MATERIALS & PROCESS DESIGN FOR HIGH TEMPERATURE CARBURIZING

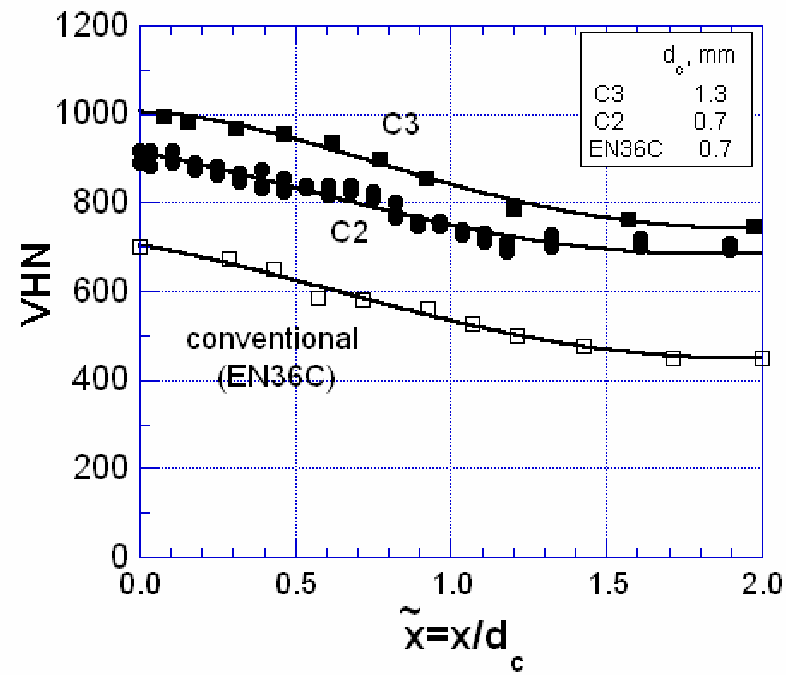
Integrating Processing & Performance

Goal: Integrate model-based robust control of the HTC with concurrent design of novel HTC steels for higher performance and processability

Challenge: Need mechanistic model to achieve robust control and performance Data to validate optimal processing

Benefits: 10X reduction in process cycle time, reduces scrap from quench distortion, enhanced performance through optimized steels, broader applications through deeper cases.

FY05 Activities: Robust application of new process model, demonstrate enhanced performance.



Participants:
WPI (CHTE)
NU (SRG)
Midwest Thermal-Vac
GM
QuesTek Innovations

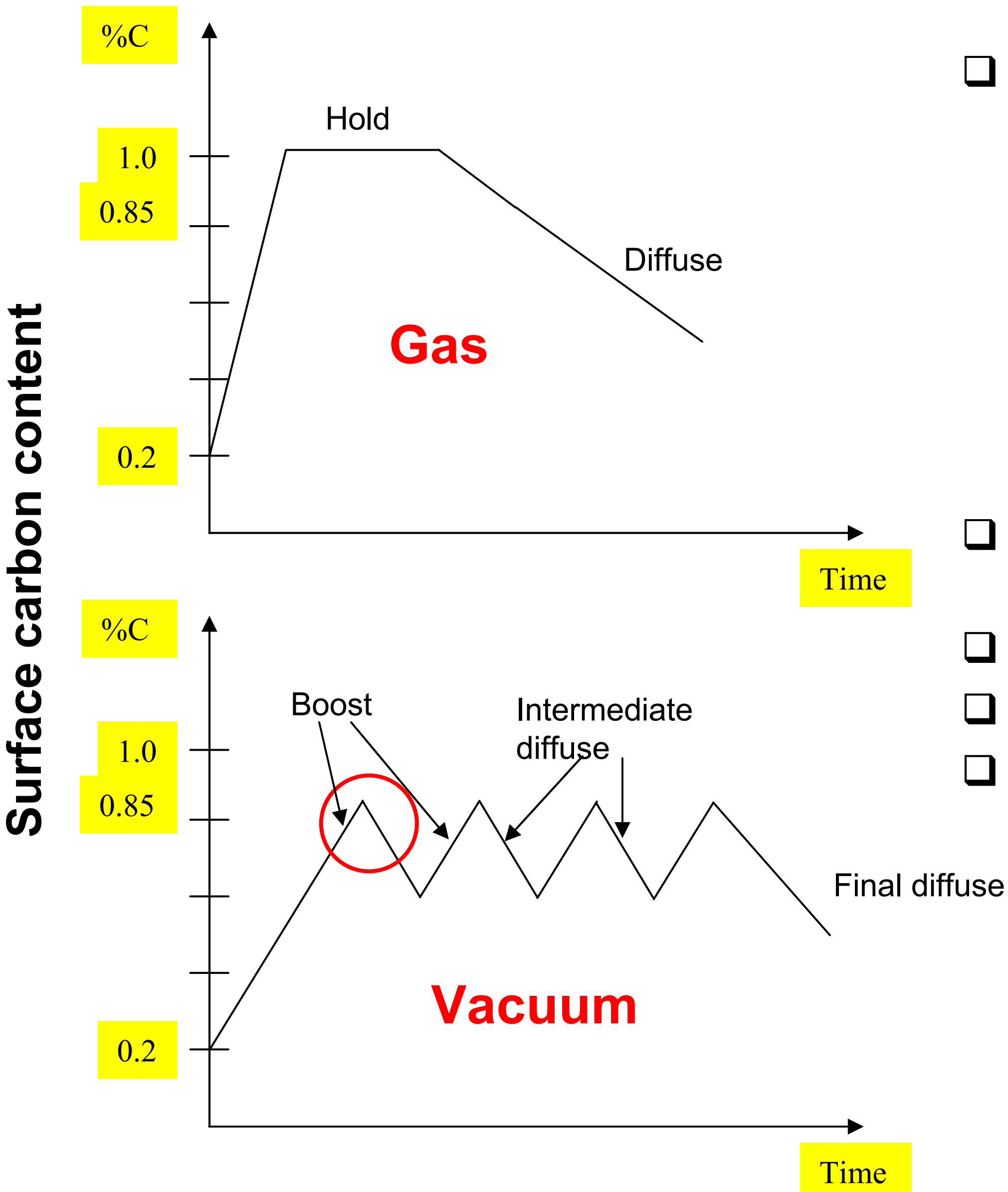
MATERIALS & PROCESS DESIGN FOR HIGH TEMPERATURE CARBURIZING
Integrating Processing & Performance

Barrier-Pathway Approach

Barriers	*Pathways*	*Critical Metrics*
• Lack of industry process control	• Mechanistic process model for robust control	• Acceptable part-to-part variability (H, %C)
• Lack of optimized steels	• Concurrent materials & process design (including final surface treatment)	• Enhanced case hardness, residual stress, grain coarsening resistance, hardenability (reduced distortion)
• Limited performance data	• Industry test program	• Fatigue Strength (single-tooth, RCF)
• Limited applications	• Deeper cases	• New markets (camshafts, tool & die)

Benefits (est.)
CycleTime Reduction – 10X
Process Energy Savings – 20 trillion BTU/Yr
Reduced Scrap (Eliminate Quench Distortion)
Higher Performance Energy Efficient Powertrain
AIM Technology Acceleration

Gas Carburizing vs. Vacuum Carburizing



- Limited by soot formation

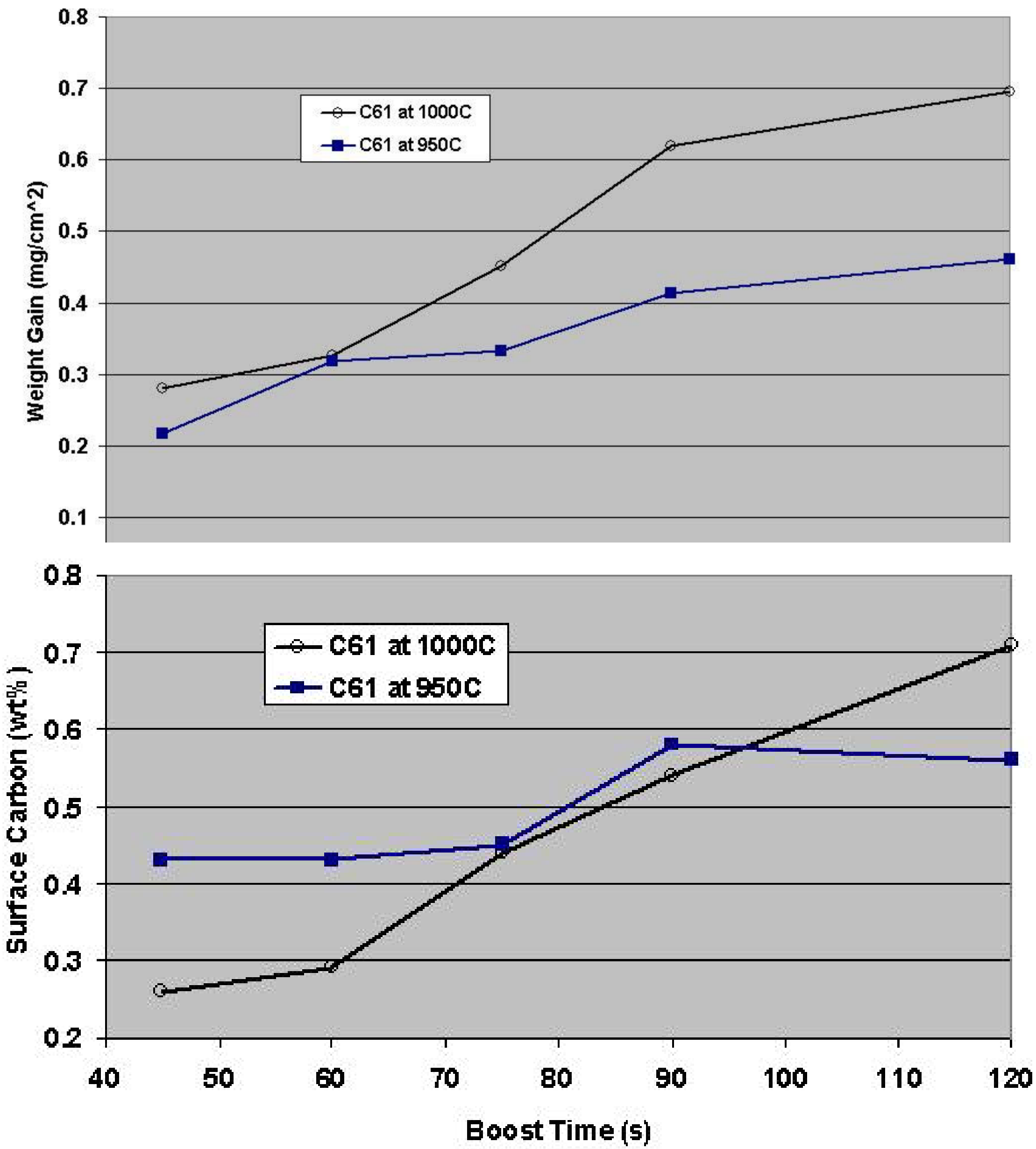
- Limited by saturation of Austenite or formation of continuous films
- Faster (higher carbon potential/temp)
- More homogeneous
- Very predictable and reproducible

Features of Vacuum Carburizing and Capabilities of Software in Use

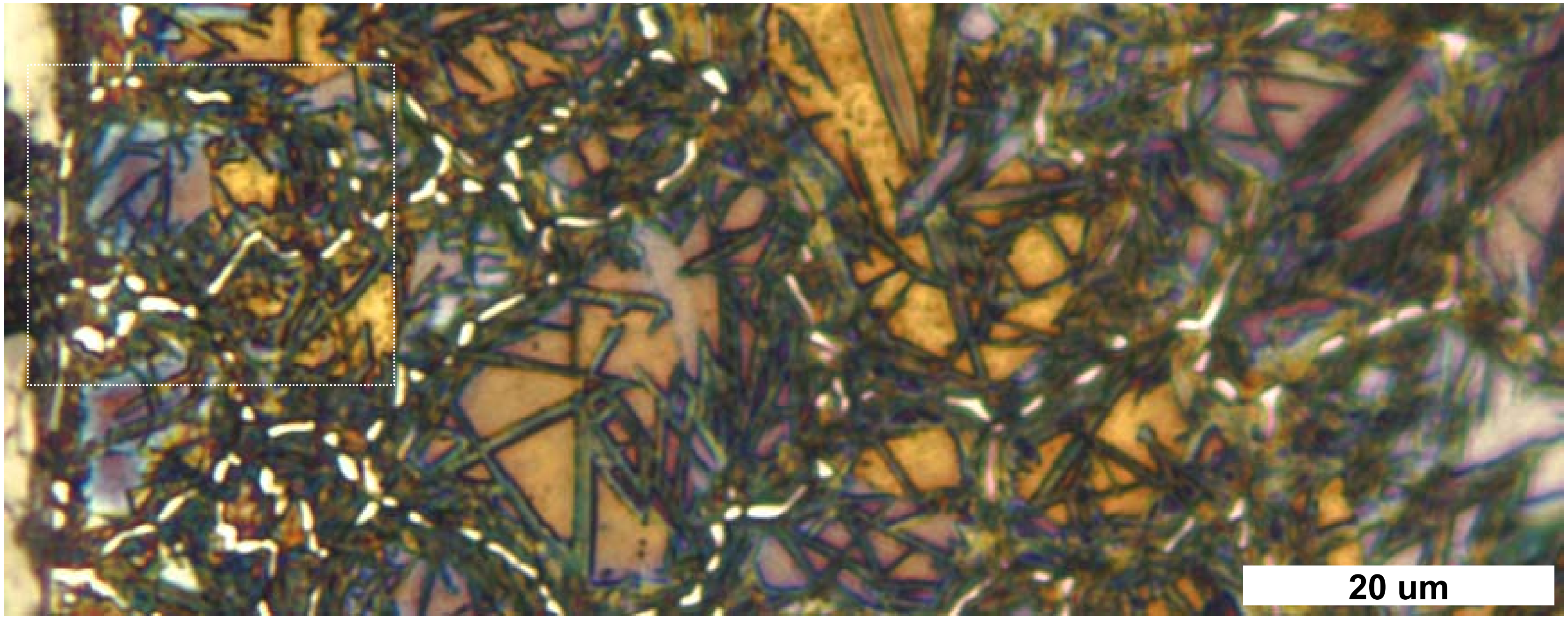
1) Diffusivity, D(C,T), varies with C content and time
2) Flux, J(t), varies with time
3) Carbide formation and dissolution
4) Multiple phase diffusion process (only after continuous film formation)

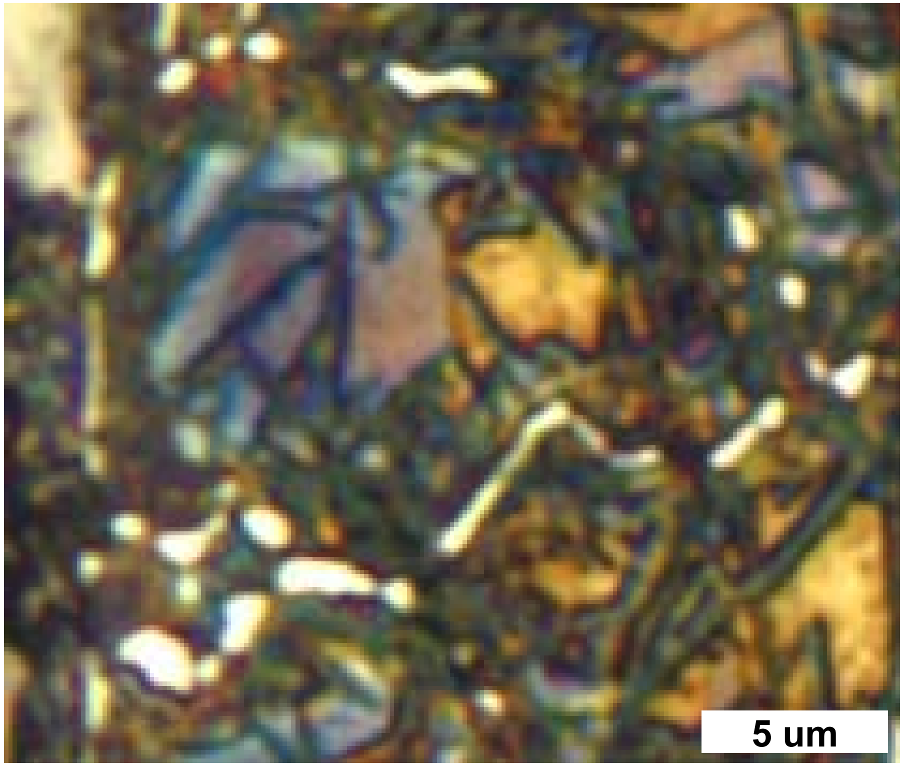
- Simple 1-D:
  - D(T)
  - J=constant
- DICTRA 1-D
  - D(C,T)
  - J(t)
  - Carbide formation and dissolution
  - Multiple phase diffusion
- DEFORM 2D/3D
  - D(C,T)
  - J (t)

Weight Gain and Surface Carbon Measurement for C61



- Large enough surface area required for accurate weight gain measurement (for average or instant flux calculation)
- Too long boost → carbide formation
- Too long boost → retained austenite and plate martensite

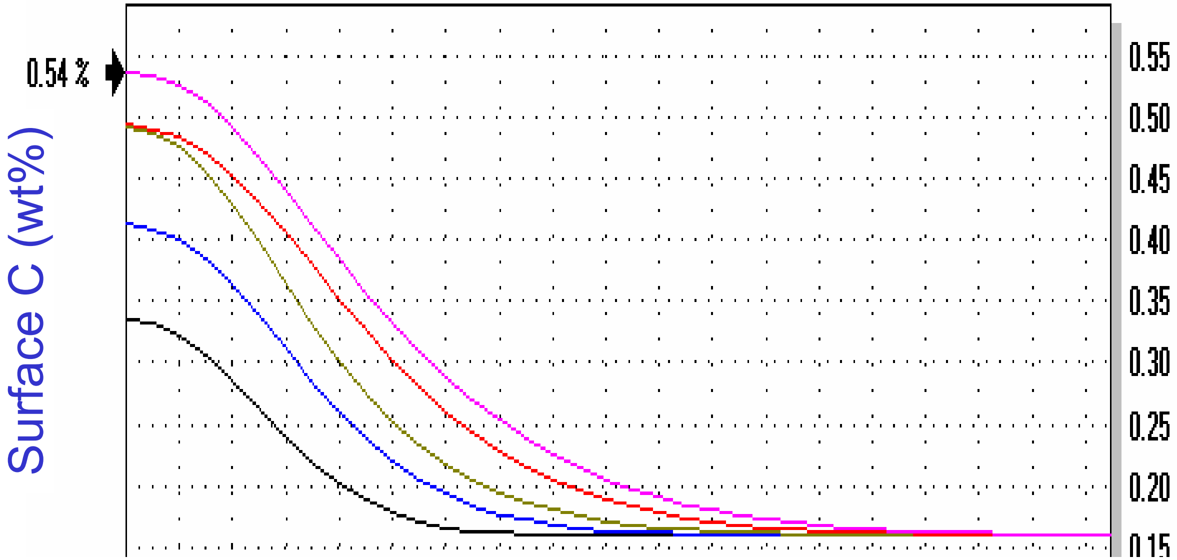




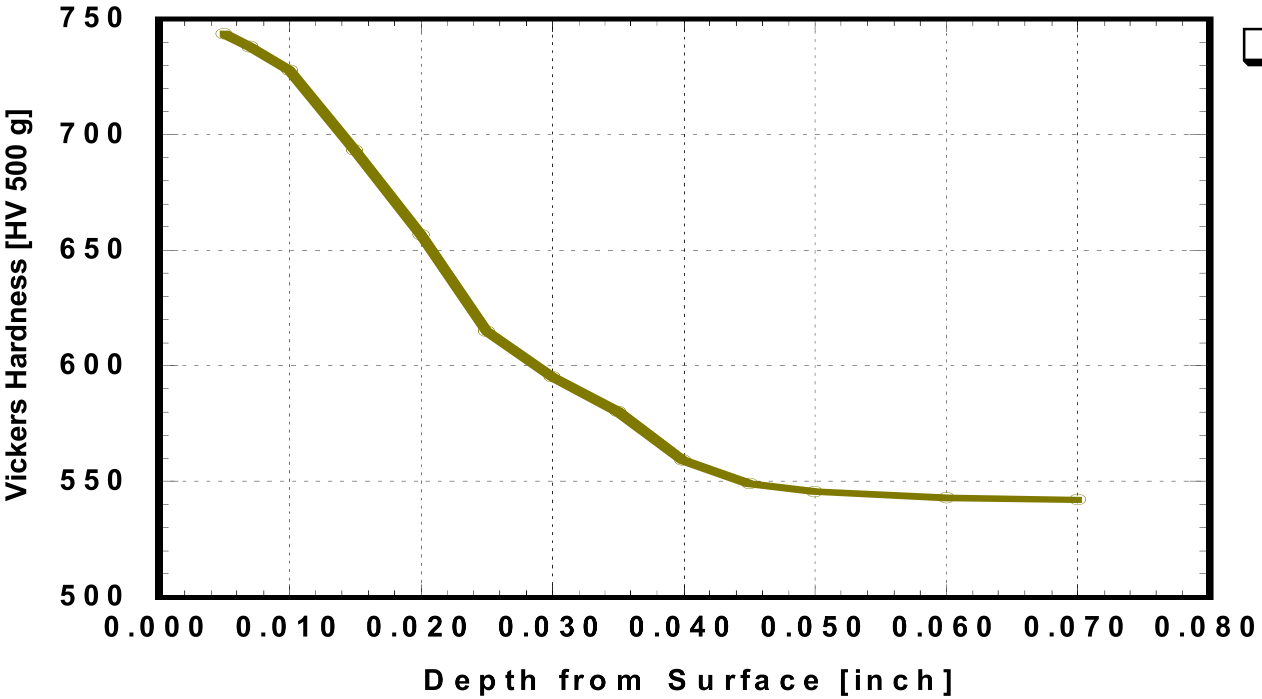
Phases and Morphology after Long Boost for C69

- ❑ Carbides on grain boundaries and left surface
- ❑ Retained austenite in case
- ❑ Plate shape martensite in case

Simulated Carbon and Measured Hardness Profile for C61

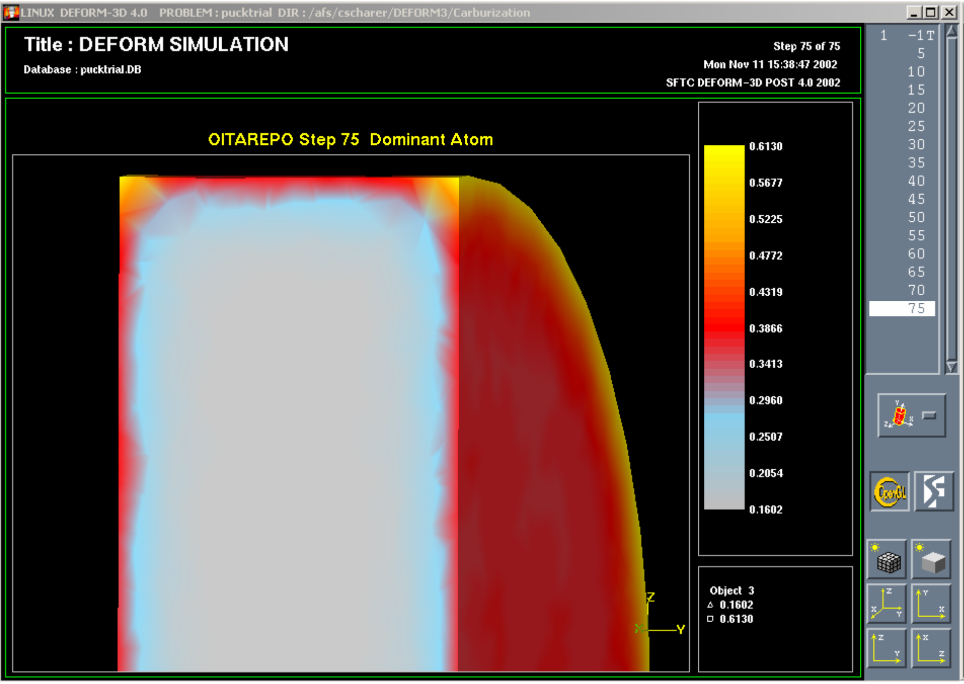


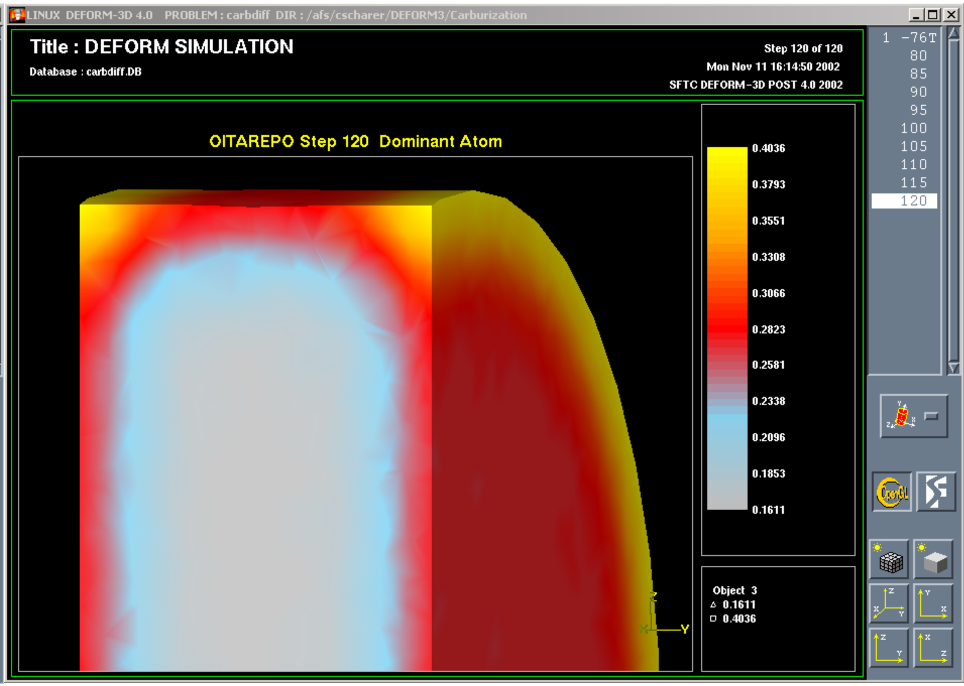
- Simple 1D simulation



- Real profile

DEFORM 3D Simulation for C61 Carburized at 950C



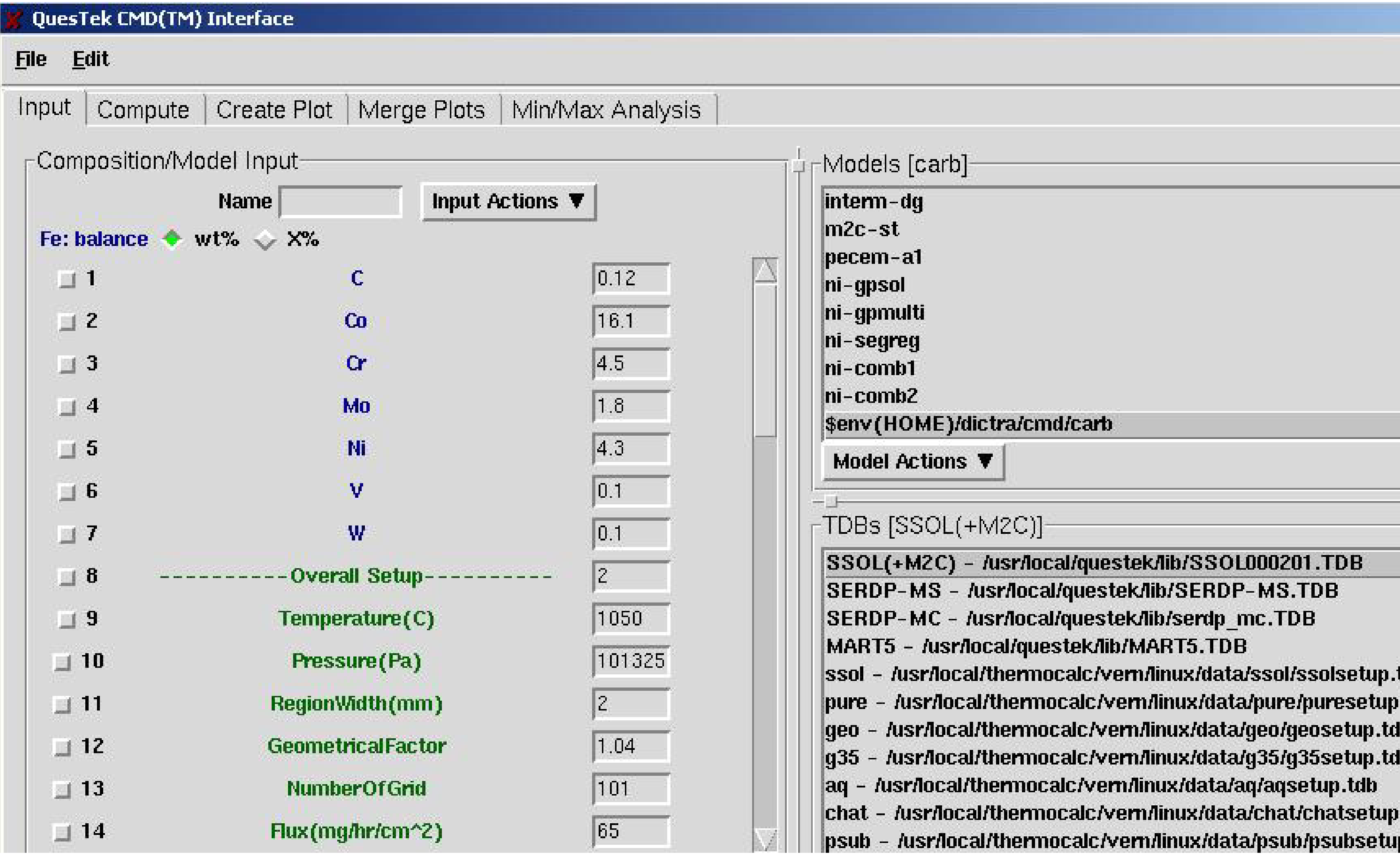


Boost only
Depth: ~ 110um
Surface Hardness: ~HRC 65

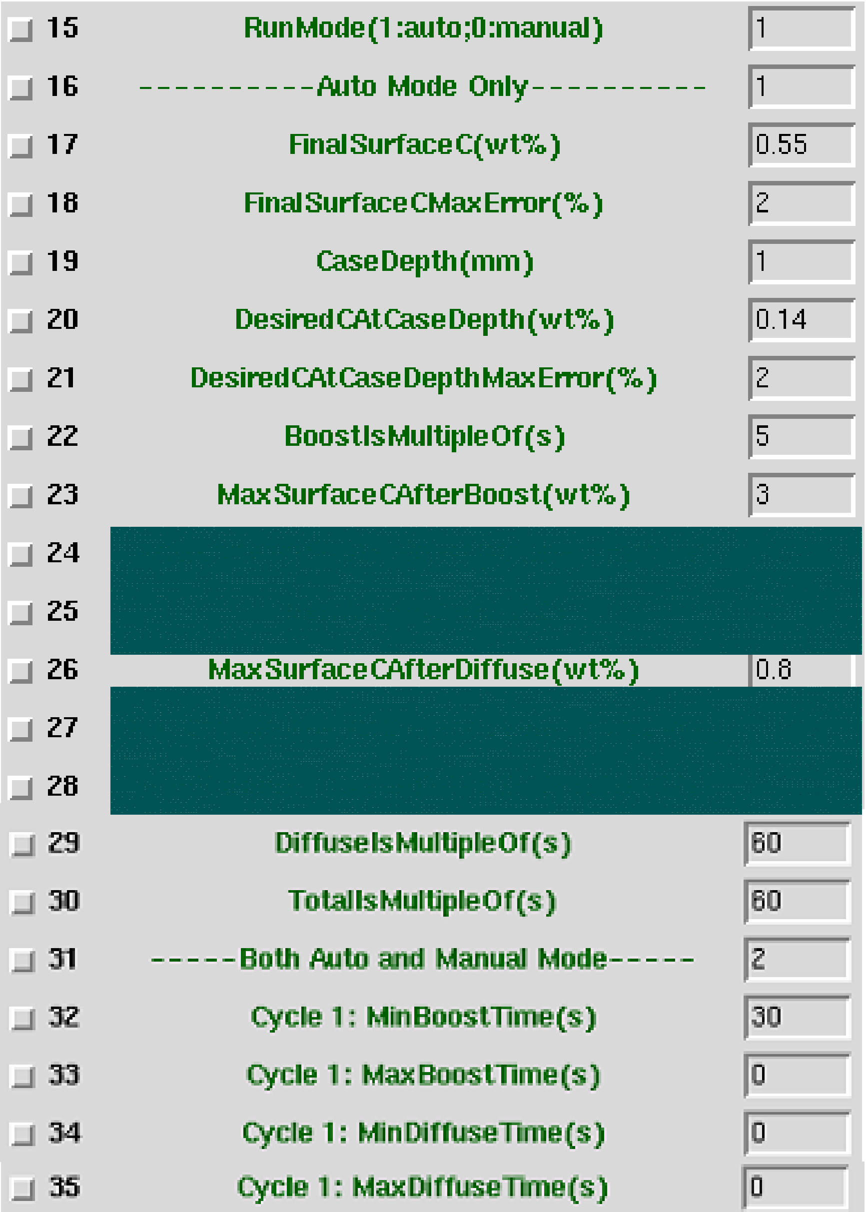
Boost + short diffuse
Depth: ~ 139um
Surface Hardness: ~ HRC 58

- Corner effect:
  - High C potential of the gas
  - Can even be induced in diffuse cycles with low C potential

GUI of Versatile and Multi-constraint Software



GUI of Versatile and Multi-constraint Software



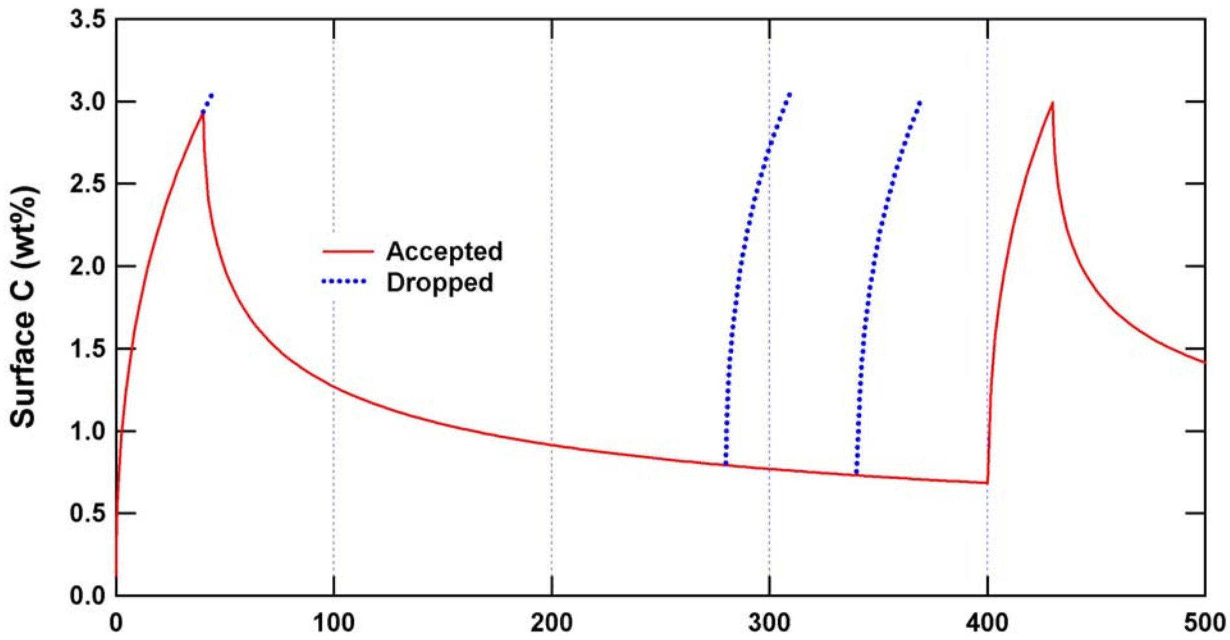
- Challenge:
  - When to start a final diffuse trial
  - DICTRA workspace management (for rollback or different final diffuse trials)
  - Exportation from workspace
  - File management (plotting for different final diffuse trials)

  - Toughest challenge: implement all these flexibilities and constraints into one code

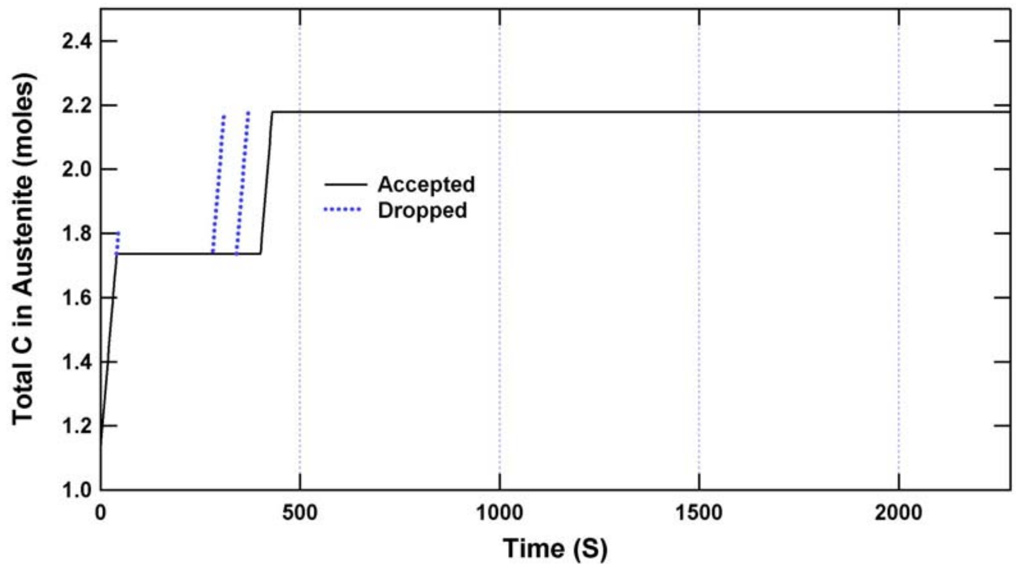
Case Study (1mm Depth)

Surface C

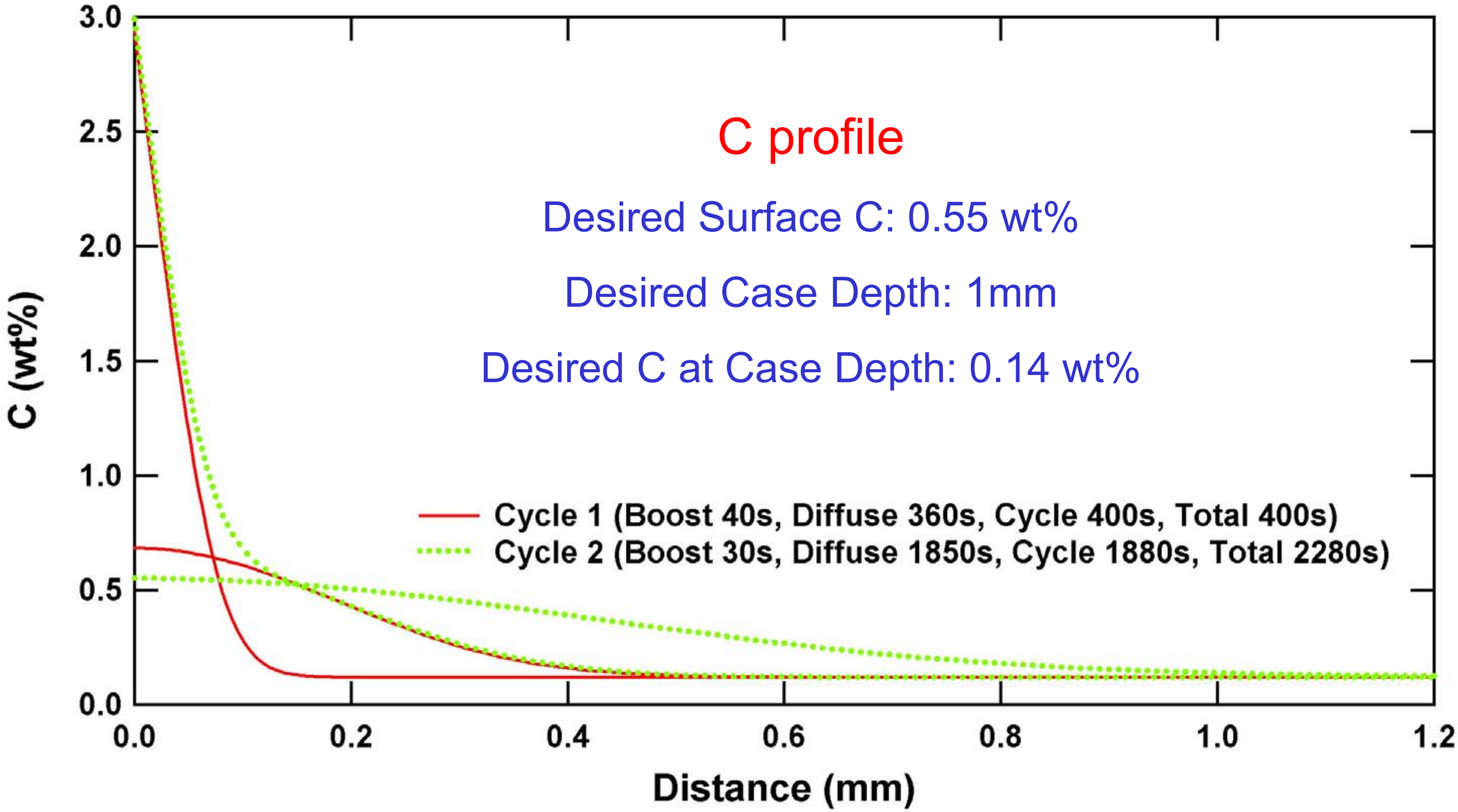
(max: 3 wt%)



Total C in region



Case Study (1mm Depth)



ARCHITECTURE DESIGN

Integration Infrastructure

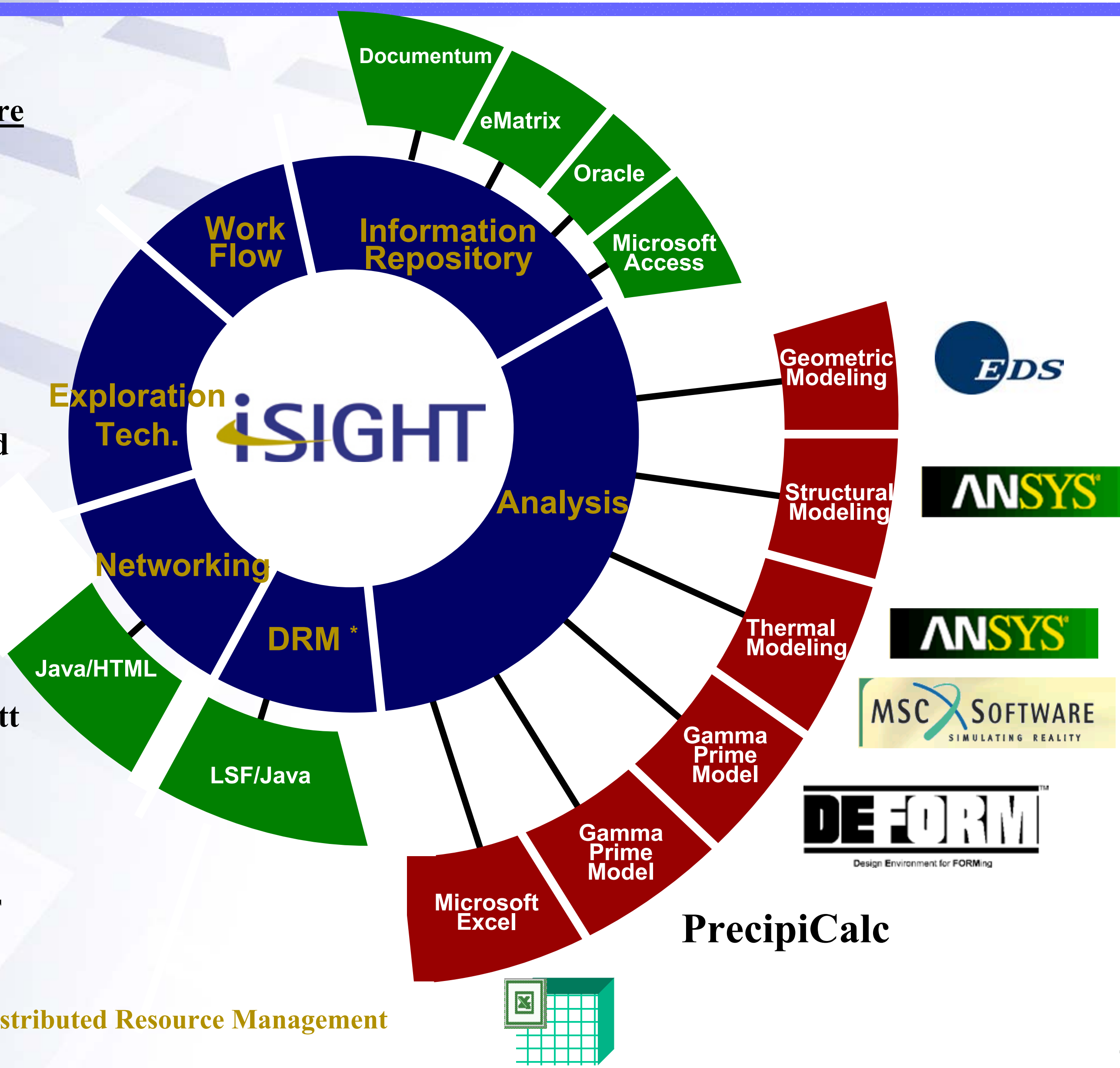
iSIGHT framework provided by Engineous Software

Core Utilities

3RD Party tools to extend iSIGHT's integration capabilities

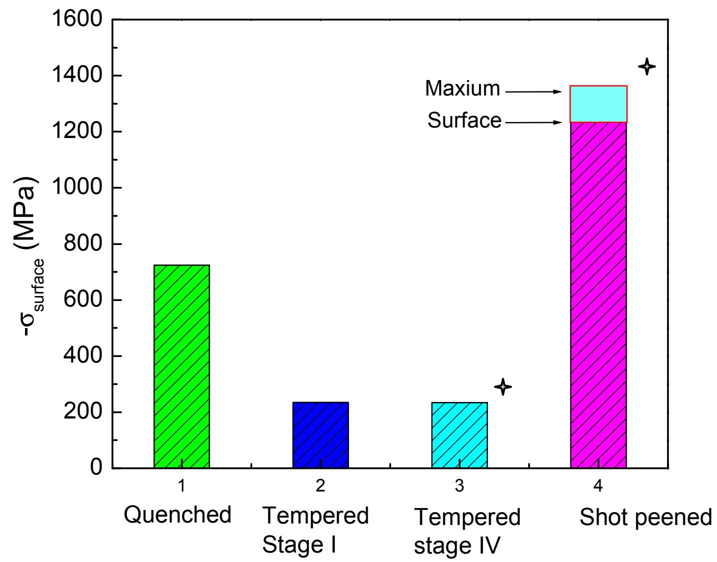
Analysis Components

Models provided by Pratt & Whitney, General Electric, Questek, and others. Integrated by Engineous into the DKB architecture via iSIGHT

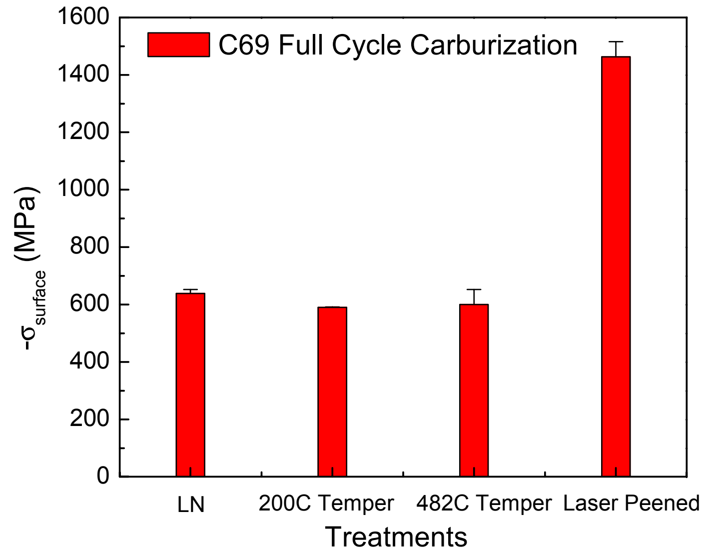


* Distributed Resource Management

Effect of Surface Treatments on Residual Stress



C61



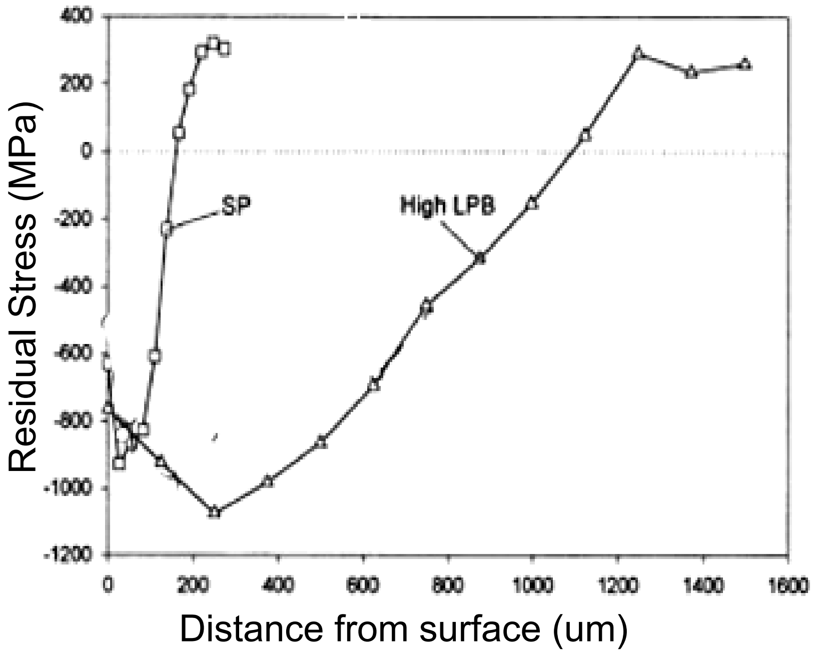
C69

Peening processes allow us to achieve -1.2 GPa, ~-1.5 GPa residual stresses on the surface of C61, C69, respectively.

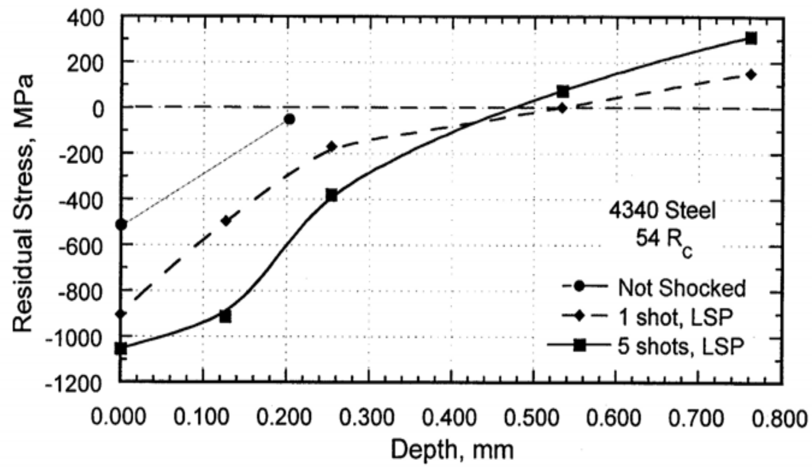
**Data Courtesy: B. Tiemens*

Effects of Surface Treatments

On Residual Stress



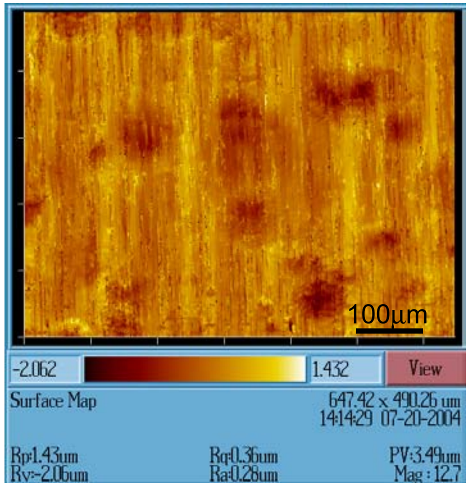
IN 718, *Zhuang & Halford, International Journal of Fatigue, 2001 (23), S31*

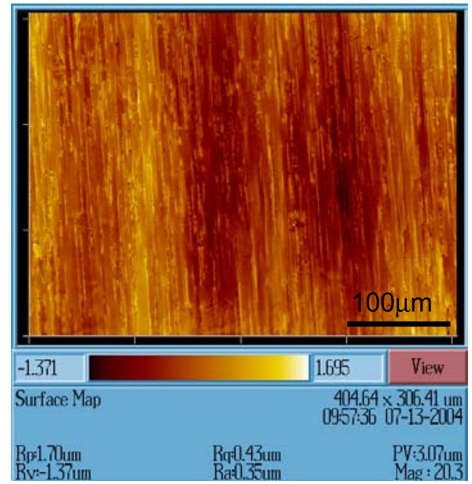


4340 steel sheet with both sides laser peened. The mid-thickness of the sheet is at 0.75mm

Surface Optical Image after Peening

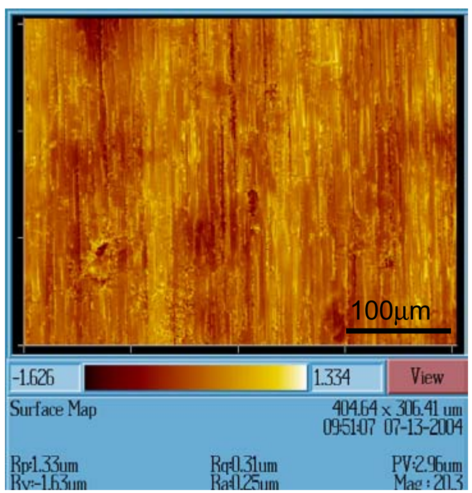
C61 SP

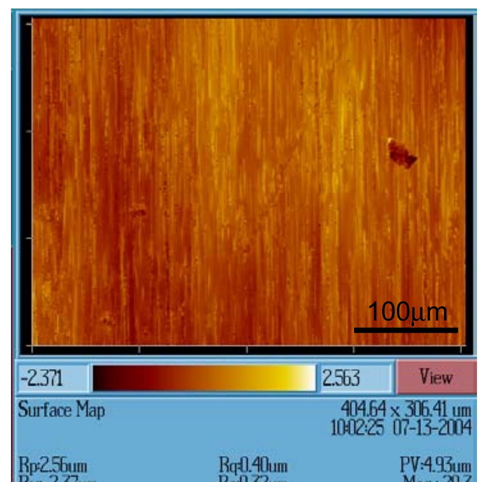




C69 LP

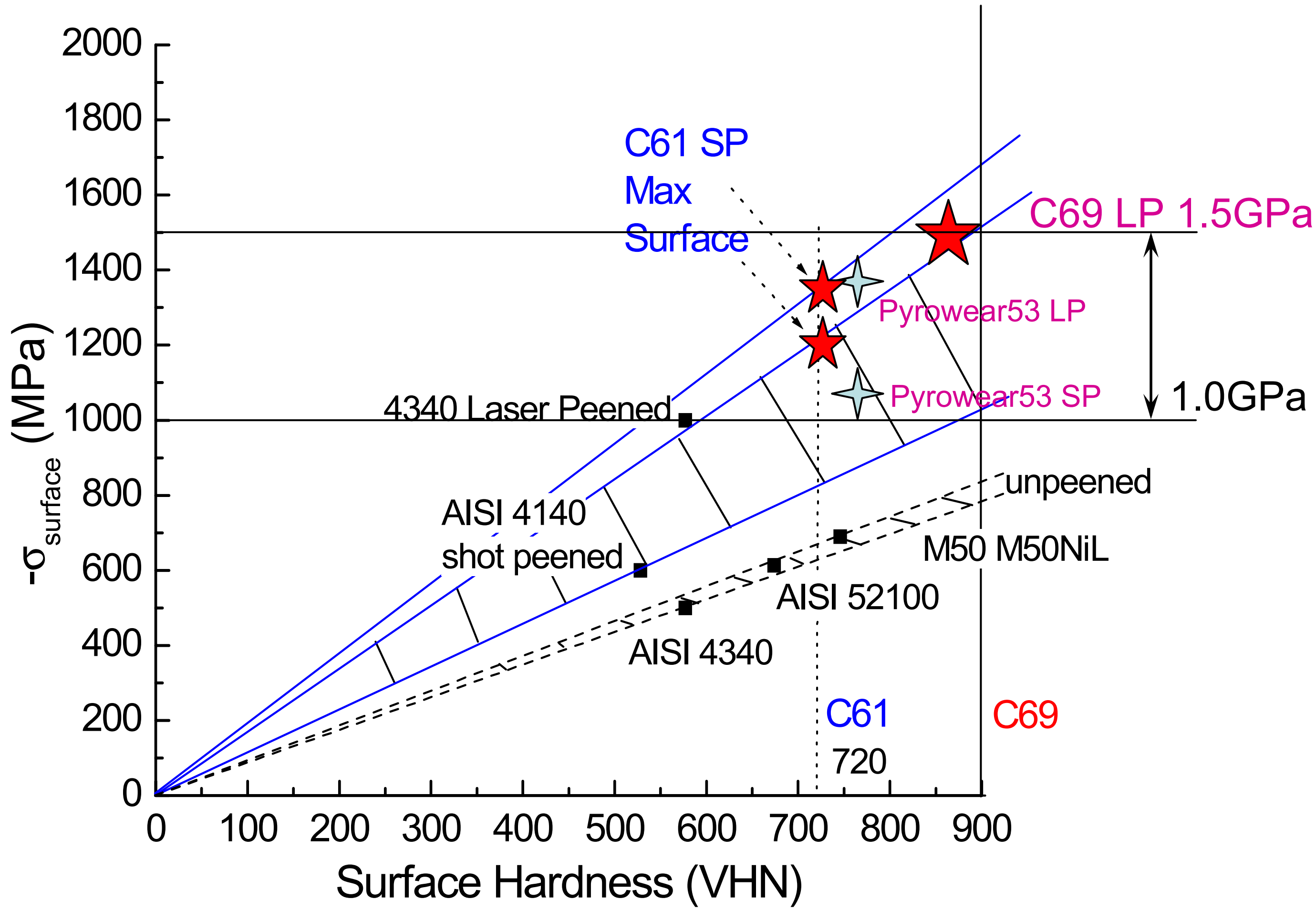
Pyrowear53
SP



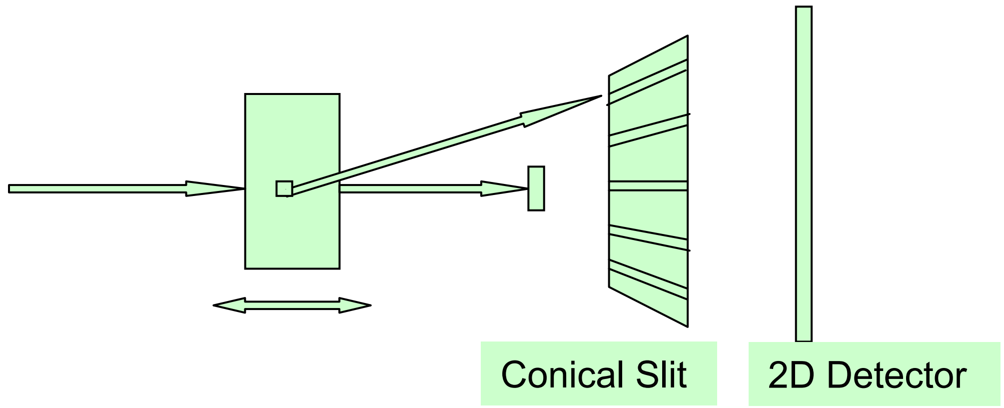


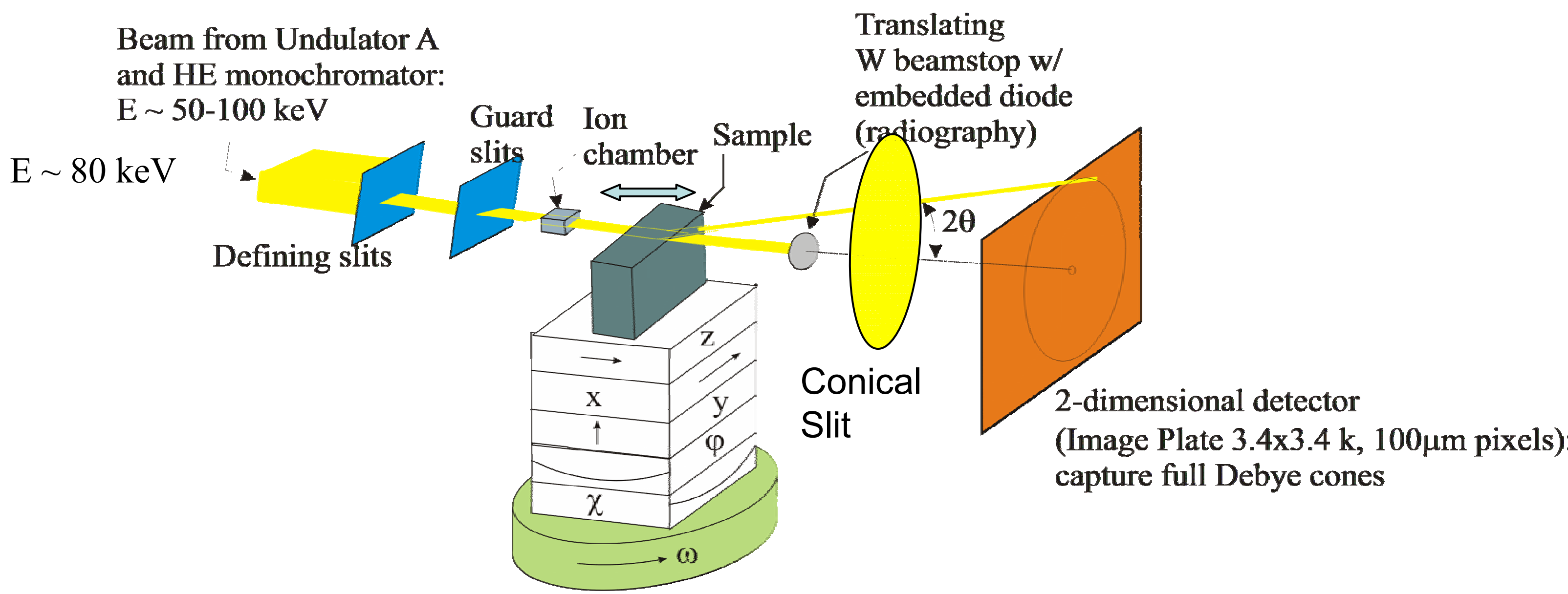
Pyrowear53
LP

Surface Residual Stresses in Materials



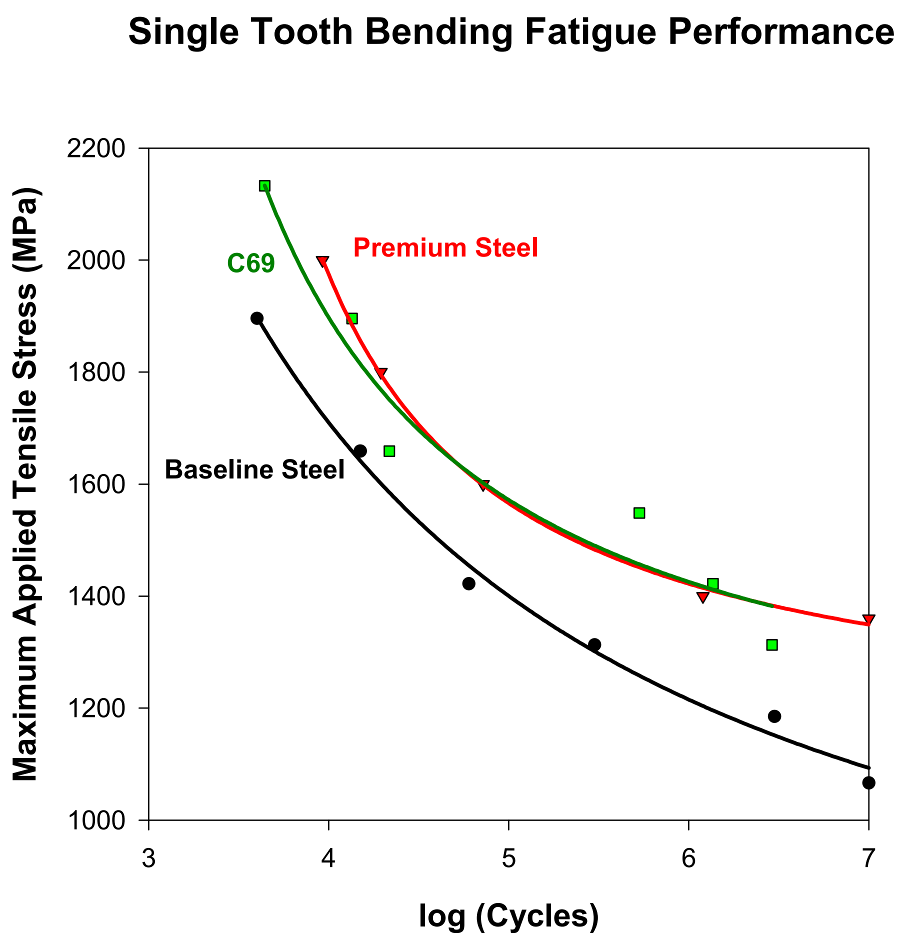
APS Experiment

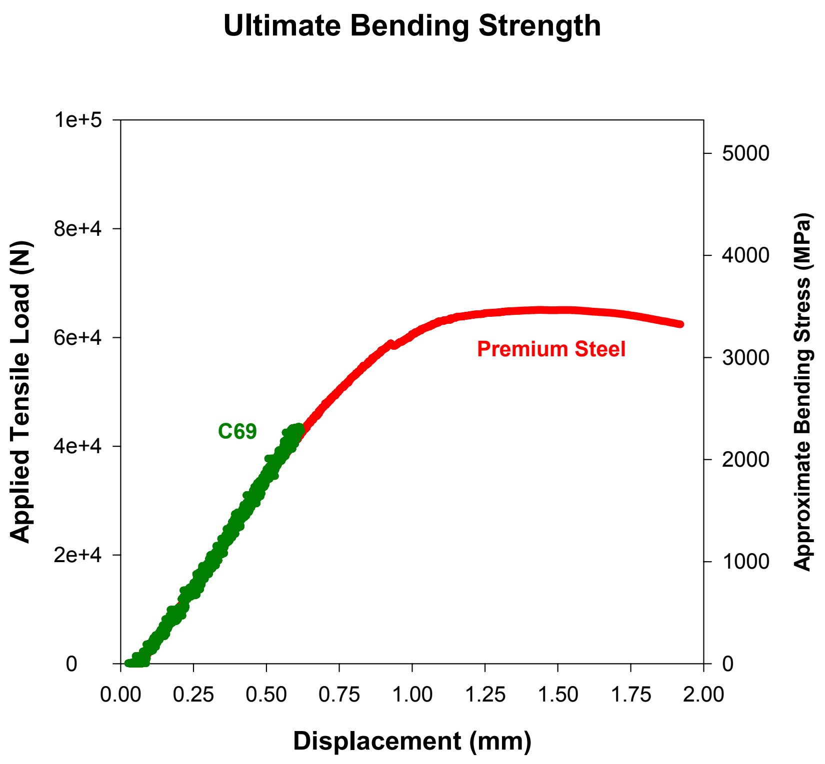




3D Probe of Strain/Stress

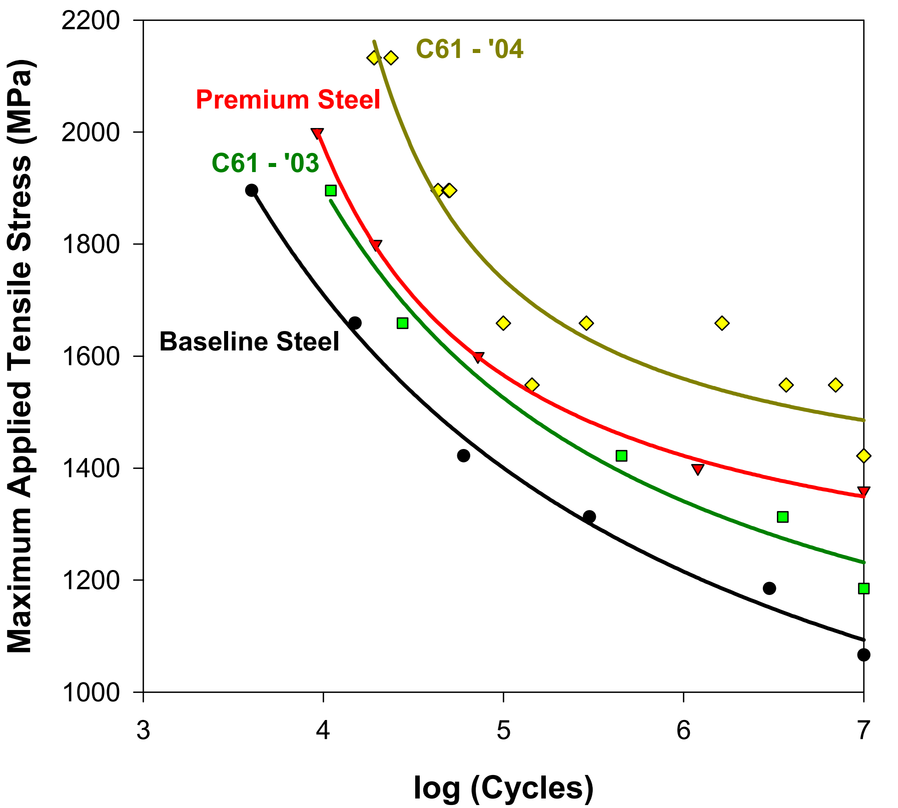
C69


Single Tooth Bending Fatigue Performance
Maximum Applied Tensile Stress (MPa)
2200
2000
1800
1600
1400
1200
1000
3
4
5
6
7
log (Cycles)
C69
Premium Steel
Baseline Steel

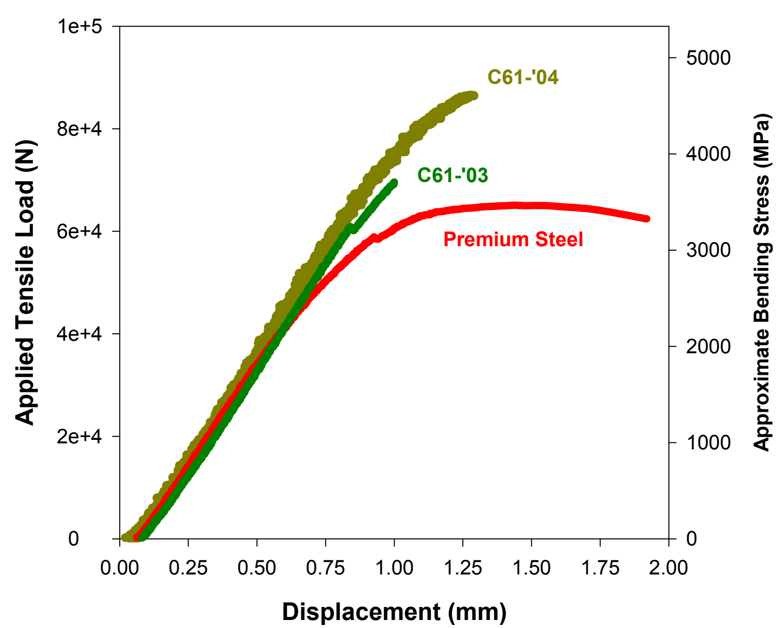

Ultimate Bending Strength
Applied Tensile Load (N)
1e+5
8e+4
6e+4
4e+4
2e+4
0
Approximate Bending Stress (MPa)
5000
4000
3000
2000
1000
0
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
Displacement (mm)
C69
Premium Steel

C61

Single Tooth Bending Fatigue Performance



Ultimate Bending Strength



Role of Load

Surface Residual Stress of Fatigue Tracks

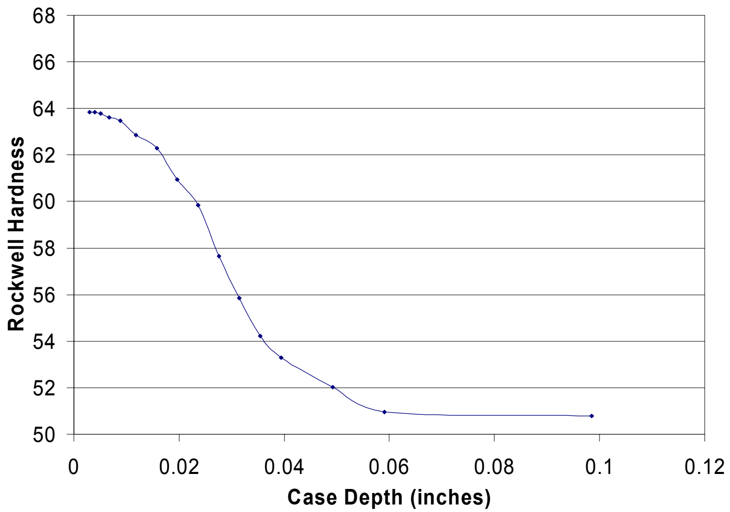
Material	Non-fatigue track		Fatigue Track	
	Axial (MPa)	Hoop (MPa)	Axial (MPa)	Hoop (MPa)
Pyrowear53, SP	1119±5	946±2	?1569±7	756±3 Relaxation: -20%
Pyrowear53, LP	1418±33	1410±3	1085±6 Relaxation: -23%	823±4 Relaxation: -42%

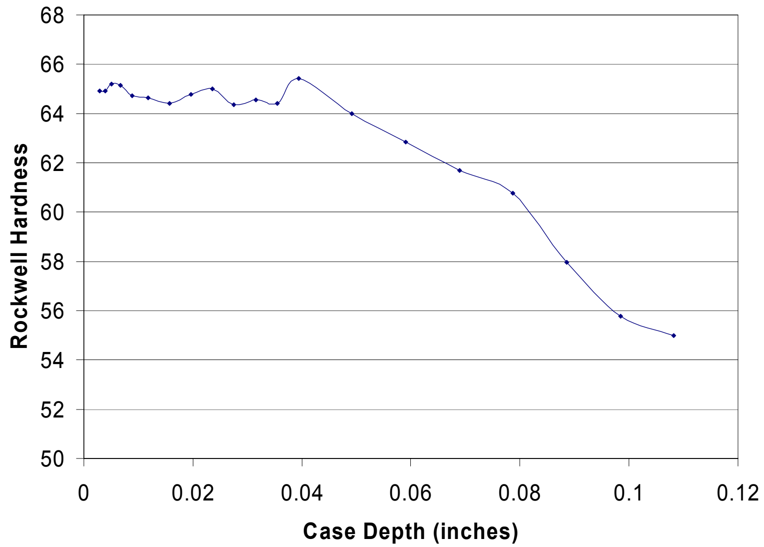
Residual stress relaxation of laser peened material is greater than that of shot peened material.

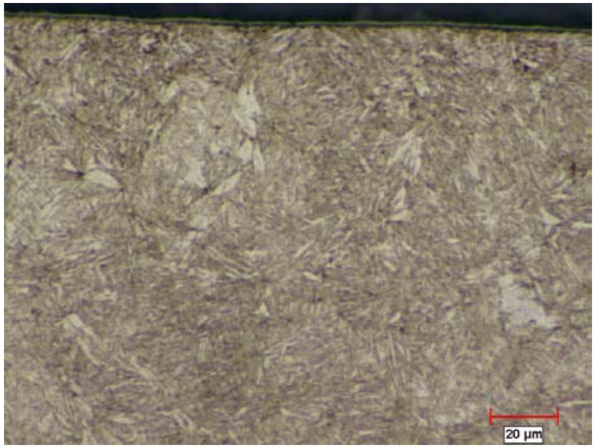
ID Number	Task / Milestone Description	Planned Completion	Actual Completion	Comments
1a	ThermoCalc Modeling	7/31/05		*90%*
1b	Process Experiments	7/31/05		*80%*
1c	Industrial Experiments	7/31/05		*35%*
1d	Hardenability	10/31/03		*10%*
2a	Redesign Alloys	10/31/04		*60%*
2b	Grain Stability	10/31/04		*60%*
3a	RCF and Wear	7/31/05		*50%*
3b	Residual Stress	7/31/05		*35%*
3c	Redesign for Performance	7/31/05		*30%*
3d	Forming Dies	7/31/05		*20%*
3e	Forging/Casting Dies	7/31/05		*0%*

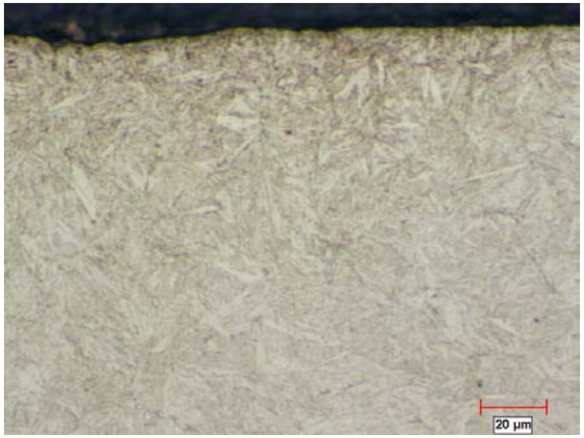
Microstructural Design Example: C69

- Gears
  - 0.015” to 0.050” case
  - 0.040” typical
- Camshafts
  - 0.100” typical





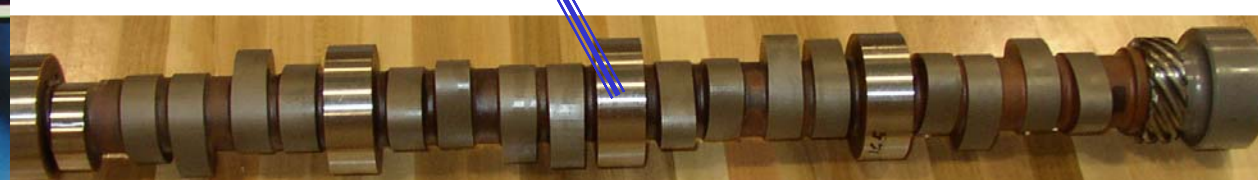




Current Sales *Ferrium*® C61

Ring and Pinion

Camshafts



Commercialization History of Carburized Alloys

- Product Sales
  - Ring and Pinion
  - Camshafts
- Application Trials
  - Gears
    - Racing
    - Aerospace
    - Helicopter
    - Marine
  - Dog Rings (racing)
  - Input Shafts (racing)
  - Roll Forms
  - Cutlery
  - Skate Blades
- Markets Surveyed
  - Ball Screws
  - Tool and Die
  - Golf Clubs

Materials to be studied at WPI

- 8160 gears -- GM
- 5120 gears -- GM
- 8620 shafts -- Deere
- SAE 4118/4122 -- CAT
- SAE 9310 -- CAT
- Fe-Mo-Ni (P/M)-- Hoeganaes Corp.
- Fe-Cr-Mn-Mo (P/M) -- Hoeganaes Corp.

Carburization trial will be conducted at Surface Combustion, OH, using their low pressure carburizing facilities.

FY05 (Y4) Plans

- AIM / iSIGHT robust process design
- Residual stress optimization of C69
- Performance testing of PM-C69Ti
- Prototype characterization of new LC alloys
- Quantify CCT
- Expand deep case applications (cams; tool & die)
- CHTE dissemination of process control (vendors & steels)