µm to below 0.10 µm with 10 minutes of finishing.

Research Objectives

- Characterize hybrid magnetic tools
  - Determine effect of tools on flatness and roughness
- Investigate finishing characteristics as a function of glue content

Experimental Case Study: Yttrium Aluminum Garnet (YAG) Ceramics

- Used in high power industrial lasers (~500 MW)
- Requires extensive processing to reach desired surface characteristics



10 mm Un-finished YAG ceramic surface

Sa: 2.16 µm *Sz*: 15.16 µm *PV*: 19.71 µm

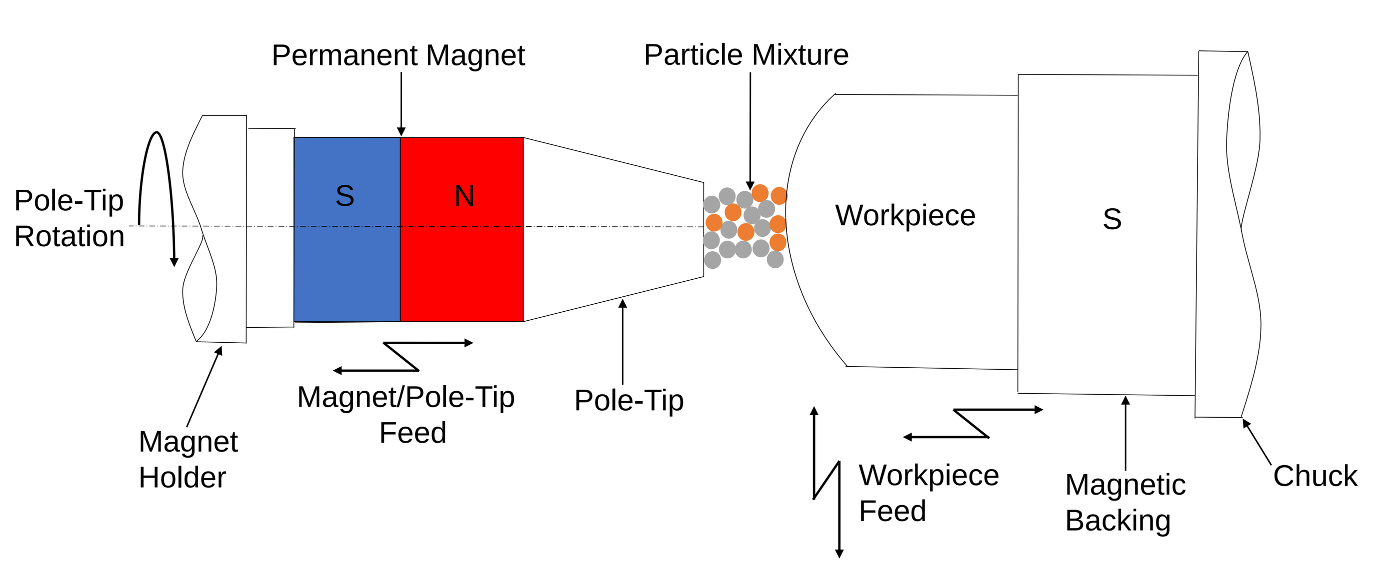
Target values:
- Flatness: < λ/10
- Parallelism: 10 arcsec (1/360°)
- Roughness: 0.2 nm *Sa*

Magnetic Abrasive Finishing (MAF)

- Use magnetic field/particles to manipulate abrasive
- Force on abrasive is sensitive to magnetic particle size:

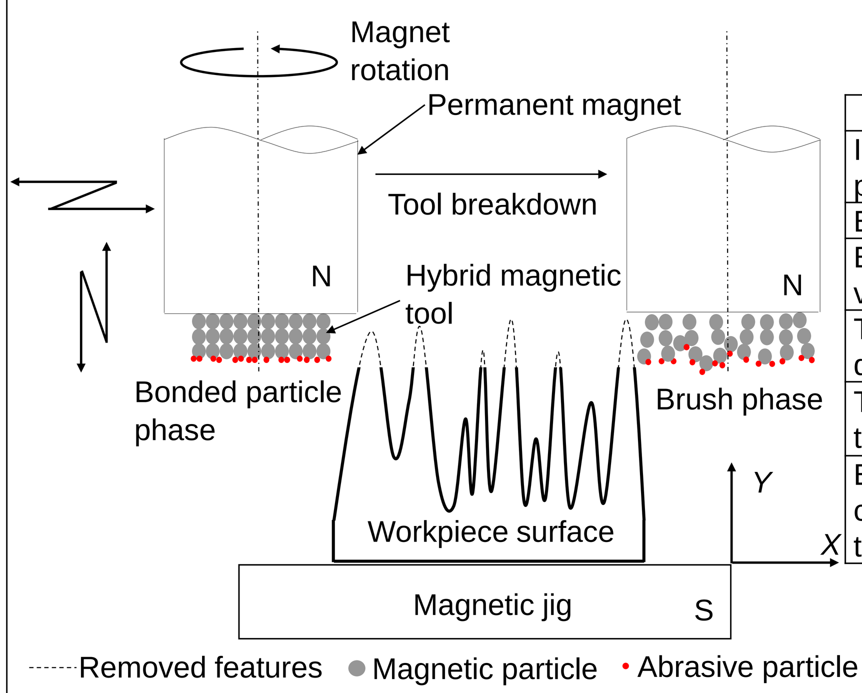
$$F = V\chi \boldsymbol{H} \cdot \nabla \boldsymbol{H}$$

V: magnetic particle volume χ: magnetic susceptibility $\boldsymbol{H}$: magnetic field strength



Hybrid Magnetic Tools

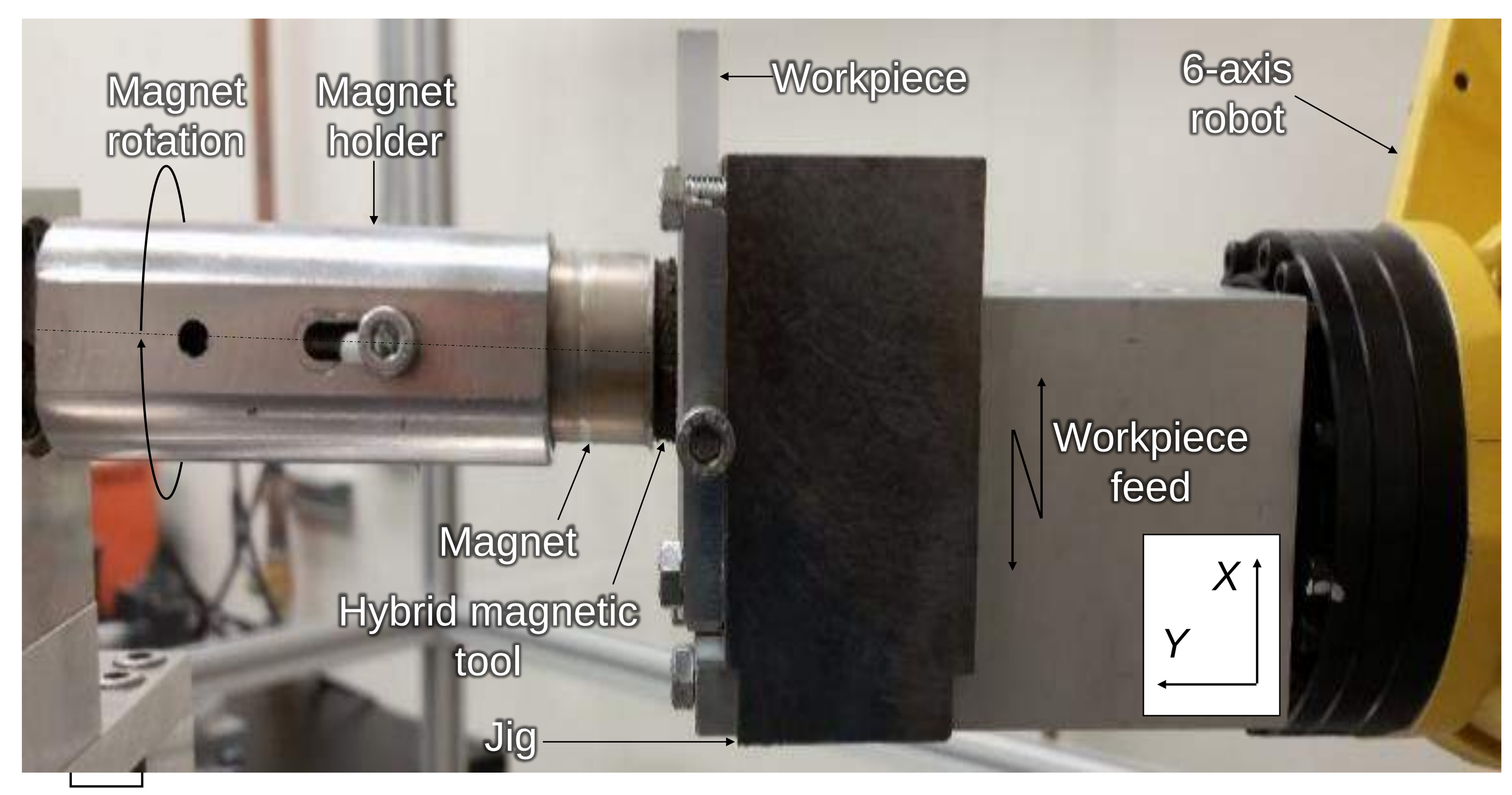
- Dual phase technology
  1. Bonded particle phase (grinding phase)
  2. Brush phase (polishing phase)



Hybrid Magnetic Tool Parameters							
Iron particles	#30-#80 (150-600 µm mean diameter), 5 g						
Binder	Water soluble polyvinyl acetate craft glue						
Binder volume	0 mL	0.1 mL	0.2 mL	0.3 mL	0.4 mL	0.5 mL	0.6 mL
Tool diameter	–	25 mm					
Tool thickness	–	3.5 mm	3.6 mm	3.5 mm	3.6 mm	3.6 mm	3.7 mm
Binder curing time	48 hr						

Experimental Setup

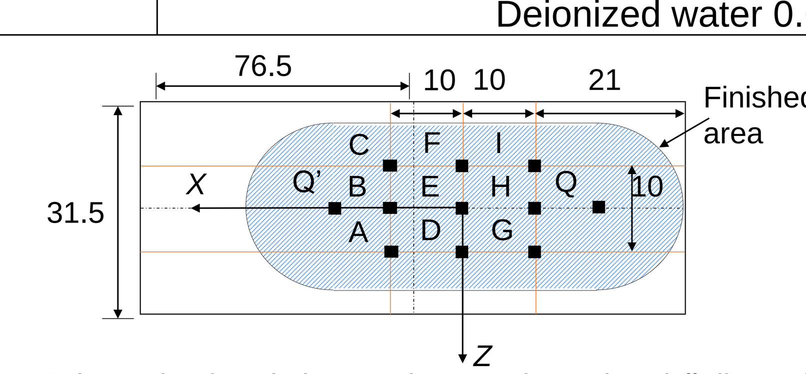
- Magnet and tool are allowed to move in *Y* to maintain pressure



10 mm

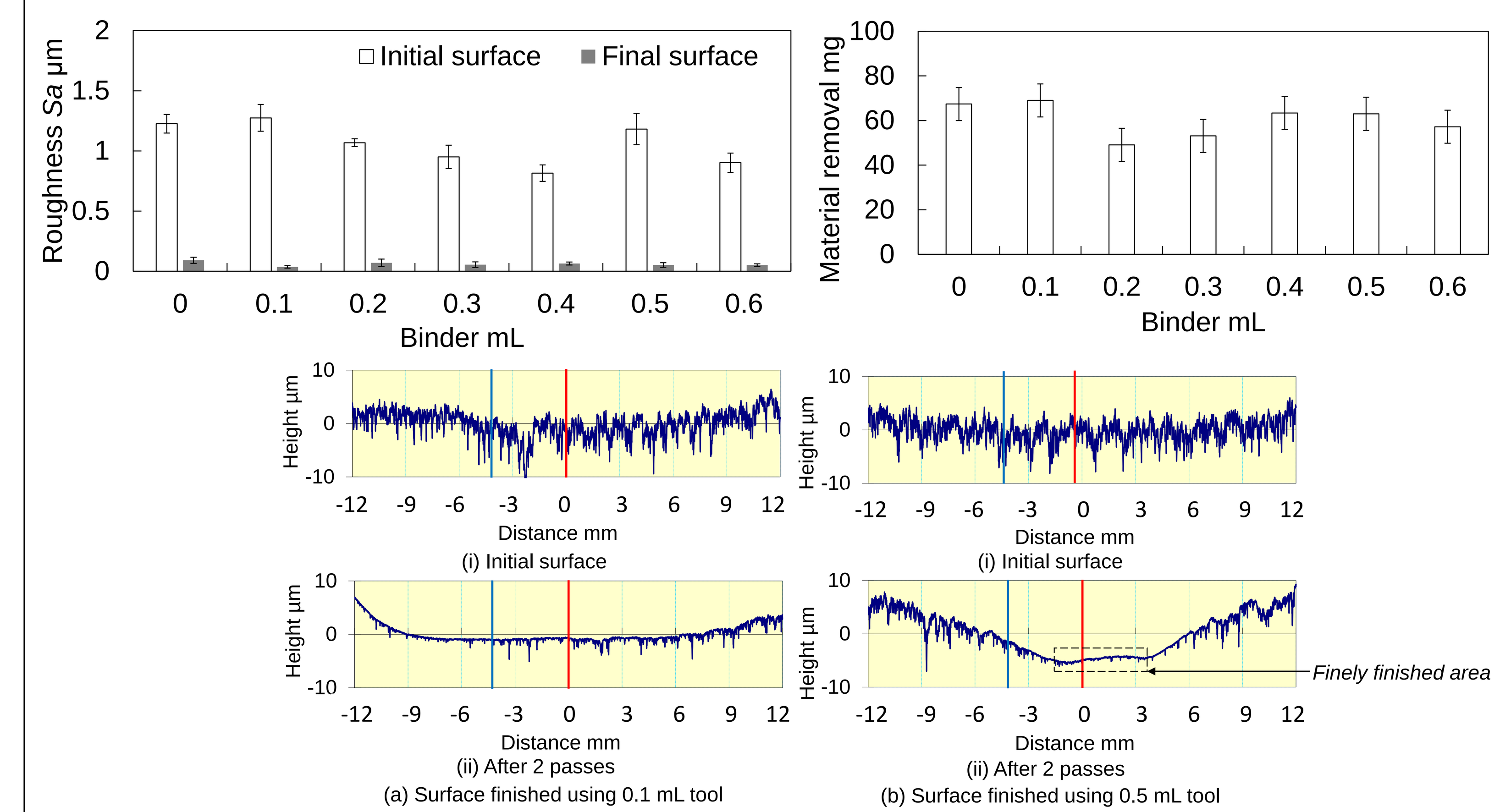
Experimental Conditions

Experimental Conditions	
Abrasive	4-8 µm diamond, 0.400 g
Workpiece	YAG ceramic plate (31.5×76.5×10 mm)
Workpiece feed per pass	Length 74 mm/s, feed rate1 mm/s
Finishing time	8 passes (9 min 52 s)
Magnets	Nd-Fe-B ∅24.5×12.7 (3 magnets)
Maximum magnetic flux density	0.70 T at center magnet surface, 0.67 T at workpiece surface
Magnet rotation	500 min^{-1}
Final gap between magnet and workpiece	2 mm
Lubricant	Water soluble-type barrel finishing compound 1.0 mL + Deionized water 0.6 mL



Schematic of workpiece and measuring points (all dimensions are in mm)

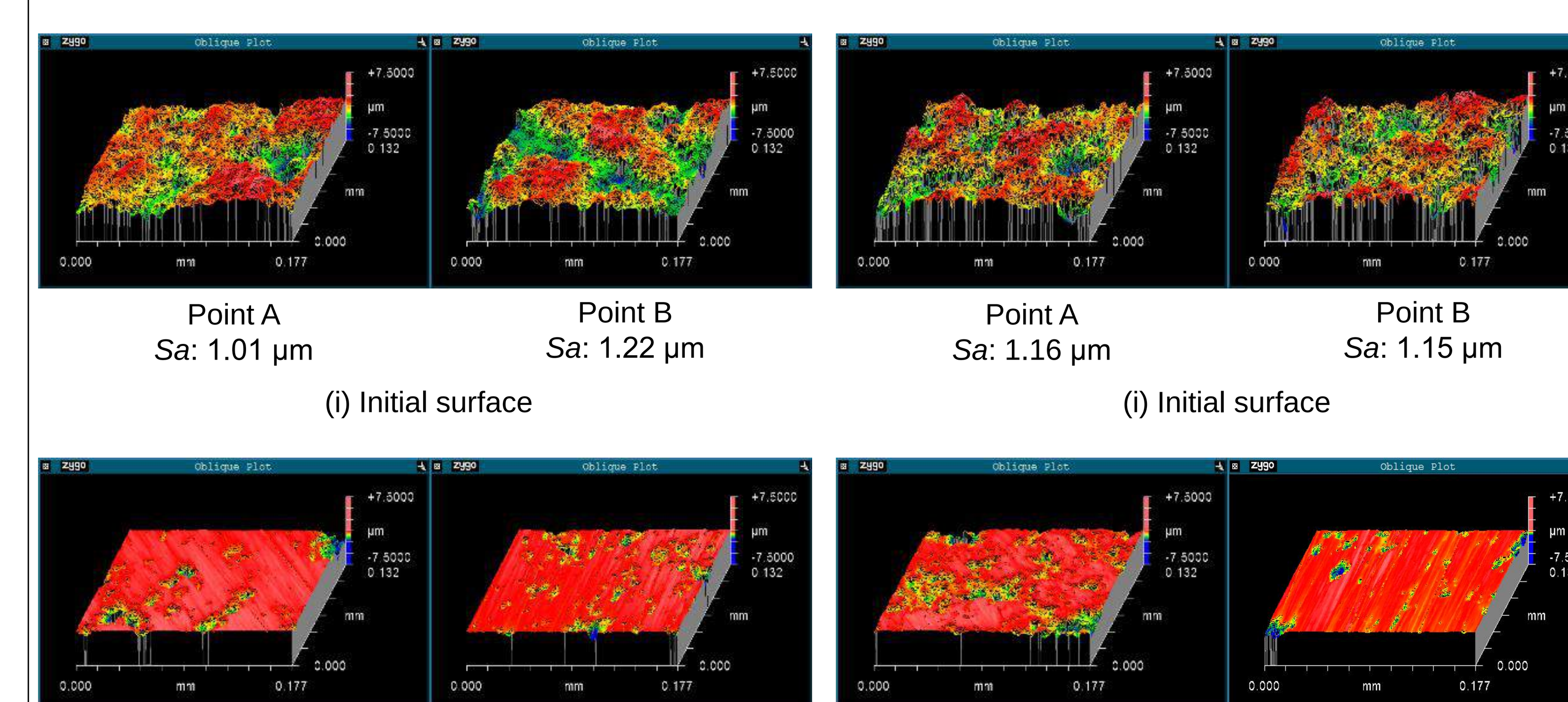
Effect on YAG Ceramic Surface



Profile along line D-E-F before and after 2 passes with the 0.1 mL and 0.5 mL HMTs

| Line B-E-H | Line A-D-G

3-D Geometries



(a) Point A	(a) Point B	(b) Point A	(b) Point B
(i) Initial surface: *Sa*: 1.01 µm	*Sa*: 1.22 µm	*Sa*: 1.16 µm	*Sa*: 1.15 µm
(ii) After 2 passes: *Sa*: 0.25 µm	*Sa*: 0.19 µm	*Sa*: 0.40 µm	*Sa*: 0.09 µm

(a) Surface finished using 0.1 mL tool   (b) Surface finished using 0.5 mL tool

Conclusions

- Hybrid magnetic tools exhibit two phase:
  - Bonded particle phase
    - Removes material from peaks of the surface
    - Flattens surface
  - Brush phase
    - Removes material evenly from the surface
- Tool finishing characteristics can be controlled through binder content

Future Work

- Test tools with varying abrasive sizes
- Expand finishing capabilities to non-planar workpieces

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