An Investigation Into The Effects Of Hard Turning Surface Integrity On Component Service Life

Steve Smith
Advisor: Shreyes N. Melkote

The George W. Woodruff School of Mechanical Engineering
Georgia Institute of Technology

With In-Kind & Technical Support From:
Kennametal Inc., Valenite Inc., and The Timken Company

Overview

This research addresses the following fundamental question:

- Considering surface integrity, how does hard turning affect workpiece service life/component function? How does it compare to the 'traditional' finishing process of grinding?

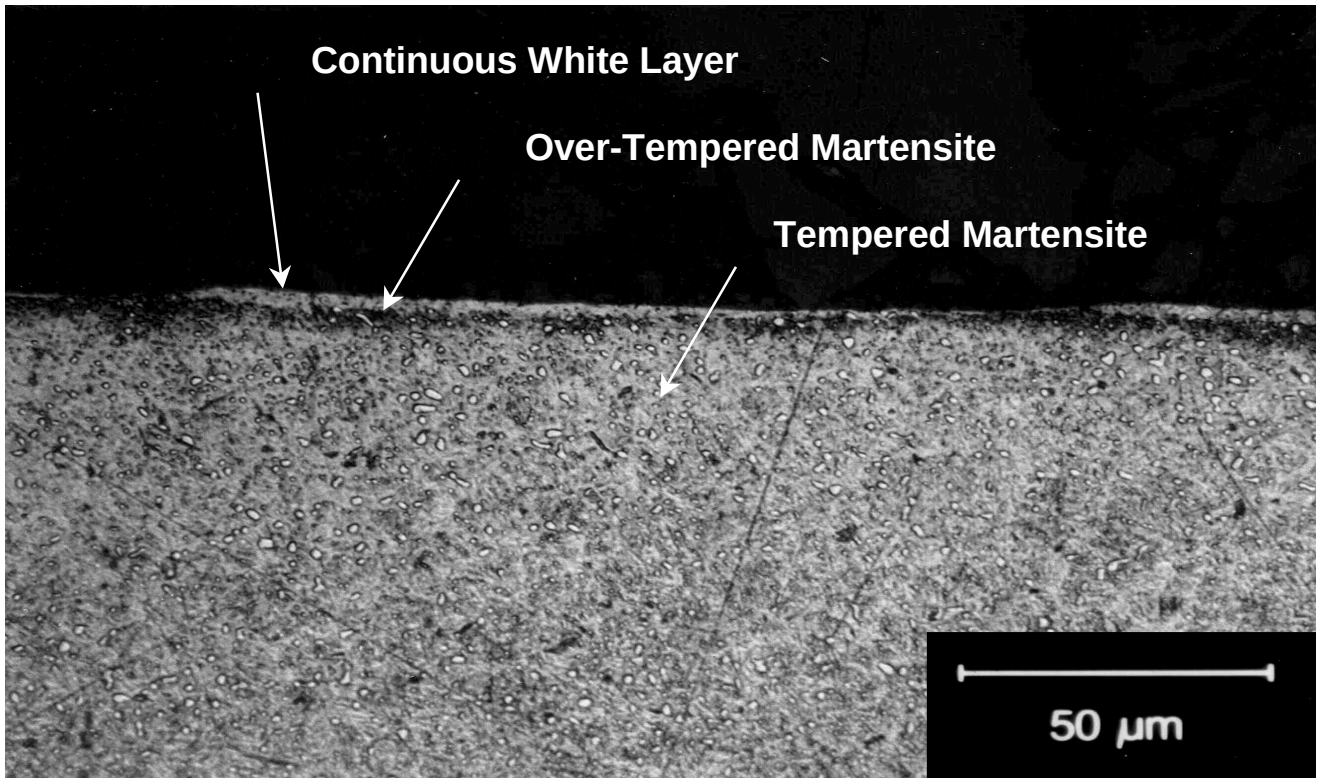
Motivation:

- Hard Turning offers attractive alternative to grinding
- Must quantify the effects of the process on service life

Specific Objectives

- **Identify how the surface integrity resulting from hard turning AISI 52100 affects service life**
  - Identify function of ‘white’ and ’dark’ layers
  - Consider fatigue life and wear performance
- **Compare service lives for surface conditions:**
  - Hard turned surface without white layer
  - Hard turned surface with 1-3 µm white layer
  - Ground Surface (no damage)
  - Hard turned/ground with ‘superfinish’

Example of hard turned microstructure



Longitudinal View of Continuous White Layer. 25.4 µm Chamfer. 0.15 mm/rev Feed. 57 HRC Workpiece

Characterization of ”Surface Integrity”

- **Surface texture mapping (Zygo)**
- **Hardness testing**
  - Nano-hardness testing at ORNL
- **Microstructural analysis**
  - Nikon to identify WL and plastic deformation
  - TEM to analyze micro-structure and micro-chemistry
- **Residual stress distribution**
  - X-ray diffraction

Service Life Testing

Service conditions faced by high strength materials:

- **High cycle fatigue testing**
  - axial loading with R=0.1
  - test 7-12 specimens for each surface condition at a single stress level. Compare distributions.
- **Surface tribology tests**
  - wear and friction testing using Pin-on-Disk tester

Experimental Design - Fatigue

Axial Fatigue Test: **R=+0.1**

Material: **AISI 52100**

Hardness: **62 HRC**

Number of specimens per surface condition: **7-12**

Total Number of specimens: **45-50**

Stress Level: **1300 MPa**

[based on published data this should give failure around $1x10^4$ cycles]

Pairwise comparisons:

- Ground versus Hard Turned (finish machined surface finish)
- Hard Turned with and without White Layer
- Ground versus Hard Turned with superfinish

Experimental Design - Wear

Test: **Pin-on-Disk Wear Tests**
Material: **AISI 52100**
Hardness: **62 HRC**
Normal Load: **55 N (12 lbs)**
Speed: **0.16 m/s (6.0 in/s)**

Number of specimens per surface condition: **2-3 Replications**

Surface Conditions:

- Ground
- Hard Turned – No white layer
- Hard Turned – 1-3 µm white layer

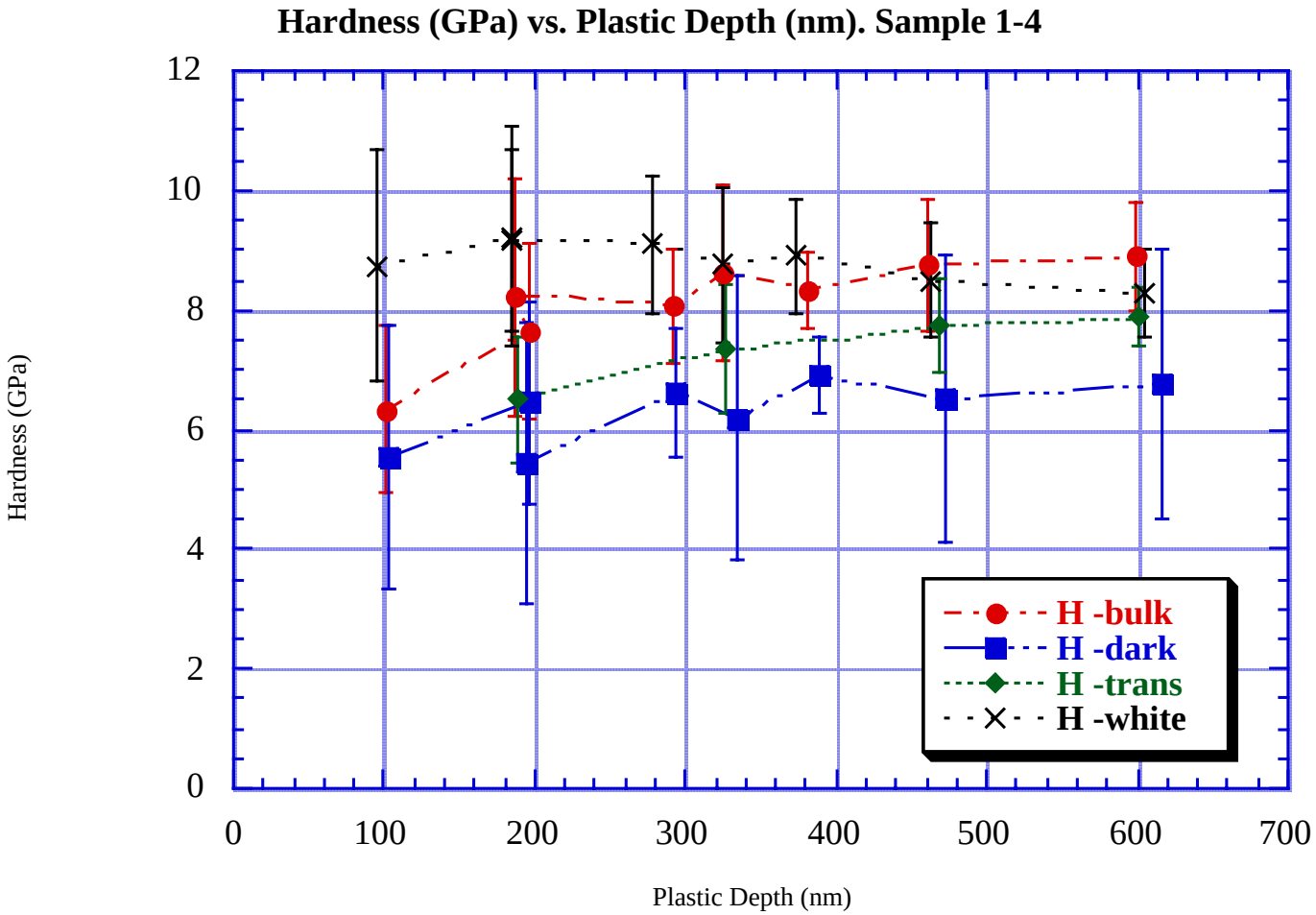
(surface finishes may require pairwise comparisons)

Results - Nano-hardness

Nano-hardness indentations conducted at ORNL

- Data indicates:
  - White Layer is harder than Bulk
  - Dark Layer is softer than Bulk
- Differences are not as large as in other publications
  - Possibly due to small specimen size
  - Etching introduced noise

Nano-Hardness Results

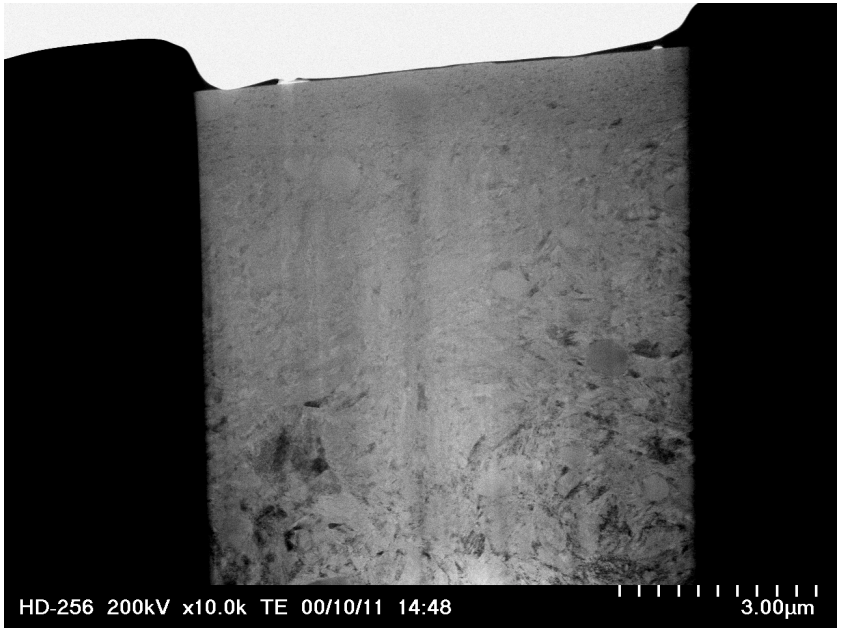


Results - TEM analysis

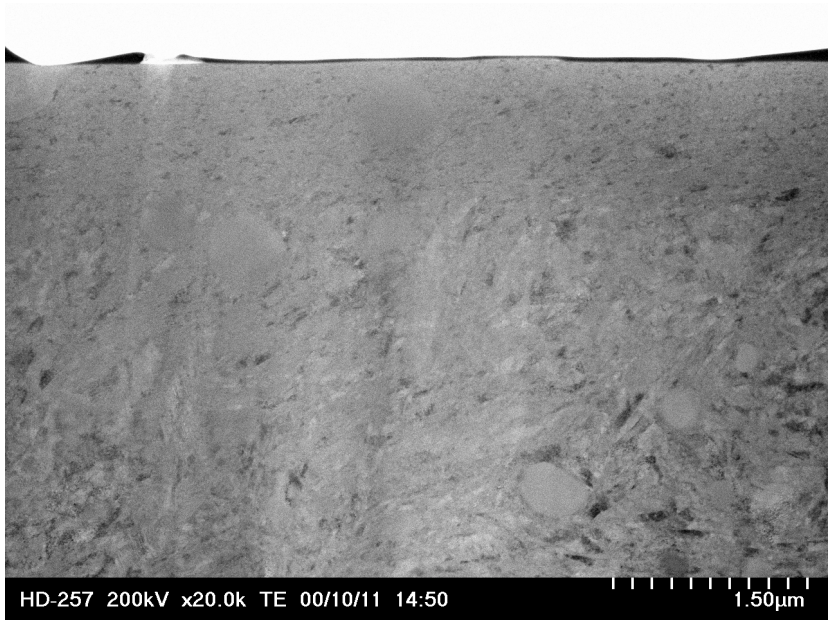
STEM tests conducted at ORNL on Hitachi HD-2000

- TEM samples approx. 6µm x 10 µm
  - Prepared with Hitachi Focused Ion Beam Milling Instrument
- Images clearly show altered microstructure
  - Refined grain size in WL area
- No difference in trace elements between WL and Bulk
- Material showed ‘pockets’ of high Cr content
  - These areas have approx. 4.3% Carbon

Sample STEM Images

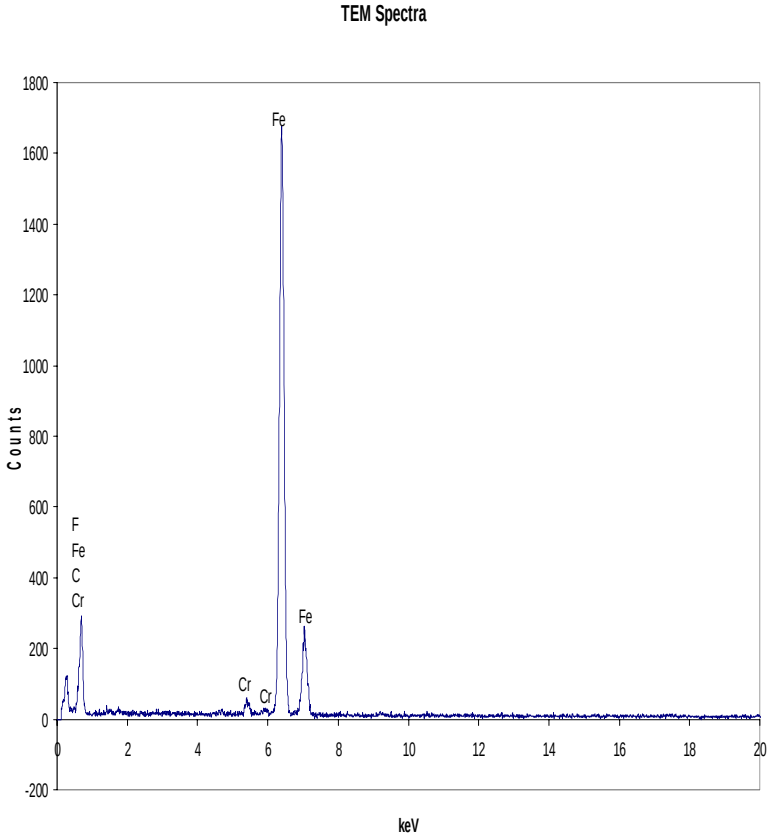


10,000x magnification

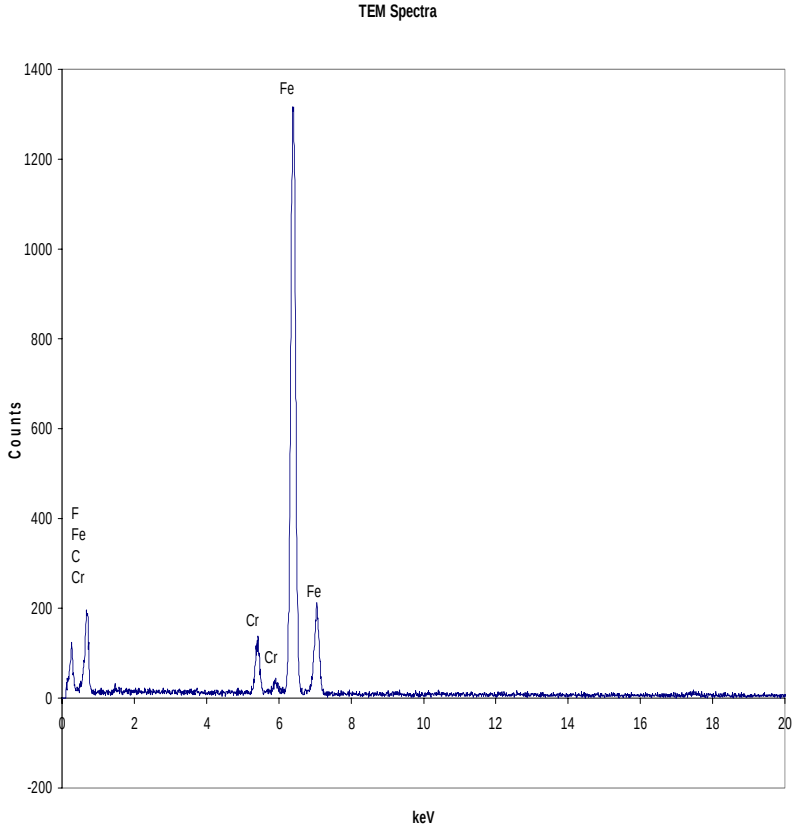


20,000x magnification

Sample Element Traces



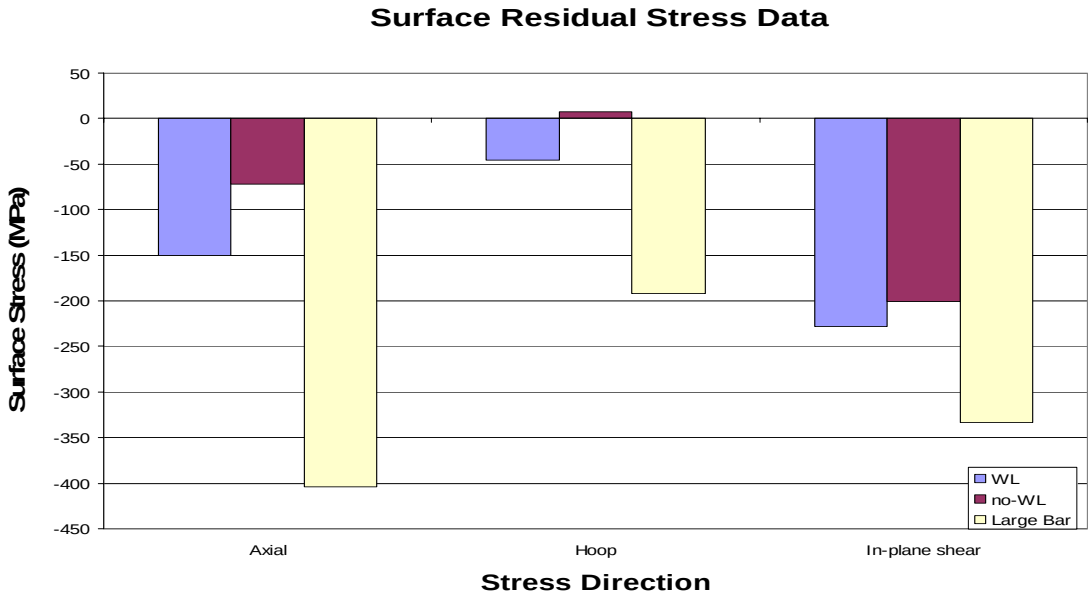
Bulk Material



Cr Concentration

Results - Residual stress

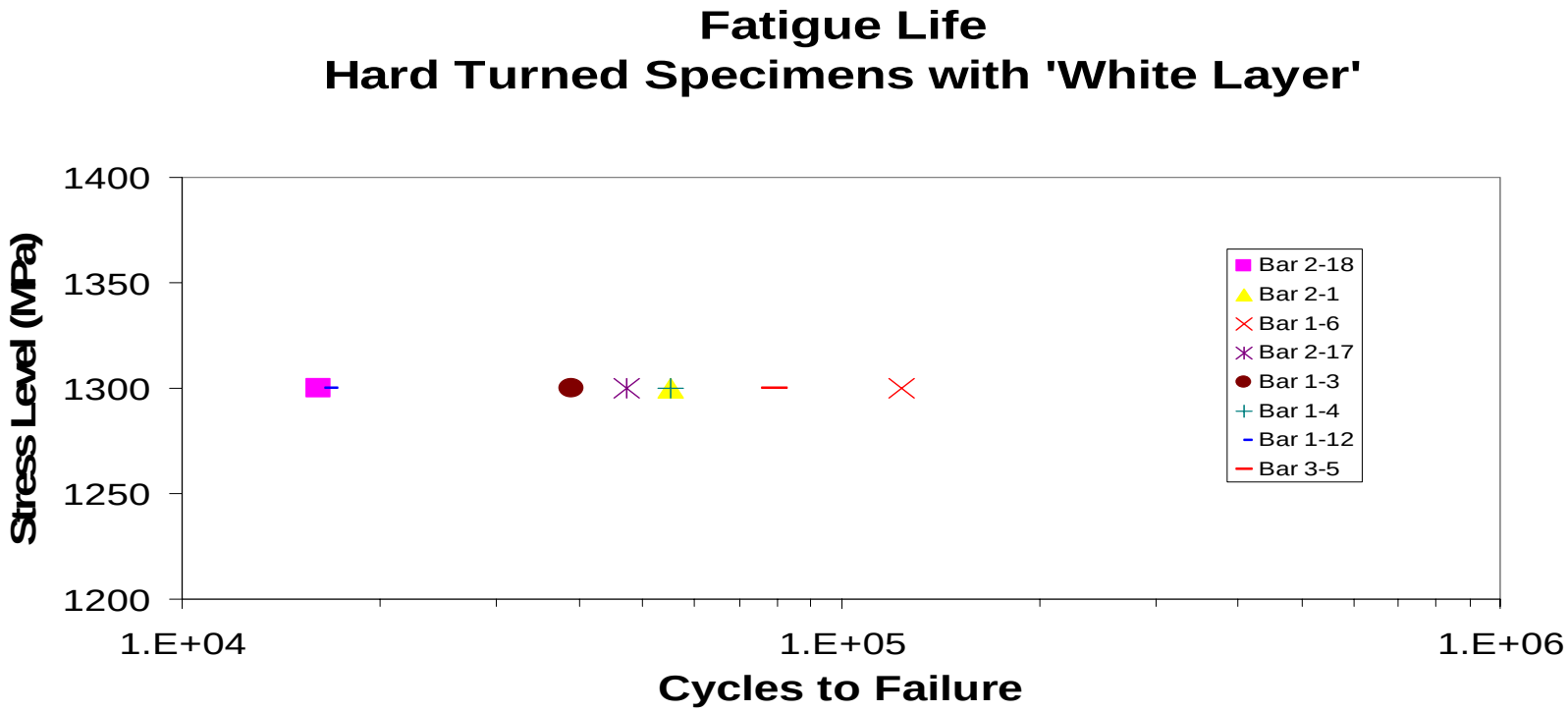
- Surface residual stresses similar for ‘WL’ and ‘no-WL’ conditions
- Surface residual stresses less compressive for fatigue bars than for 1.25” diameter bars
  - Possible size effects (fatigue bar is 0.300” dia)
  - Possible fixturing effects (fatigue bars located on tail-stock center)



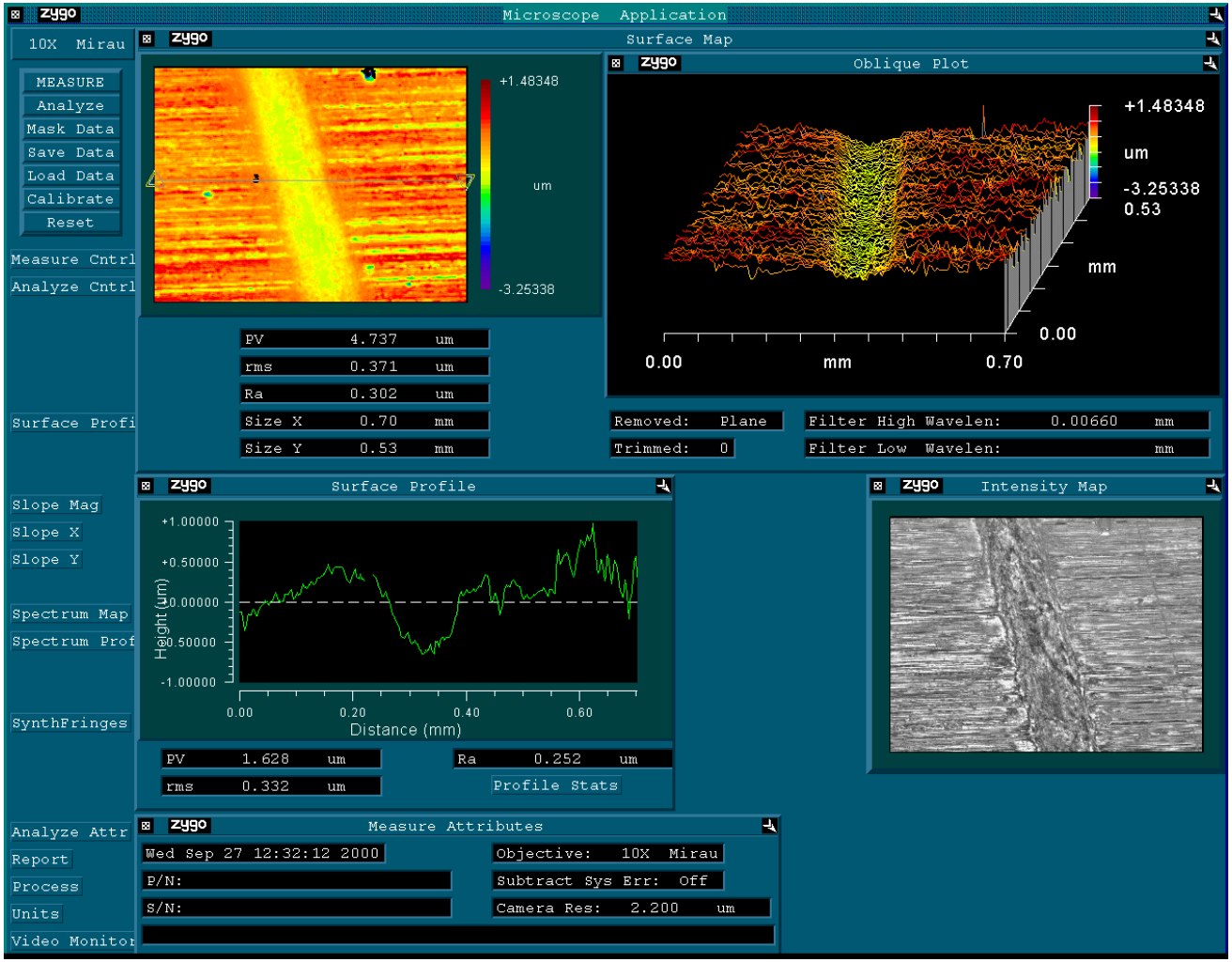
Results - Fatigue Testing

Most “White Layer” bars have been tested

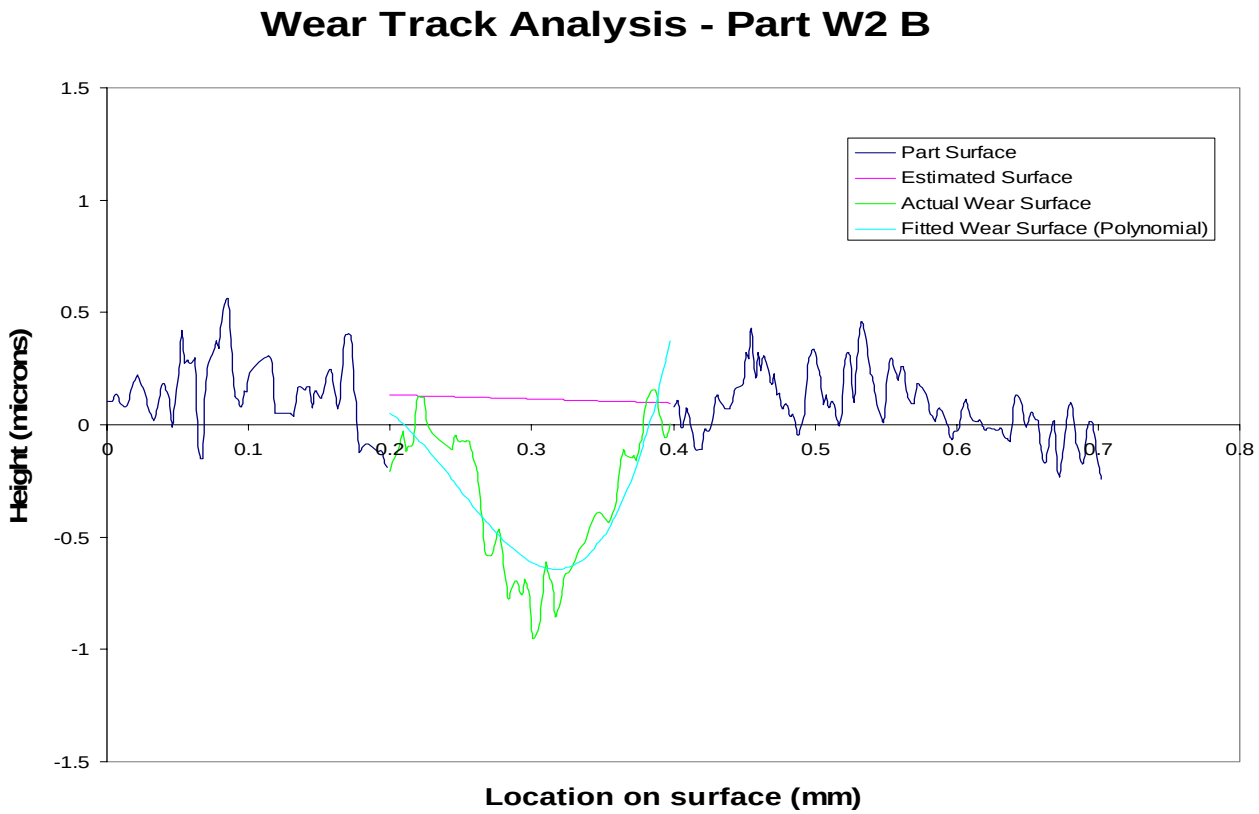
- Large scatter in data



Wear Testing - Analysis Sample



Wear Testing - Analysis Sample



Summary

Goal:

- Identify effects of hard turning on workpiece service life as compared to grinding.

Approach:

- Generate specimens using various processes
- Quantify the surface integrity of each specimen
  - Surface typography
  - Residual Stress
  - Subsurface microstructure/nano-hardness
- Functionally test each surface condition
  - Fatigue testing
  - Wear testing

Future Work

- Complete test matrices
  - Fatigue
  - Wear
  - Residual Stress
- Attempt to identify mechanism dominating residual stresses
  - Size effects
  - Fixturing

Questions??