Process Modeling of Micro-Cutting Including Strain Gradient Effects

Kai Liu: Graduate Student

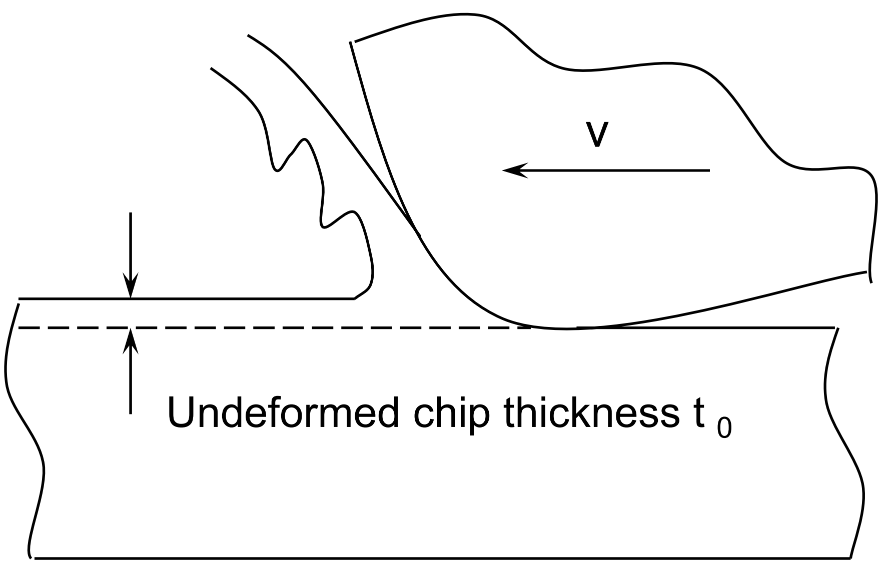
Dr. Shreyes Melkote: Faculty Advidor

Presentation Outline

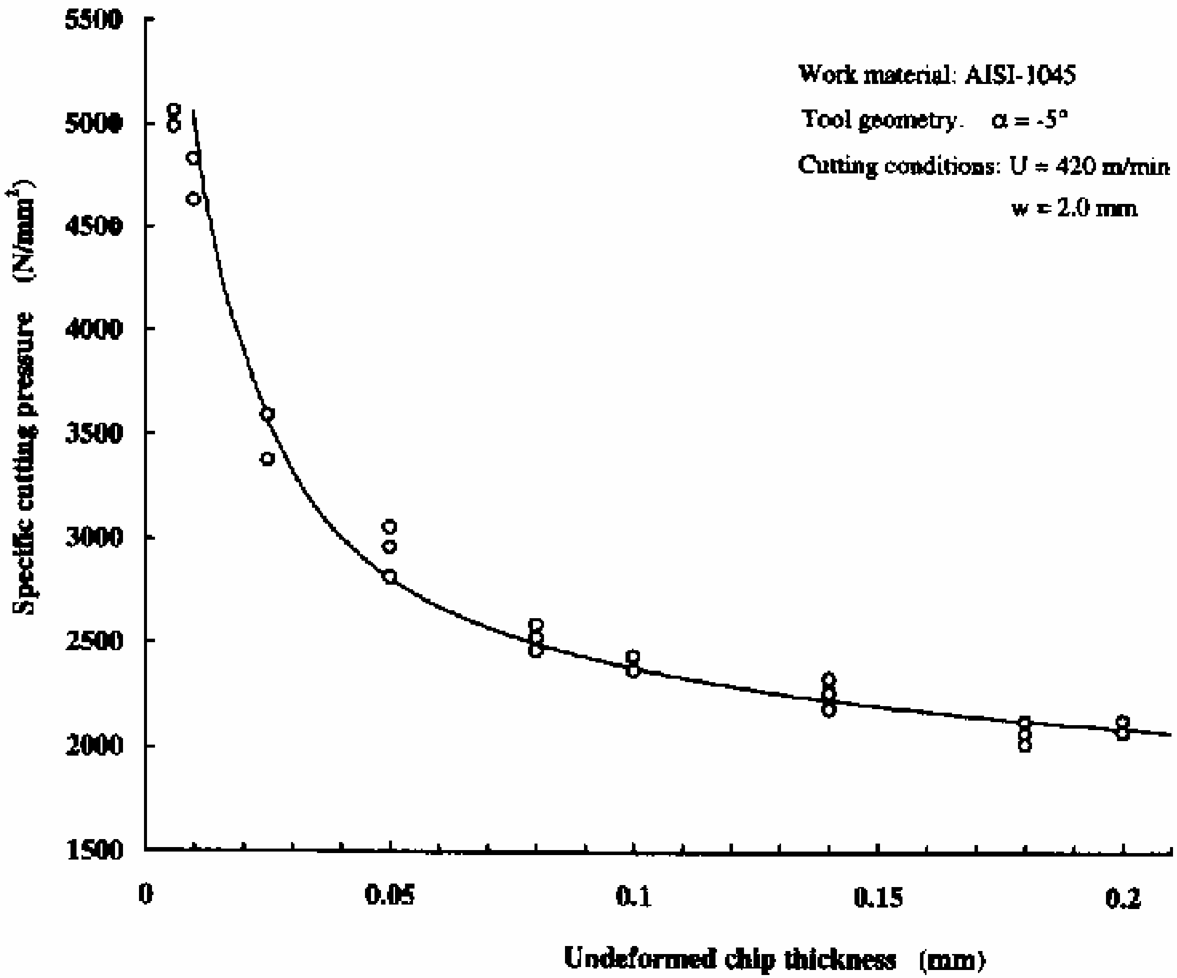
- Characteristics of micro-cutting
- Research objectives
- Numerical modeling of micro-cutting process
- Strain gradient plasticity
- Initial results
- Future work

Typical Characteristics of Micro-Cutting Process

- Very small undeformed chip thickness (1 μm~100 μm)
- Tool edge geometry dimension comparable to undeformed chip thickness.
- Large negative rake angle
- Large shear strain, strain gradient in primary shear zone.



Size effect in machining



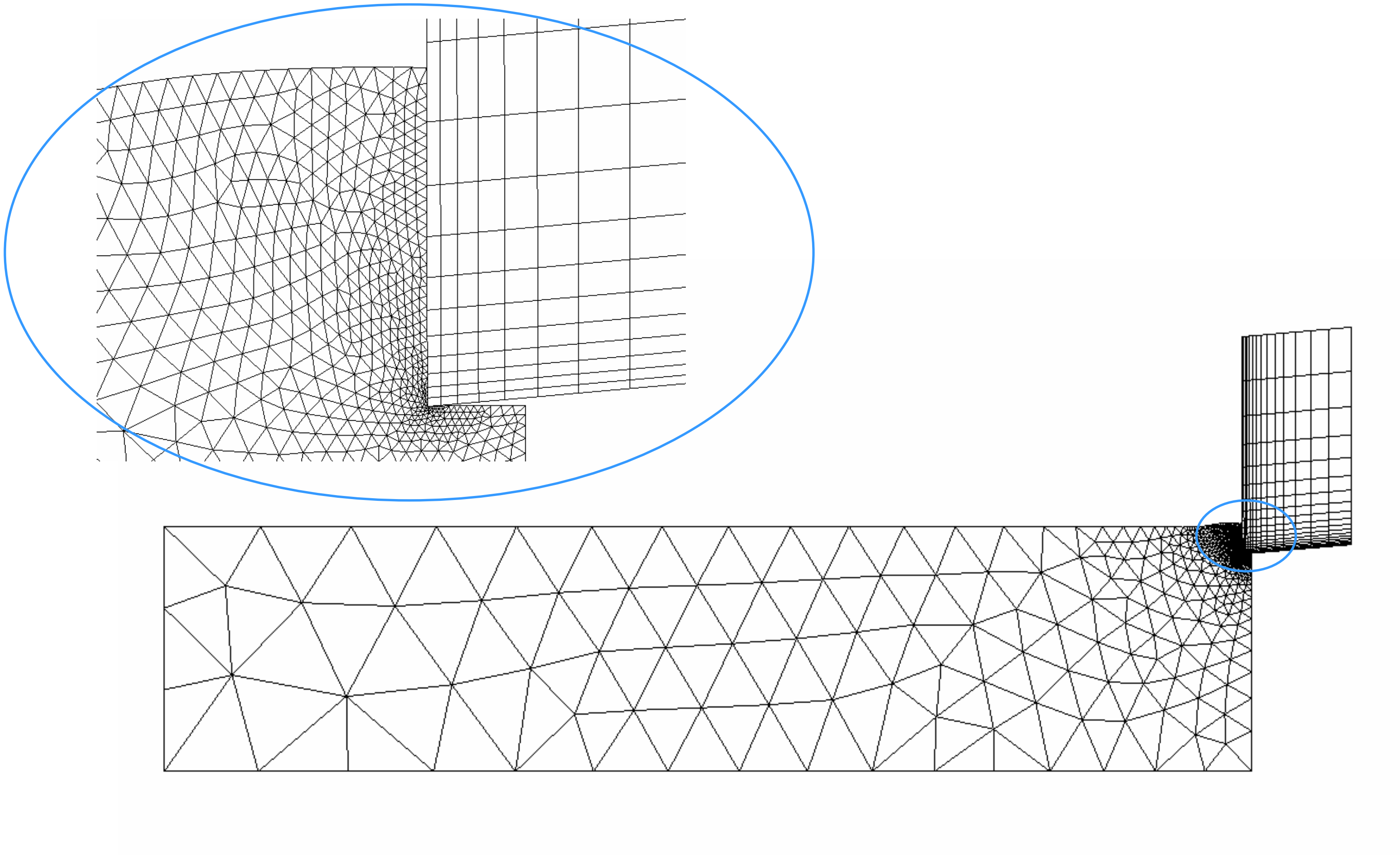
Research Objectives

- Develop a computational model to describe the micro-cutting process, taking into account the size effect.
- Predict the stresses, strains, temperatures, cutting forces and residual stresses in the micro-mechanically machined workpiece.
- Experimentally verify model.

Essential Model Capabilities

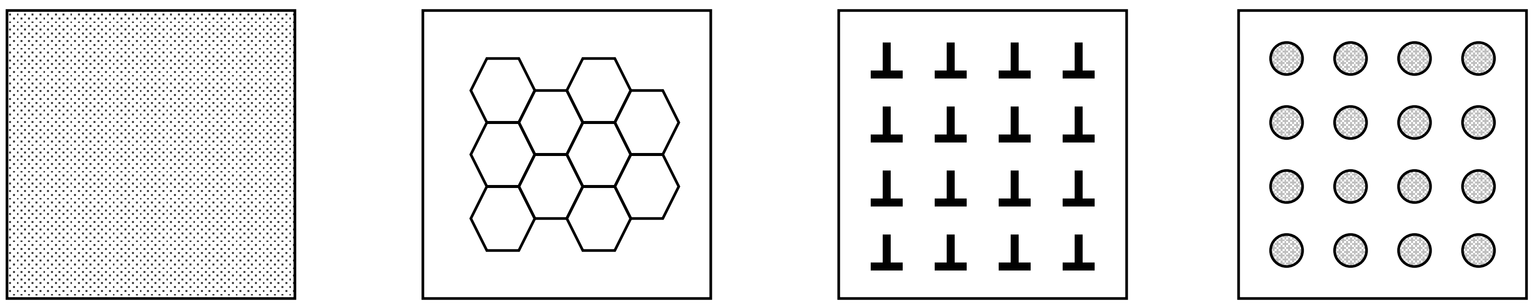
- Fully coupled thermal-mechanical analysis
- Accurate material flow stress modeling
- Physically-based chip separation criterion
- Adaptive remeshing capability
- Fracture initiation and crack growth
- Friction characteristics

Finite Element Model Configuration



Strain Gradient Plasticity

Classical Plasticity	Strain gradient Plasticity	Dislocation Mechanics	Molecular Dynamics



Min. Length Scale L	Macroscale	Polycrystal	Discrete Dislocations	Atomistic
	O(10^{-3}m)	O(10^{-5}m)	O(10^{-8}m)	O(10^{-10}m)

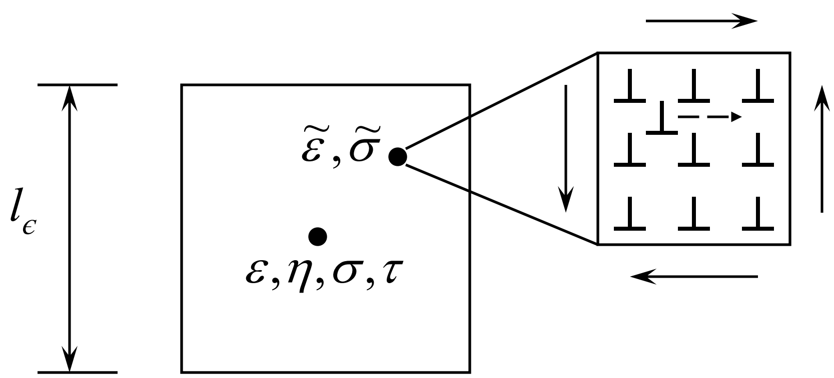
0.1 μm~10 μm

Strain Gradient Plasticity

$$E = \frac{1}{2}\left(F^T \cdot F - 1\right)$$ Green strain tensor E

$$\eta_{ijk} = E_{ik,j} + E_{jk,i} - E_{ij,k}$$ Strain gradient tensor η

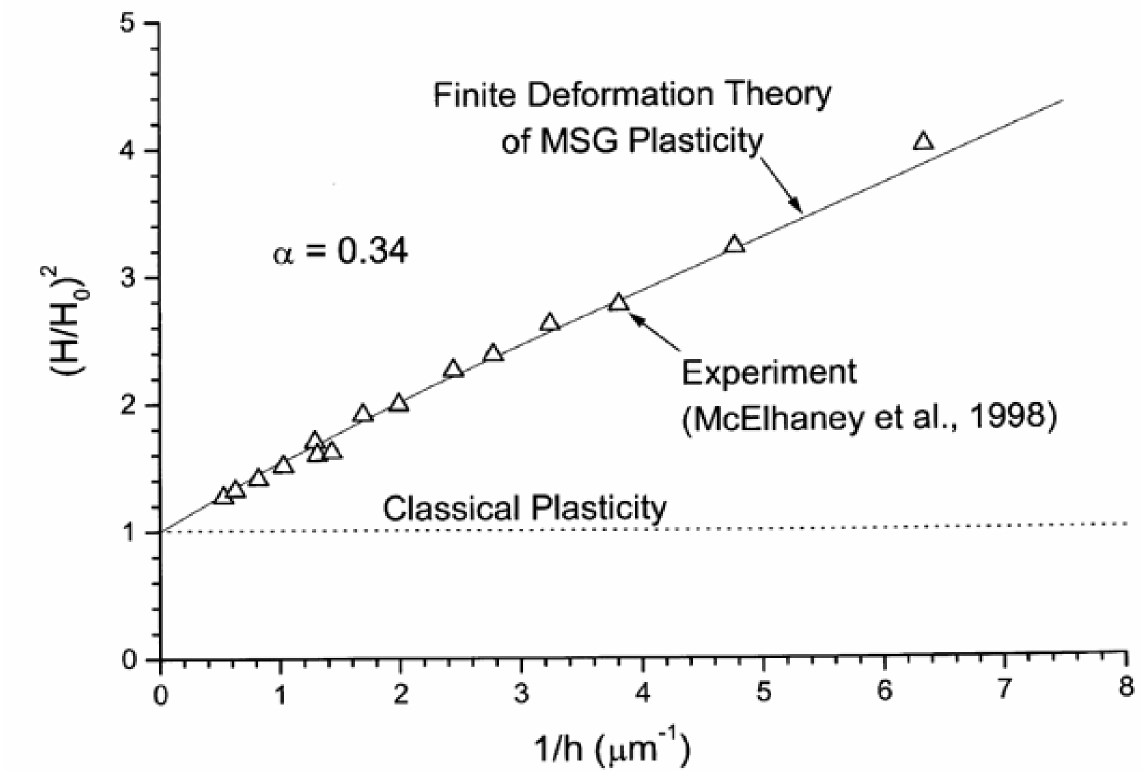
$$\tau = \alpha\mu b\sqrt{\rho_s + \rho_g} \qquad \bar{\sigma} = \sigma_y\sqrt{f^2(\bar{\varepsilon}) + l\bar{\eta}} \qquad l = 3\alpha^2\left(\frac{\mu}{\sigma_y}\right)^2 b$$



microscale $\tilde{\varepsilon}, \tilde{\sigma}$

mesoscale $\varepsilon, \eta, \sigma, \tau$

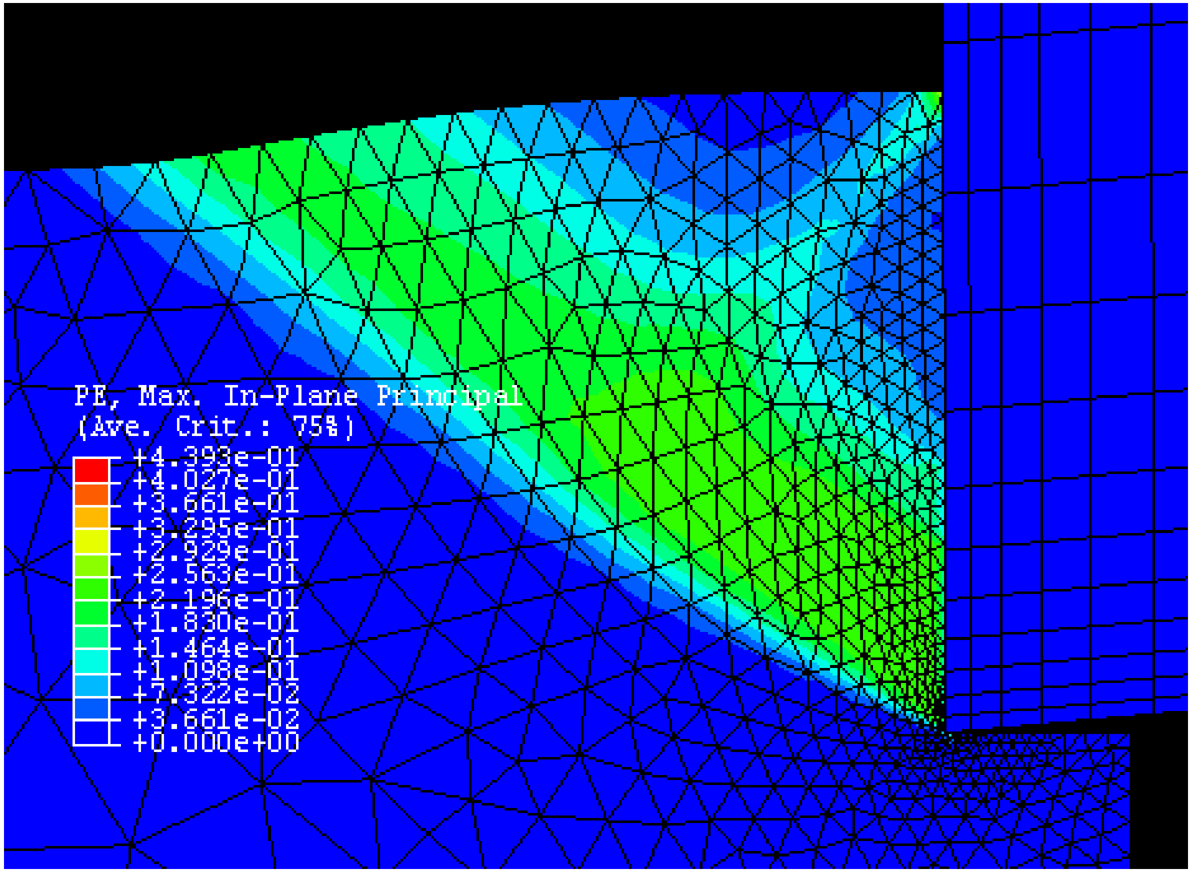
Strain Gradient vs. Classical Plasticity: Nanoindentation Example



Machining / Indentation Analogy

	Indentation	Machining
Shear strain	$\gamma \approx 0.36$	$\gamma \approx 2 \sim 4$
Strain gradient	$\eta = 4\gamma / D$	$\eta \approx 4\gamma / t$
Hardness or Specific force	$H = C'Gb\sqrt{\rho_s + (4\gamma / bD)}$	$F \approx AGb\sqrt{\rho_s + (4\gamma / bt)}$
Characteristic length Of deformation field	Indentation dimameter,D	Undeformed chip thickness, t_0
	0.1 μm~10 μm	0.5 μm~50 μm

Initial Results



Future Work

- Implement strain gradient plasticity in finite element model
- Validate model by micro-/nano-indentation and/or micro-cutting experiment data