Analysis of the Material Removal Rate and Smoothing Effect of Active Fluid Jet Polishing

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INTRODUCTION: The objective of the polishing process is to create a specular smooth surface, fine adjust the figure, and improve surface finish. AFJP is a polishing tool used in computer controlled optical surfacing. Active fluid jet polishing (AFJP) is a fine and correction polishing process (simple to complex optical surfaces).

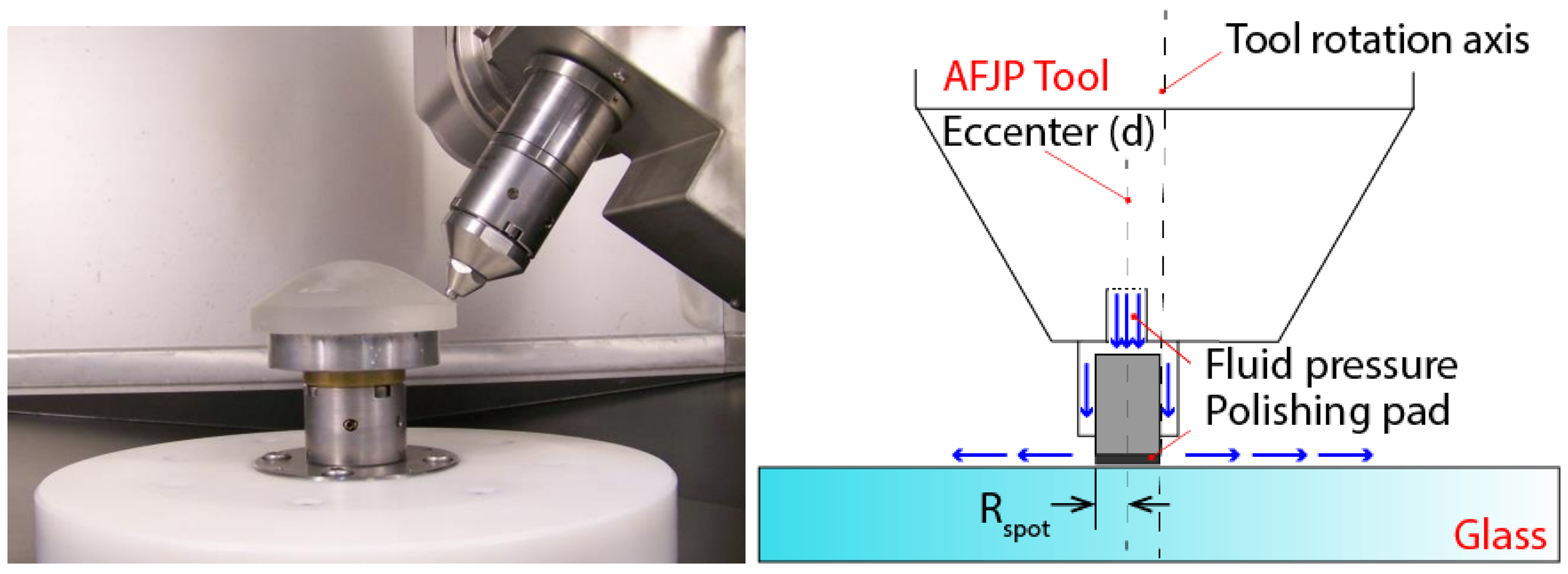

Figure 1. Active fluid jet polishing (AFJP) process (MCP 250 OptoTech).

AFJP COMPUTATIONAL METHODS: The material removal rate (MRR) during polishing is described by Preston's equation (1).

$$R(x,y) = -\frac{1}{\tau}\int_0^{\tau} kP_o e^{\left(-\frac{1}{2}\frac{(x_p - x_c)^2+(y_p - y_c)^2}{\sigma^2}\right)} v_{tw}(x,y)\, dt \qquad (1)$$

R(x,y) is the average MRR, P_o is pressure (Gaussian distribution). $V_{tw}(x,y)$ is relative velocity of tool and k is Preston's coefficient). Following is the asphere equation (2) of workpiece surface.

$$z = \frac{cy^2}{1+\sqrt{1-(1+K)c^2y^2}} + \sum_{i=0}^{i=n} A_i y^i \qquad (2)$$

z is sagittal height, y radial distance, c is curvature, K is conic constant and A_i is the asphere coefficient. The polishing process is controlled using the dwell time. While polishing, the tool is pressed against the workpiece surface and polishing slurry is supplied near the contact zone. This creates a tool influence function (TIF). TIF is convoluted along the tool path to polish the surface. ODE and DAEs interfaces (3) in the Base module of Comsol Multiphysics® 5.4 was used for the analysis. The analysis was carried using flat Schott BK7 glass (70 mm diameter).

$$e_a \frac{\partial^2 u}{\partial t^2} + d_a \frac{\partial u}{\partial t} = f \qquad (3)$$

Boundary conditions (4)

$$\frac{\partial u}{\partial t} = 0, u = 0 \qquad (4)$$

Position vector (5) of point P

$$r = r_c + \rho \qquad (5)$$

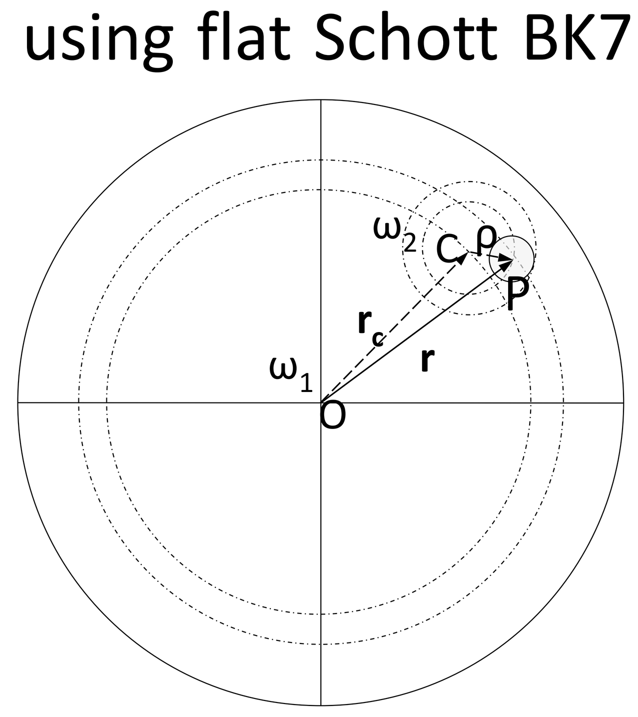

Figure 2. Active fluid Jet polishing

ω_1 and ω_2 are the angular velocity of workpiece and polishing tool. For analysis workpiece kept stationary.

Table 1. AFJP polishing process parameters

Variable	Value			Units
Pressure (P_o)	1 to 1.5			bar
Tool rotation (N_{ec})	500 to 2000			rpm
Spot radius (R_{spot})	2	3	5	mm
Ec_center (d)	0.5	1.5	2	mm

RESULTS: Polishing analysis of linear tool movement. AFJP tool is moved linearly from edge to center.

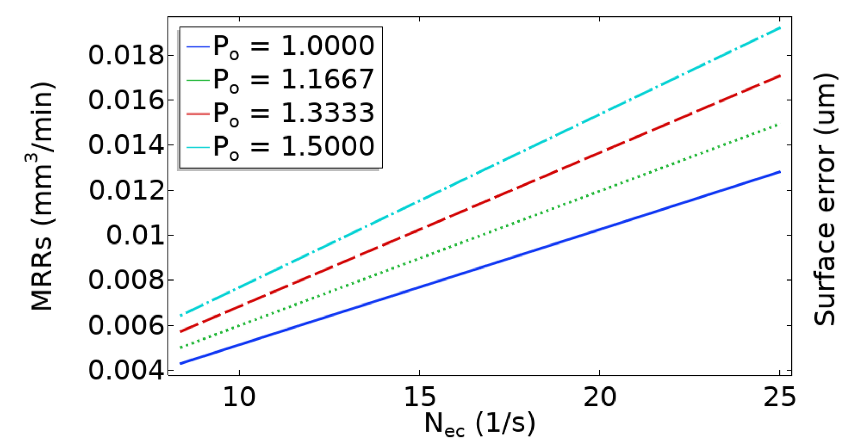

Figure 3. MRRs with varying tool rpm and peak pressure at 3 mm (R_{spot})

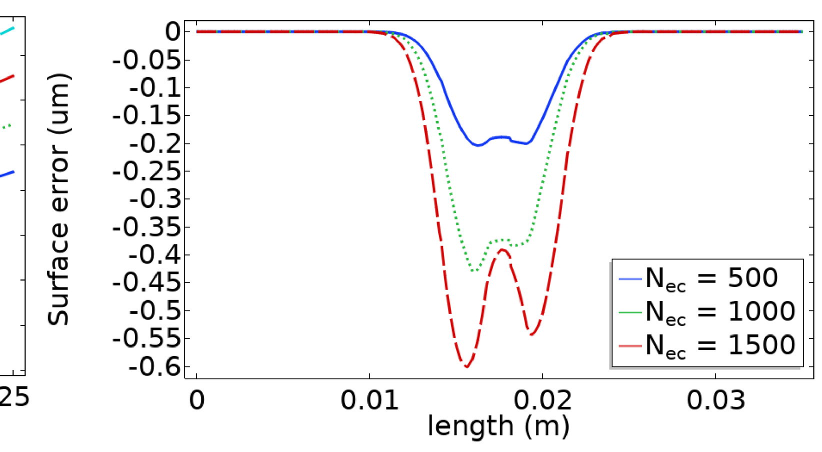

Figure 4. Removal depth at 1 bar, 3 mm (R_{spot}) and 600 s

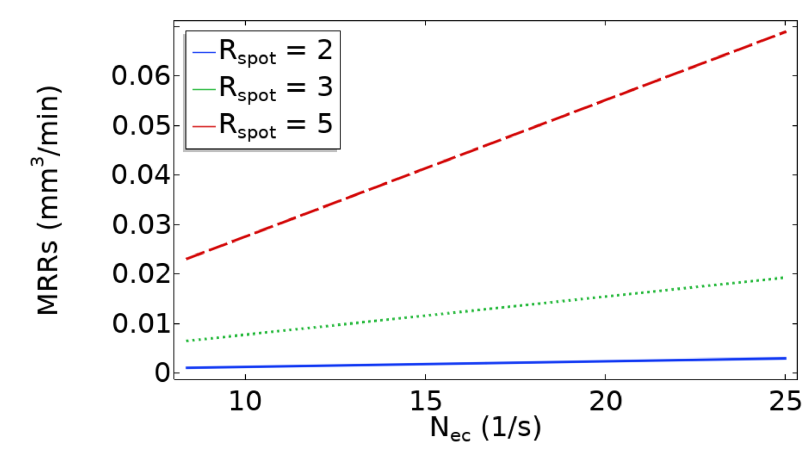

Figure 5. MRRs with different spot size at 1.5 bar

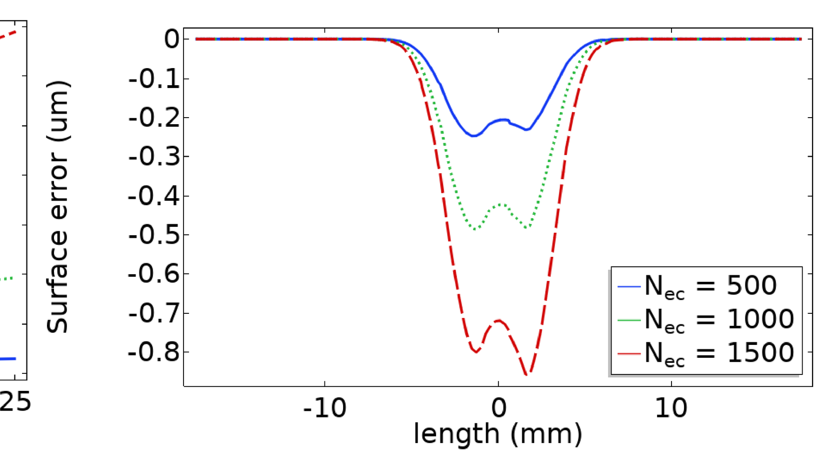

Figure 6. Removal depth at 1.5 bar, 3 mm (R_{spot}) and 600 s

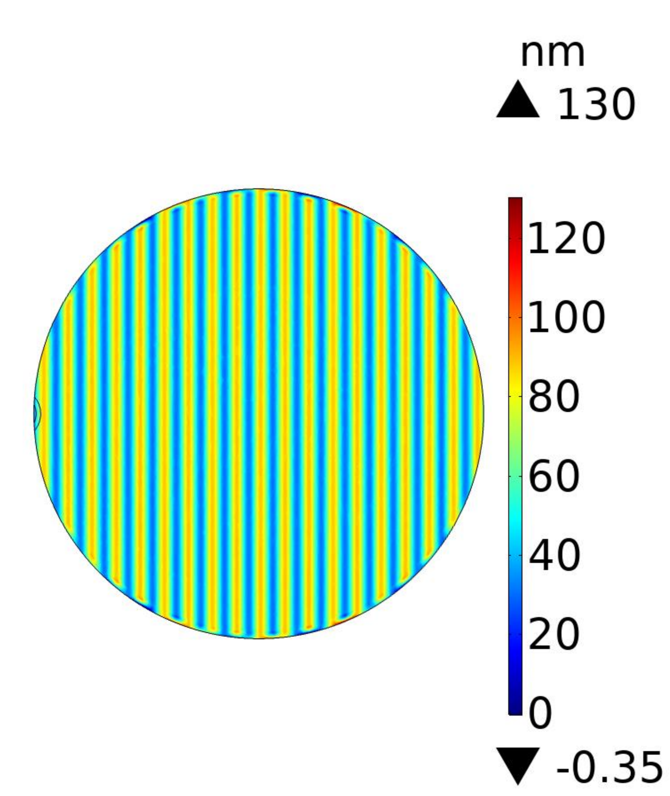

Figure 7. Initial surface error

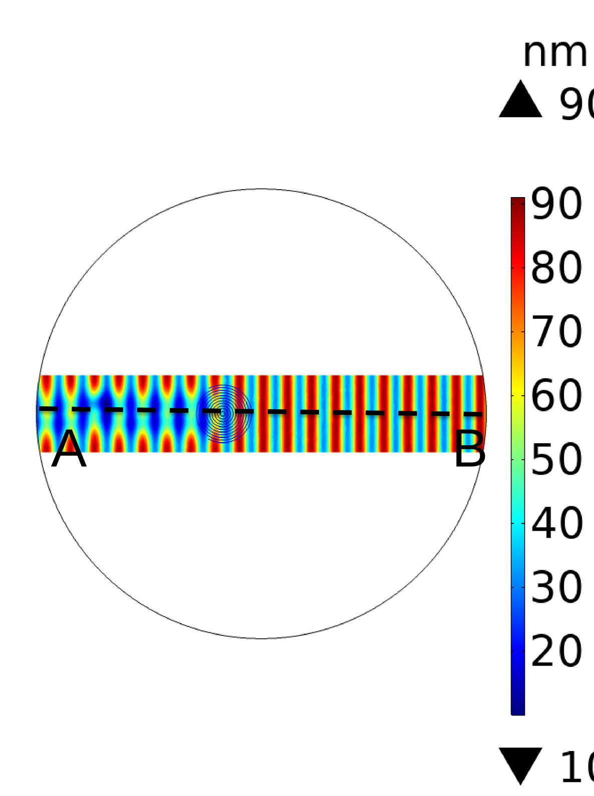

Figure 8. Simulated surface error at 120 s, 1.5 bar, and 3 mm (R_{spot})

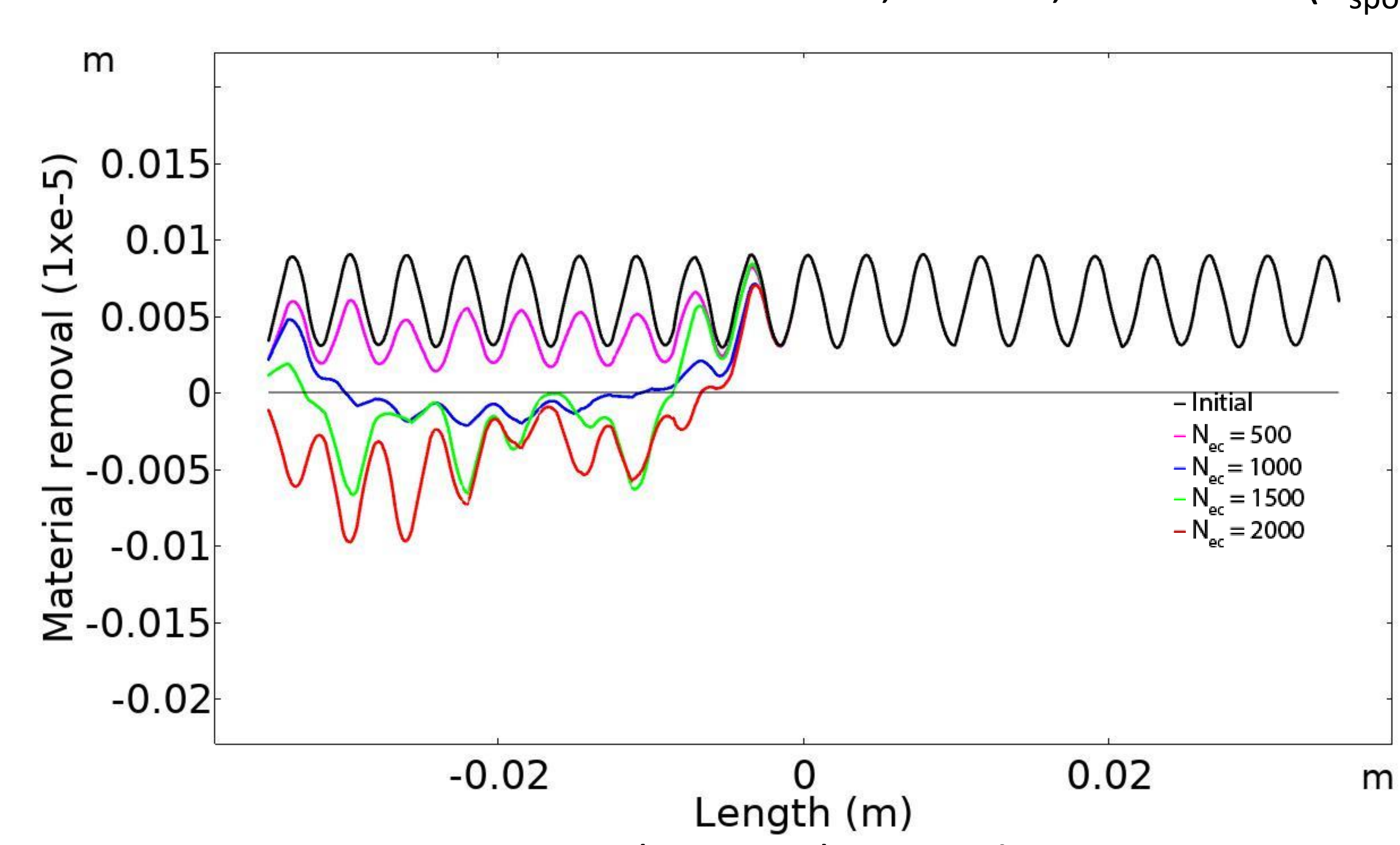

Figure 9. Section AB in contour (Figure 8), smoothing using AFJP tool, 120 s, 1.5 bar, 3 mm (R_{spot})

CONCLUSIONS:

1. AFJP can be used to obtain submicron or nanometer scale MRRs.
2. Due to low MRRs of the AFJP process, AFJP can be employed in fine and correction polishing.
3. AFJP can be employed in removing mid and high-frequency surface errors on the optical surface during sub-aperture polishing.

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