Past Accomplishments and New Project Opportunities

Shreyes N. Melkote, Ph.D.

Associate Professor

George W. Woodruff School of Mechanical Engineering

Georgia Institute of Technology

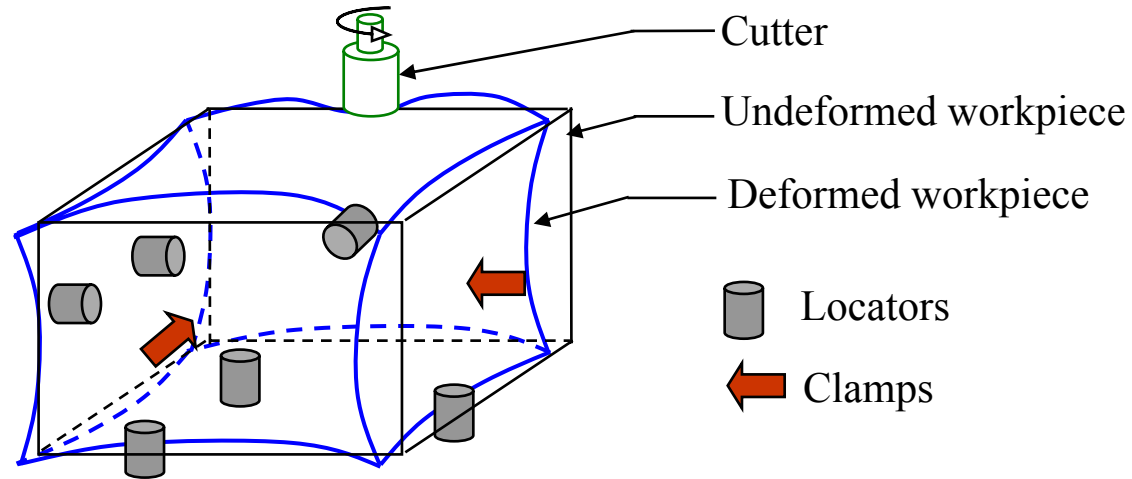**Atlanta, GA 30332-0405**

PMRC IAB Meeting, Oct. 15, 2003

Fixturing: Modeling & Analysis

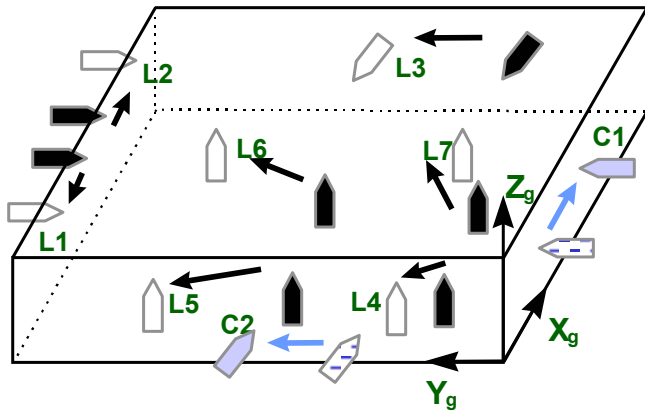## *(Sponsors: Ford, GM, NSF, Caterpillar)*

Objectives:
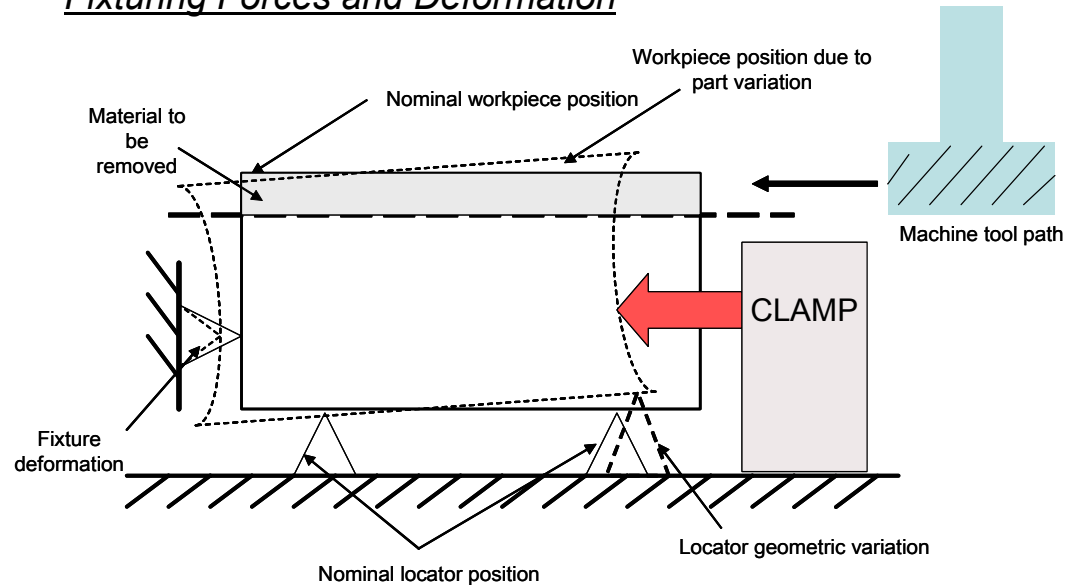
Develop and verify models for:

- **prediction of fixture-workpiece contact forces/deformations**
- **synthesis of fixture layout and clamping forces**
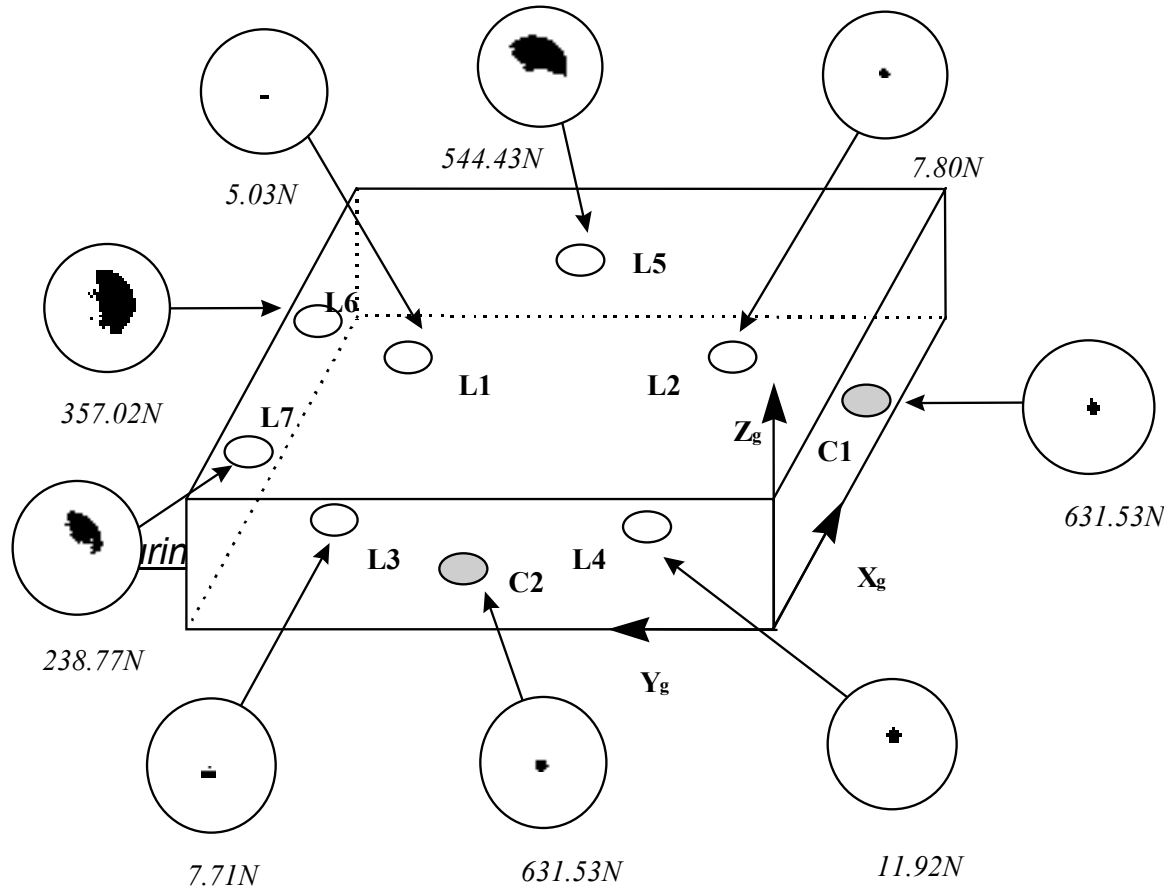- **prediction of part location errors**

Fixturing Forces and Deformation

Cutter

Undeformed workpiece
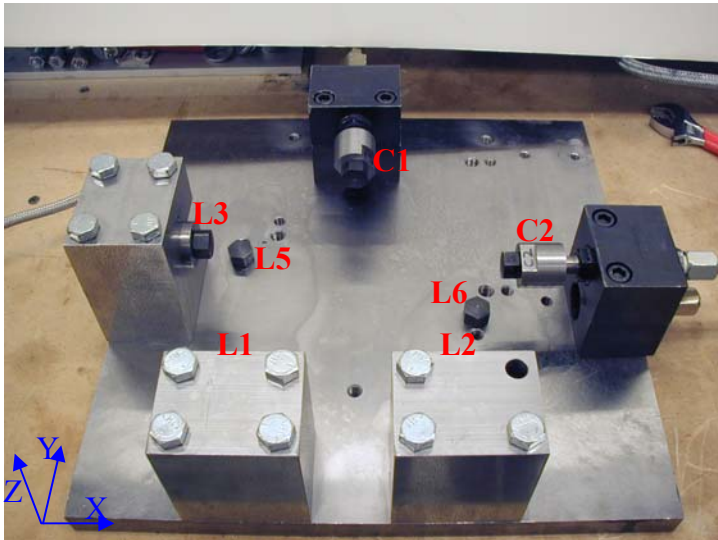
Deformed workpiece

Locators

Clamps

Fixture Layout/Clamping Force Synthesis
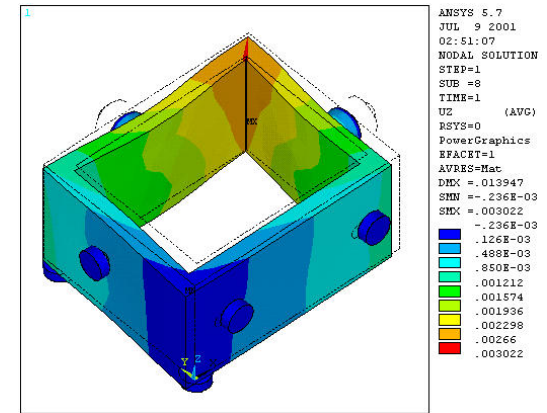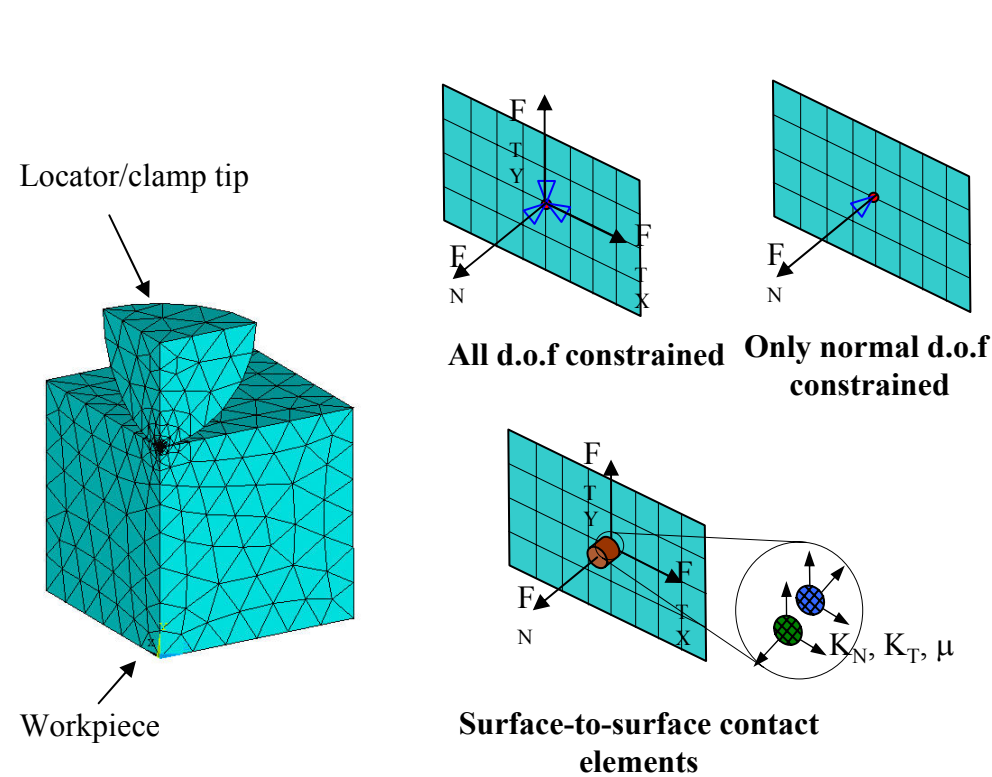

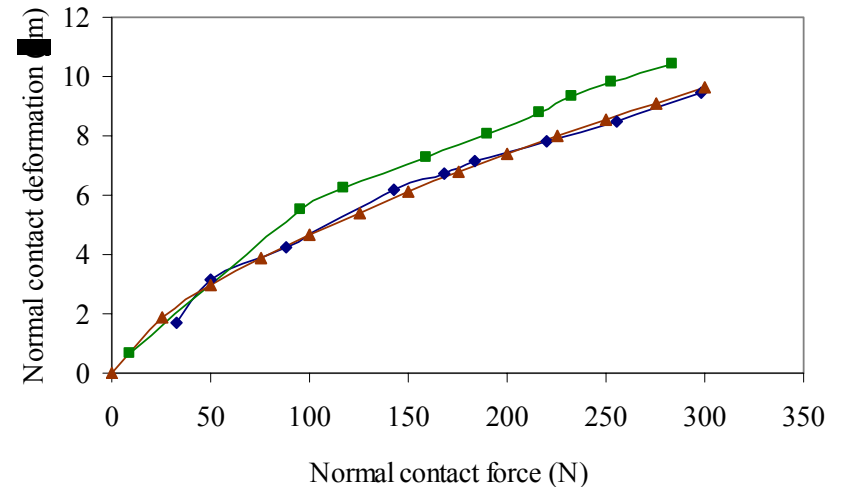*Part Location Error Sources*

Modeling & Analysis Results

Major Deliverables (Ford, GM, Caterpillar):

• *Matlab® codes for analysis of fixture-workpiece contact forces/deformations and optimization of clamping force*

• *Code implemented by sponsor (Ford AMTD, Livonia Plant)*

Modeling & Analysis Results

Locator/clamp tip

Workpiece

All d.o.f constrained

Only normal d.o.f constrained

K_N, K_T, μ

Surface-to-surface contact elements

Run 1   Run 2   FE Model

Normal contact deformation (μm)

Normal contact force (N)

Major Deliverables (Caterpillar):

• *"Best practice" rules for fixture-workpiece contact modeling using the FEM.*

• *ABAQUS® modules for spherical/planar contact fixture-workpiece contact modeling*

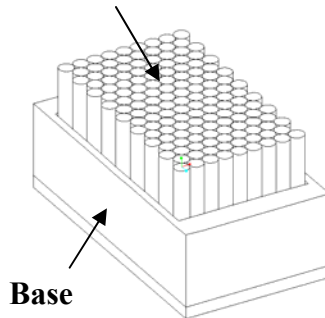# Flexible Fixturing

(Sponsors: Timken, Lamb Technicon, NIST/ATP)

Objectives:

• *Analysis of holding forces in electromagnetic chucks*

• *Design and analysis of pin-array flexible fixture for machining*

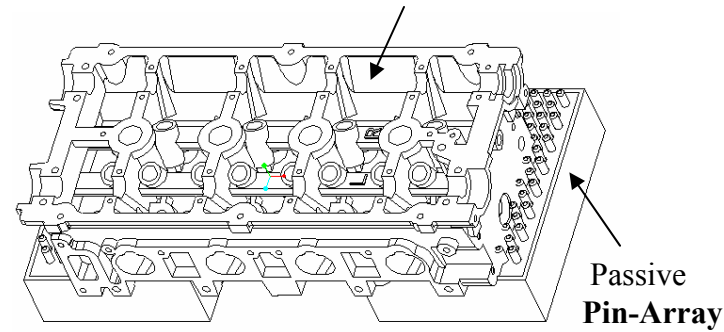• *Develop tolerance-based fixture stiffness optimization method*
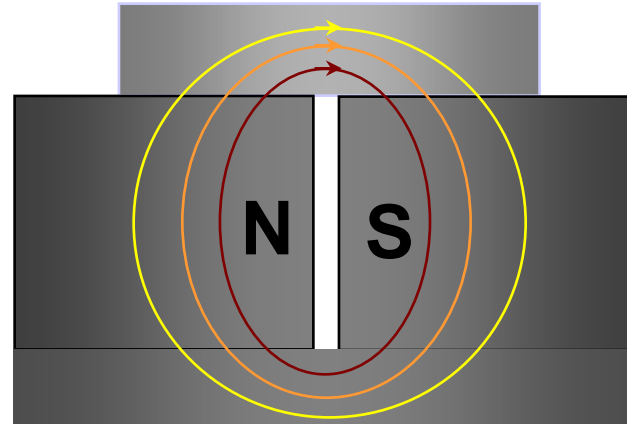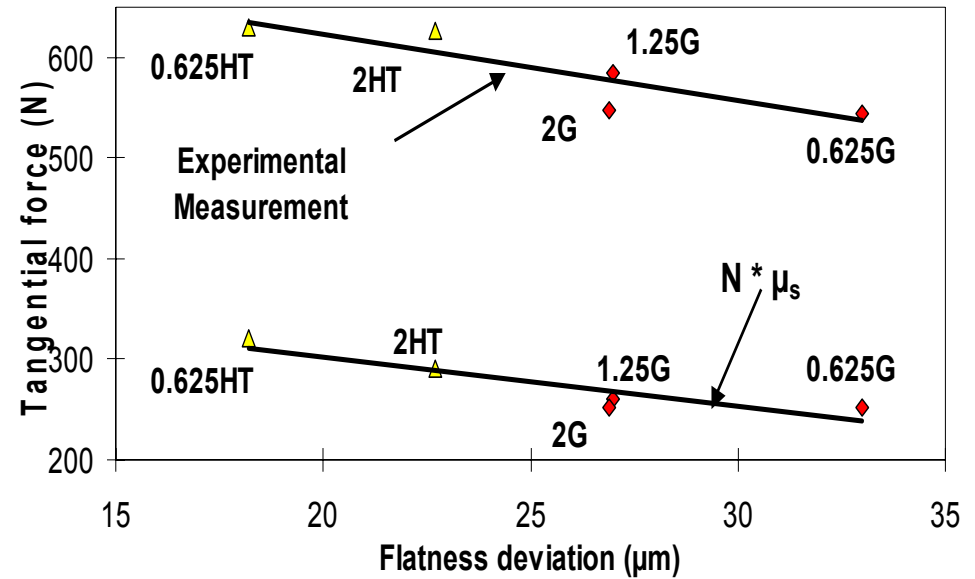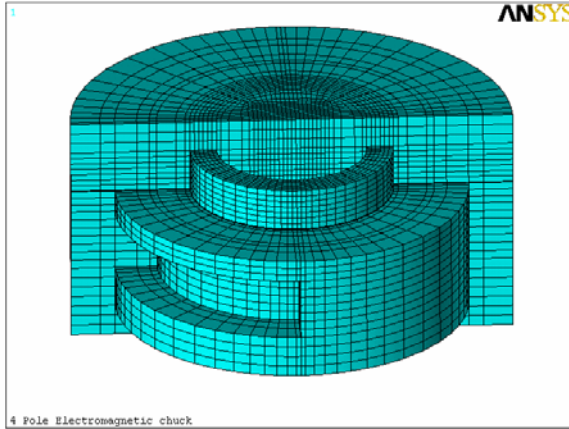

Magnetic Chuck

Air Actuated Pins
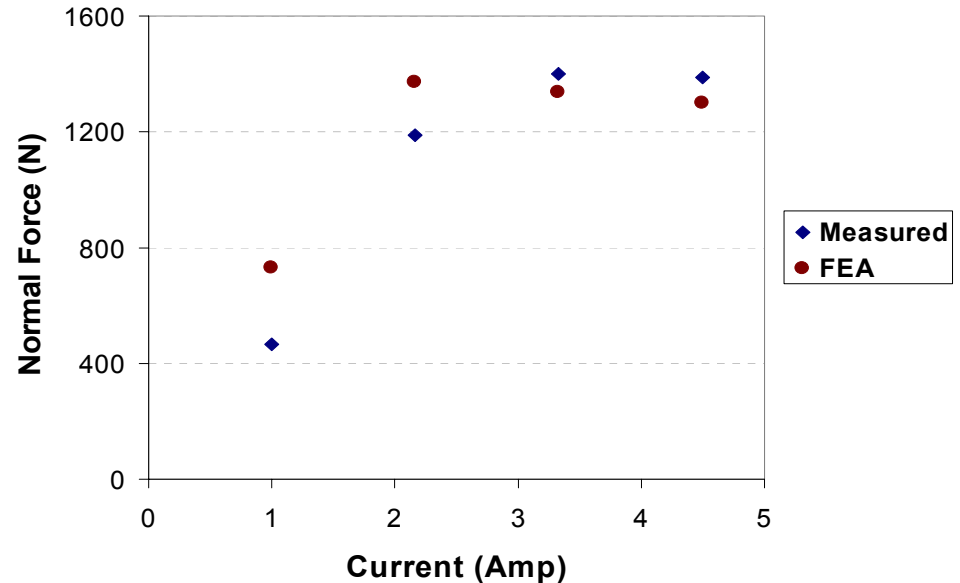
Base

Automotive Part

Passive **Pin-Array**

Pin-Array Flexible Fixtures

Flexible Fixturing Results
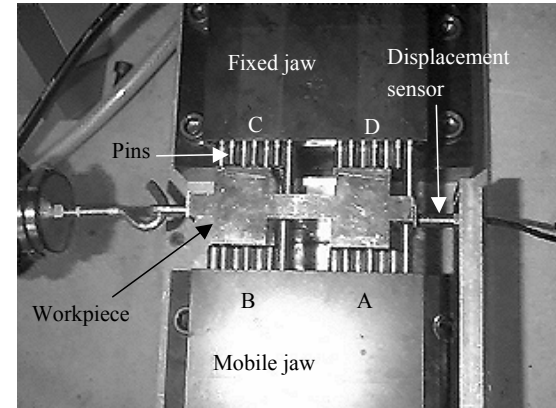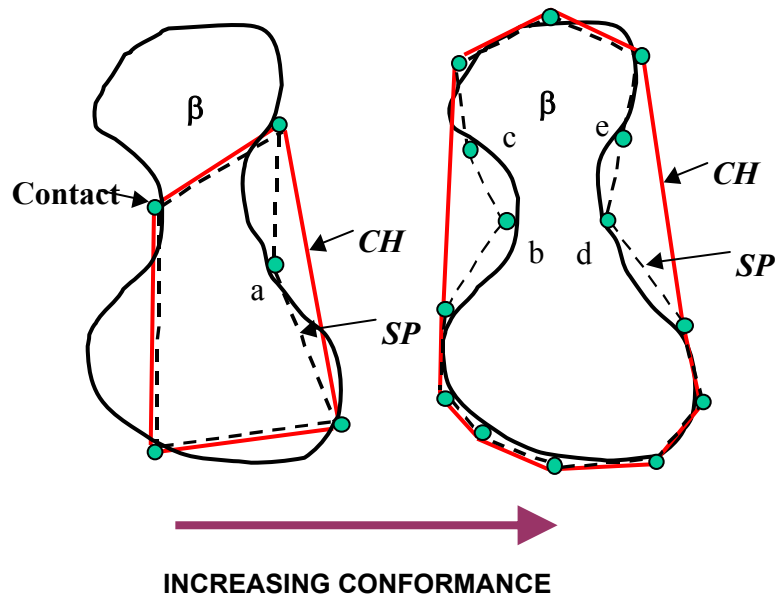

4 Pole Electromagnetic chuck

Major Deliverables (Timken):

• *Holding force measurements on e-mag chuck*

• *Matlab code for estimation of normal holding force in chuck*

Flexible Fixturing Results

INCREASING CONFORMANCE

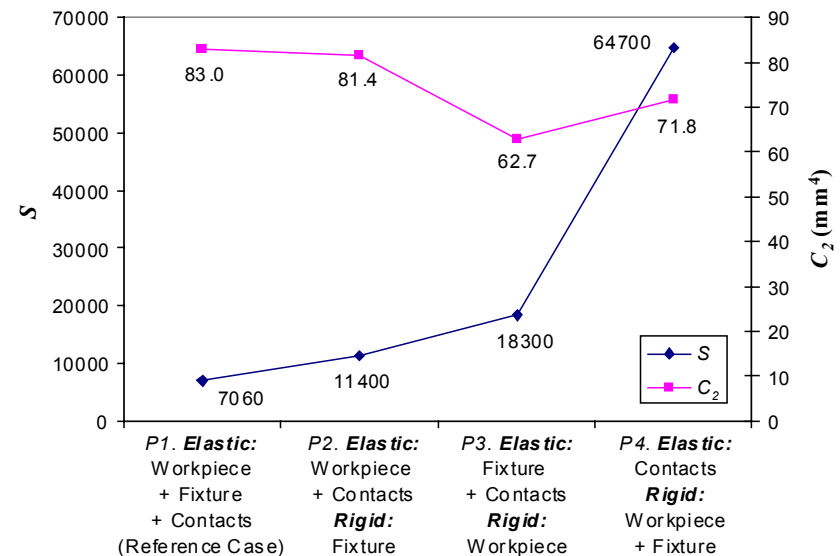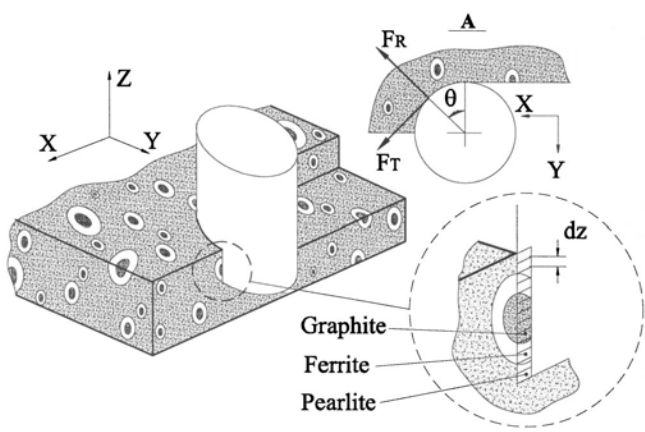**Active Pin-Array Vise
Holding a Complex Part**

Major Deliverables (Lamb):

• *Matlab code for optimizing pin geometry and stiffness*

• *Elements of pin-array fixture design*

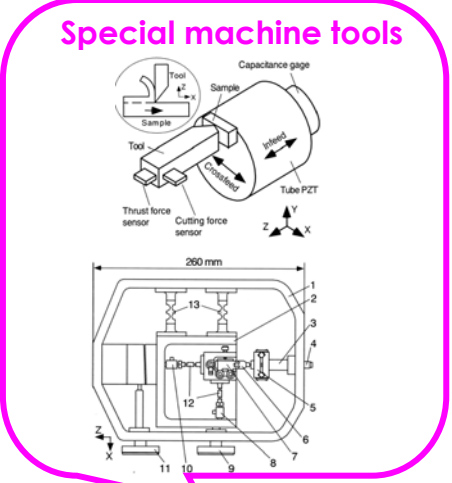• *U.S. and World-wide patents pending*

New Research Projects:

- *Micro/Nano-Cutting Process Science*
- *Interrupted Hard Turning*
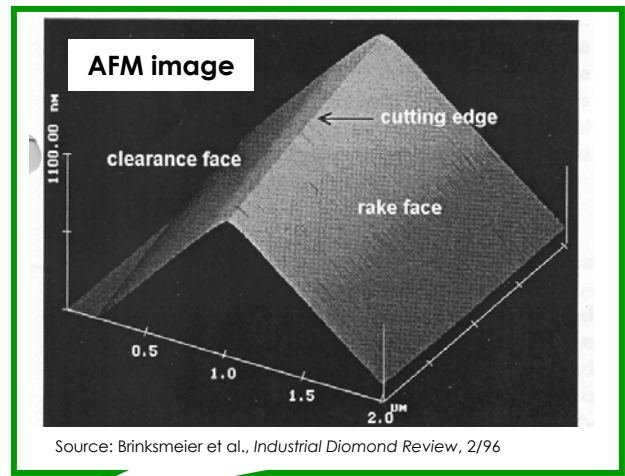**- *Analysis of White Layers in Hard Turning***

Special machine tools

AFM image

cutting edge

clearance face

rake face

Source: Brinksmeier et al., *Industrial Diamond Review*, 2/96

Effect of Microstructure

Source: Vogler et al, *J. Manuf. Sci. Engg. Trans. ASME* Vol. 125, May 2003

Graphite
Ferrite
Pearlite

Effect of edge geometry

UPC-R
A tool edge contour of 0.05 µm (50nm/0.000002") is achieved over a wide working angle of 90°.

An enlarged view of the tool nose

Corner Radius 5 µm

Special cutting tools

Macro Cutting
VS
Micro/Nano Cutting

TOOLS? **PROCESS?**

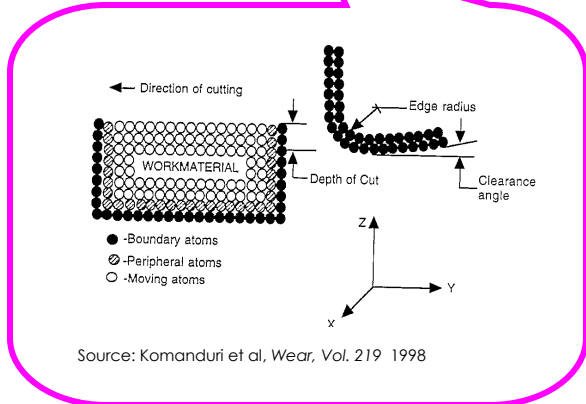$$F_c = \frac{H}{3\sqrt{3}} \frac{A_c}{\sin\phi} \cos\phi + \frac{H}{3} A_c + F_{c_{elastic}}$$

$$= \frac{HA_c}{3}\left(\frac{\cot\phi}{\sqrt{3}} + 1\right) + \mu_f \sigma_f A_f$$

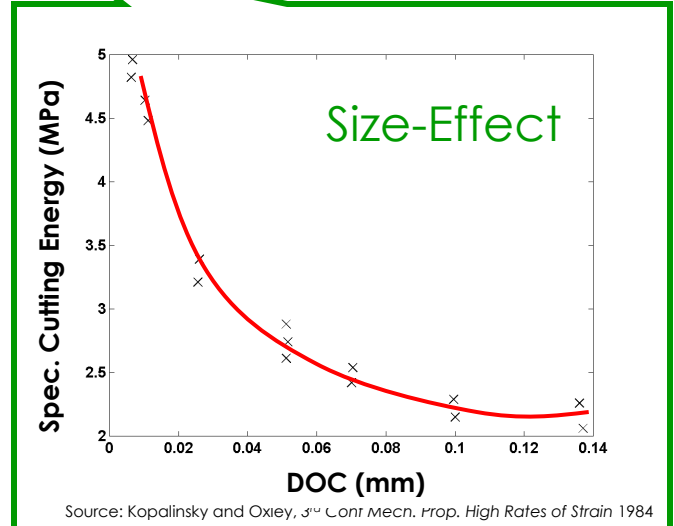$$= \frac{HA_c}{3}\left(\frac{\cot\phi}{\sqrt{3}} + 1\right) + \mu_f A_f \left(4.1H\sqrt{\frac{H}{E}}\right)$$

Unique Force modeling
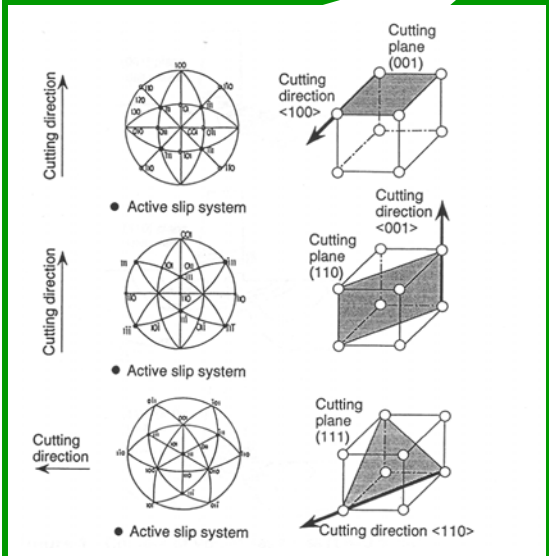
Effect of Crystal Planes

Source: Liang et al, *Prec. Engg.* Vol. 16, No. 2, April 1994

Cutting plane (001)
Cutting direction <100>
Active slip system

Cutting direction <001>
Cutting plane (110)
Active slip system

Cutting plane (111)
Active slip system
Cutting direction <110>

MD Simulations

Direction of cutting
Edge radius
WORKMATERIAL
Depth of Cut
Clearance angle
● -Boundary atoms
⊘ -Peripheral atoms
○ -Moving atoms

Source: Komanduri et al, *Wear, Vol. 219* 1998

Size-Effect

Spec. Cutting Energy (MPa)

DOC (mm)

Source: Kopalinsky and Oxley, *3rd Cont. Mech. Prop. High Rates of Strain* 1984
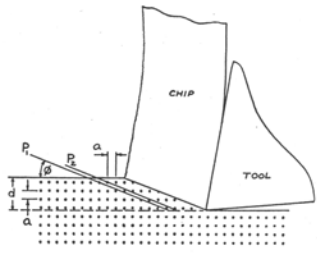
FIG. 4. Specimen with uniform array of weak spots.

Shaw: Inhomogeneity

Can help understand forces and impact on surface and sub-surface

Determines how much energy is needed to cut

Oxley: Strain-rate effect

Approach: Incorporate length scale into macro cutting models

Why study size-effect?

Strain gradient effect

Past

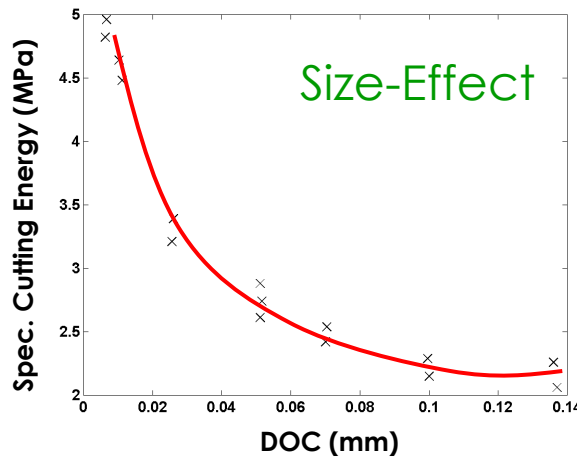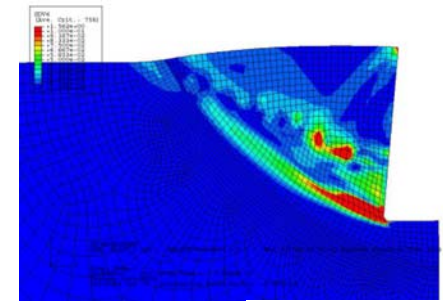Future

Size-Effect

Source: Kopalinsky and Oxley, 3rd Conf Mech. Prop. High Rates of Strain 1984
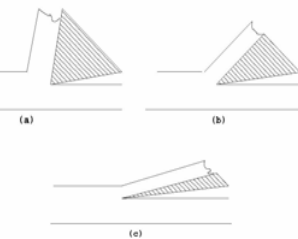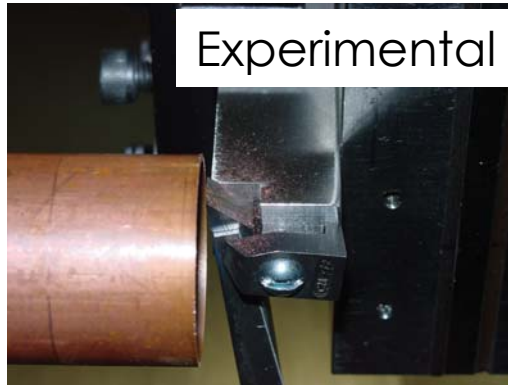
Edge radius Effect

Past

Future

Approach:
- $F = F_{inc} + F_{dec} + F_{const}$
- Perform orthogonal cuts and observe forces
- Relate force components to atomic bond energies, fracture strain energy, etc.

Experimental

FEA modeling with Strain gradient

Interrupted Hard Turning

Goal:

- To analyze hard turning process for parts with interruptions
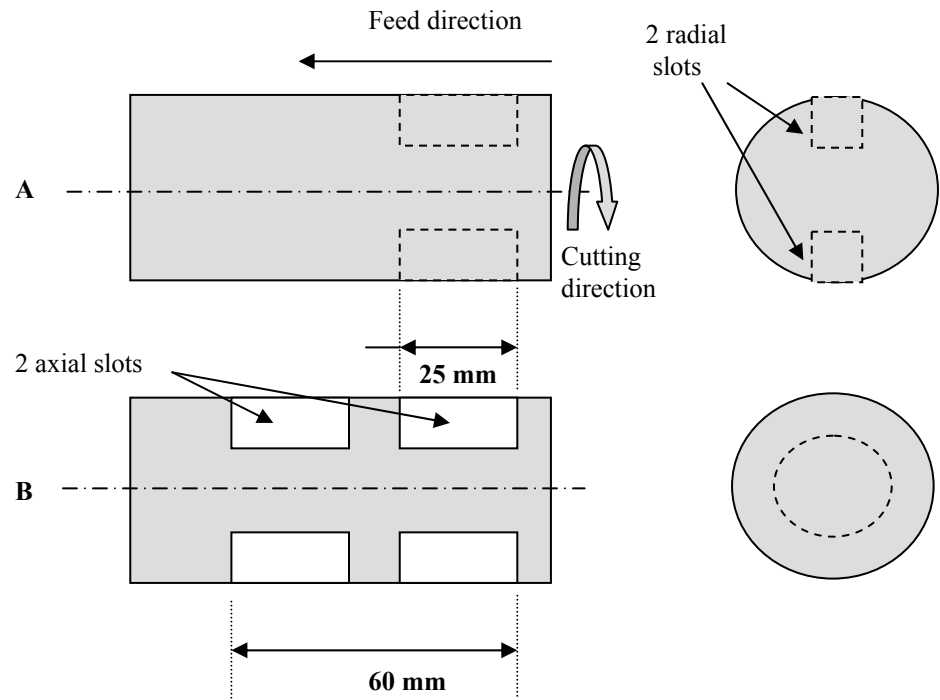
Motivation:

- Lack of scientific data on interrupted hard turning process
- Interruptions may be *deterministic* (part geom. variations) or *stochastic* (material inhomogeneities)

Approach:

- Experimental: forces, tool wear, surface texture/integrity
- Evaluate high-purity (binderless) cBN tools

Expected Results:

- Process data for interrupted hard turning
- Bounds on forces, tool wear, surface finish due to interruptions

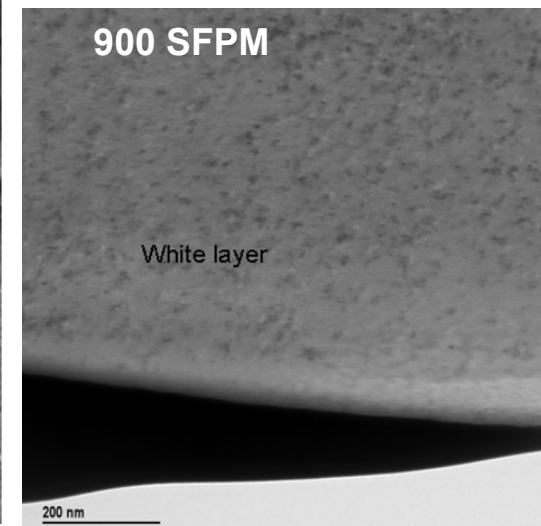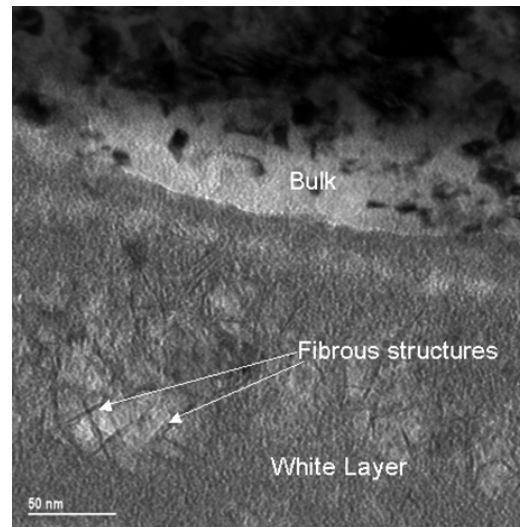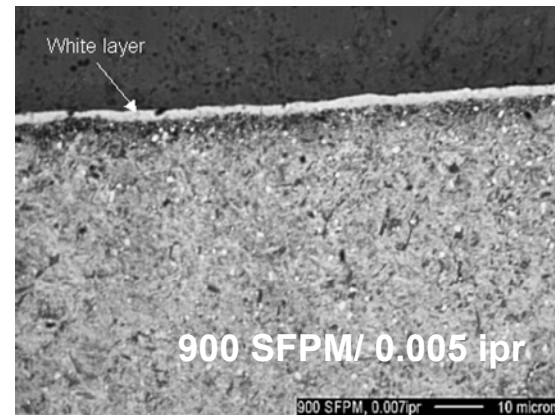# *Analysis of White Layers in Hard Machining*

Goals:

- To experimentally identify white layer formation mechanisms in hard machining

- To explain white layer formation in machining quantitatively in terms of the underlying mechanisms

Motivation:

- Lack of complete understanding of white layer formation mechanisms (mechanical vs. thermal effects)

Approach:

- Using recently developed SEM techniques

- Numerical modeling

Bright-Field TEM Images