Fatigue Enhancement in CIDI / HCCI Engine Components

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Acknowledgements

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- Cummins team members:
  - Dr. Yong-Ching Chen
  - Jeffrey Cooper
  - Uma Ramadorai
- PNNL team members
  - Dean Paxton
  - Curt Lavender
  - Elizabeth Stephens
- CRADA signed between Battelle and Cummins Inc. on October 22, 2007.

Purpose of Work

To enable improved engine efficiencies by increasing injection pressures and the overall durability of reciprocating parts

- Evaluate the capability for surface modification to improve fatigue performance of steel, aluminum and cast iron engine components
- Surface modification techniques include Laser Shock Peening (LSP), Waterjet Peening (WJP), and Friction Stir Processing (FSP)
- Materials of interest are steel used in fuel systems and aluminum alloys and cast iron structural components

Technical Barriers Addressed

- Engine systems are limited in performance by component durability and injection pressure

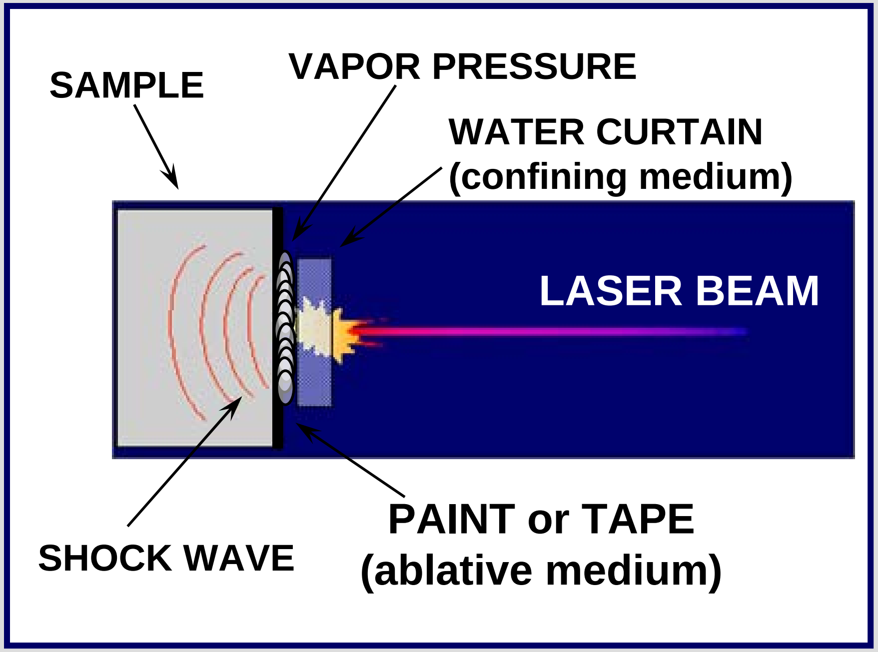
- Increasing the fatigue performance of engine materials would enable higher injection pressures and therefore more efficient engine performance and fuel utilization

- Increased fatigue strength of engine materials could further improve fuel savings by enabling engine designs with lighter weight components

LSP Technology Description

Laser Shock Peening is an innovative technique for introducing deep compressive residual stresses into the surface of metal parts

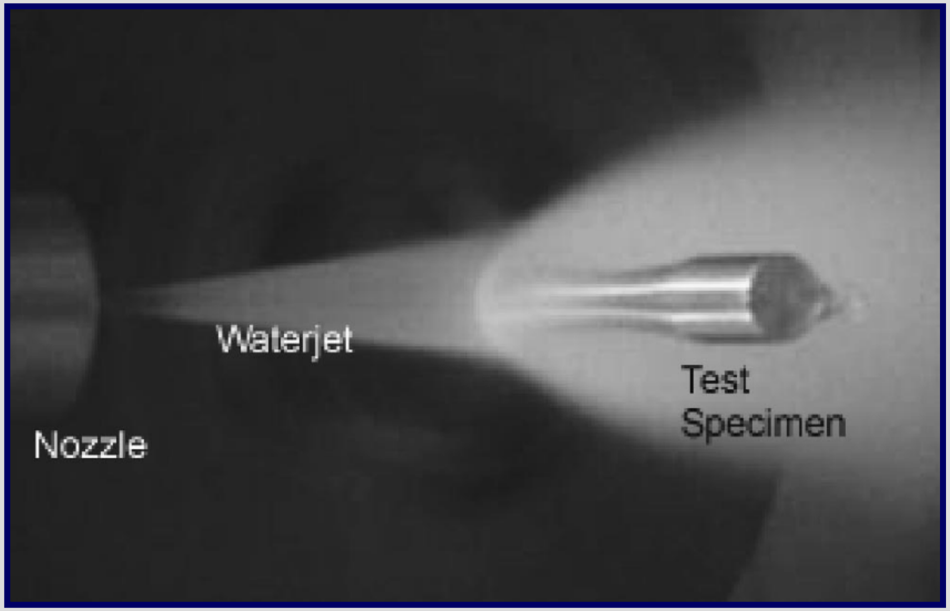
- **Material Property Improvements Include Increased:**
  - Fatigue strength and fatigue life
  - Resistance to crack initiation and propagation
  - Resistance to fretting fatigue and wear
  - Resistance to stress corrosion cracking
- **Used in aerospace industry for foreign object damage protection**
  - Fatigue life enhancement of engine and airframe components
  - Al and Ti



WaterJet Peening Process Description

Water Jet Peening is capable of creating deep compressive residual stresses into the surface of metal parts

- **Material Property Improvements Include Increased:**
  - Fatigue strength & fatigue life
  - Resistance to crack initiation and propagation
- **Benefits of WJP over Traditional Methods:**
  - Negligible impact on surface roughness
  - No residual material deposits
  - Small size of waterjet improves access to difficult to reach locations

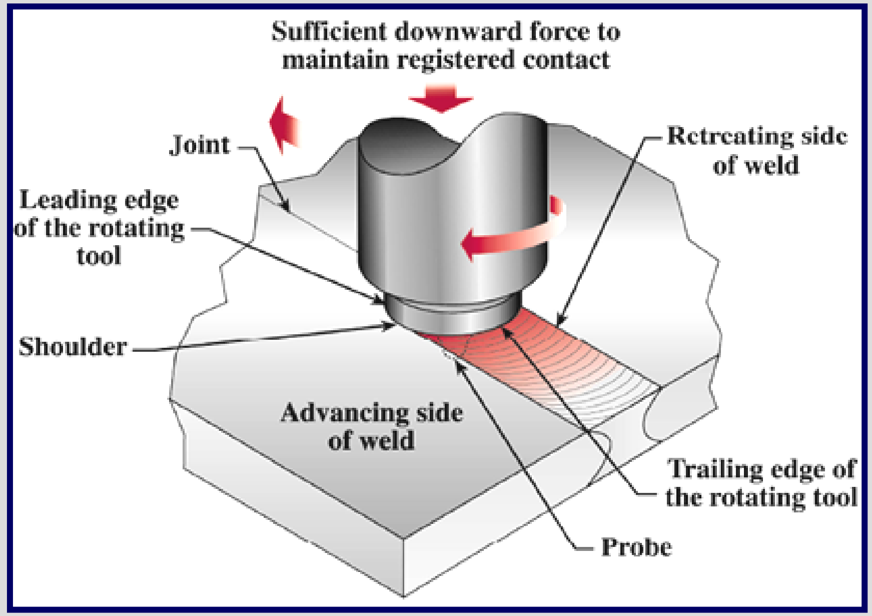


M. Ramulu et al, Fatigue Performance of High-Pressure Waterjet-Peened Aluminum Alloy, J. of Pressure Vessel Tech. Vol. 124 pp.118-123, 2002

Friction Stir Process Description

Friction stir processing is an emerging processing technique based on the principles of friction stir welding

- Developed by TWI, UK for Welding Aluminum In late 1991
- Friction Stir Attributes:
  - Large plastic strain
  - High strain rate
  - Elevated temperatures
  - Mechanical mixing
  - Material flow
- Microstructural Features:
  - Fine grain size
  - Homogenization
  - Primary particle breakdown



Technical Approach – Phase 1

- **Tasks 1 & 2 - Fatigue Testing of Surface Modified Specimens**
  - Demonstrate LSP and WJP to produce deep compressive stresses in steel (1) and aluminum (2) test specimens
  - Characterize stress distributions and compare to control specimens
  - Mechanical testing of surface modified and control specimens
  - Perform thermal stability tests of surface modified specimens
  - Develop cost model for process deployment

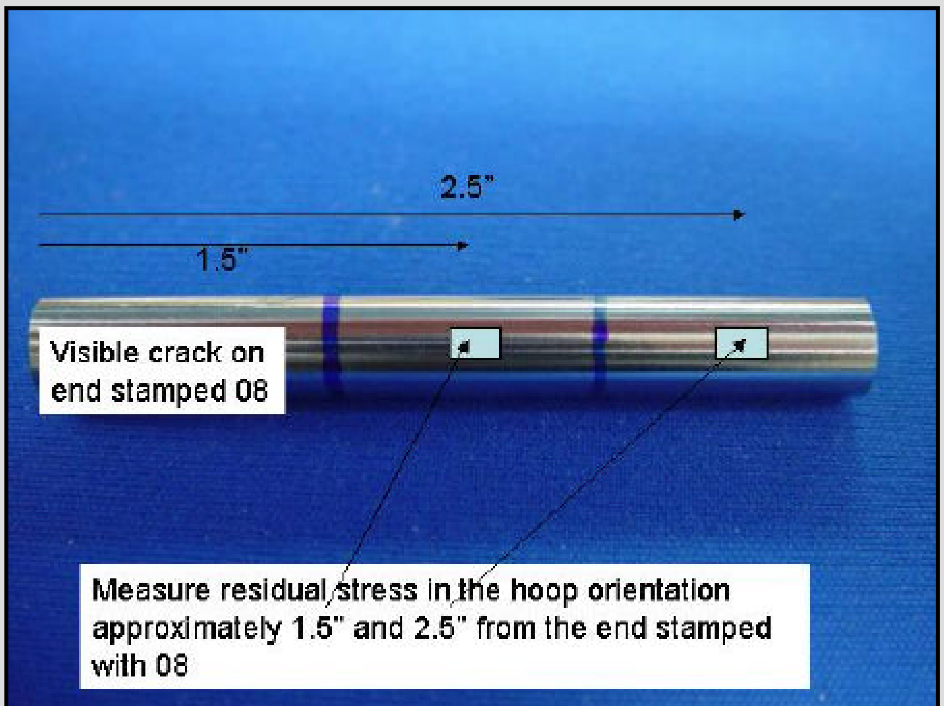
- **Task 3 – Friction Stir Process Development for Cast Iron**
  - Demonstrate FSP technique for surface modification of cast iron using conventional tools (PCBN)
  - Investigate new tool materials and designs for cast iron FSP

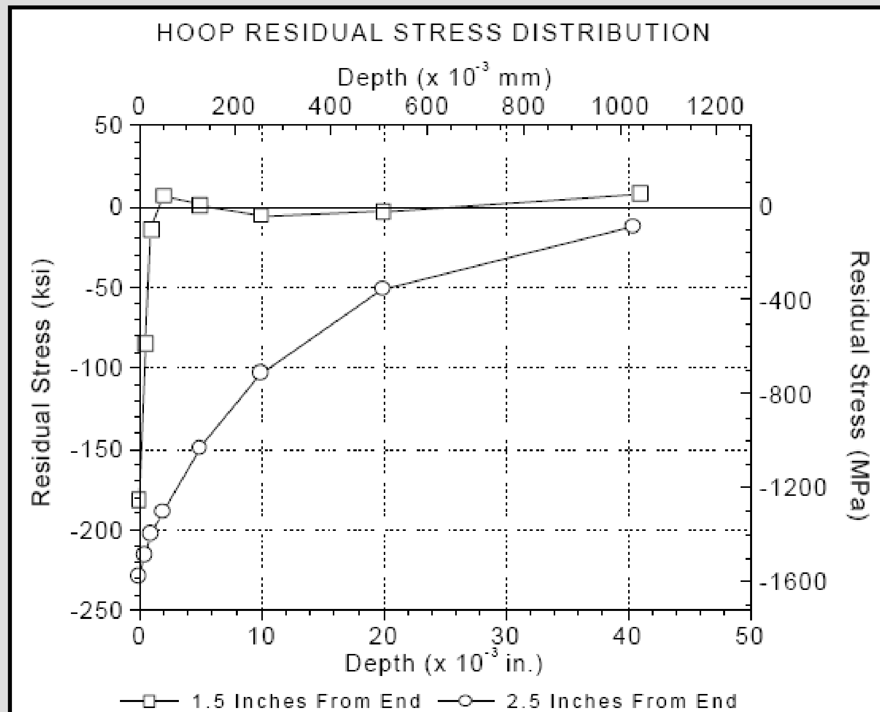
Technical Approach – Phase 2

- Demonstrate LSP and WJP surface modification approach on full-scale steel and/or aluminum components
- Apply FSP technique and advanced tool designs to cast iron component surface modification
- Develop design model to predict strategic locations for surface modification locations on full-scale components
- Develop a cost effective process sequence for LSP/WJP of a relative high volume production

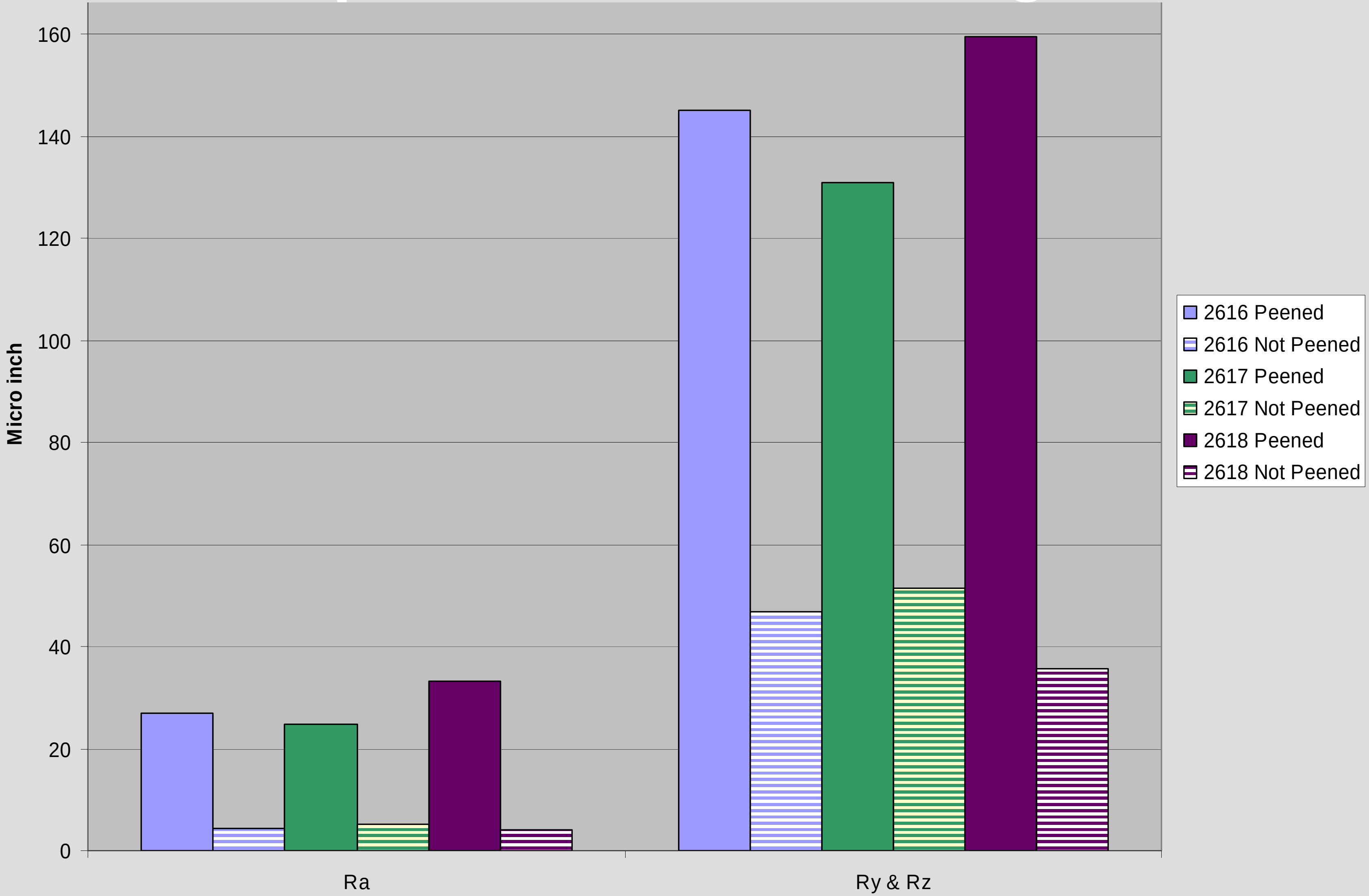
Residual Stress Characterization

- Small diameter (3/8”) rods LSP’d for Rolling Contact Fatigue
  - LSP not previously used on small rods due to elastic wave reflection
  - Significant residual stress generated and characterized
- Comparison of as-ground vs. LSP sub-surface residual stress.



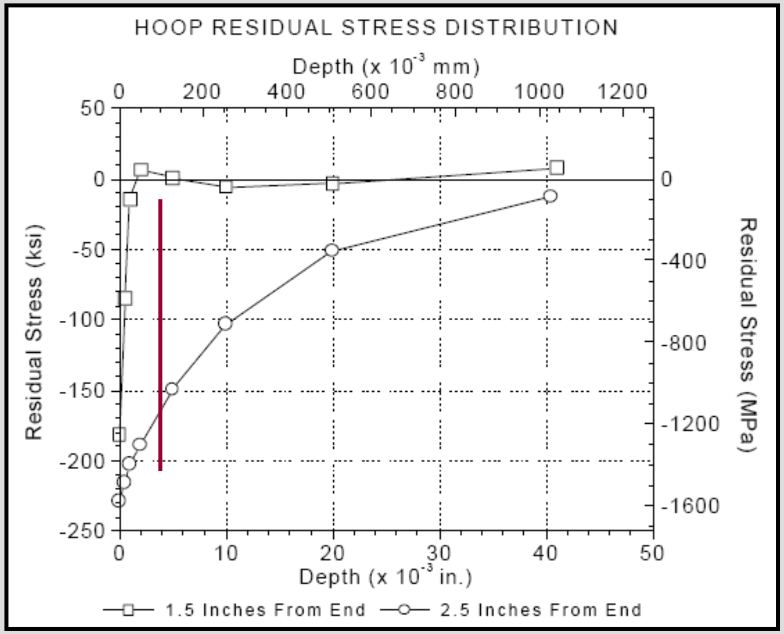


LSP Impact on Surface Roughness



Accomplishments

- High compressive residual stresses were generated in a small dia M50 steel bar.
- LSP does create significant surface roughness.
- The residual stresses are very deep and rods can be ground after LSP without removing residual stress for mechanical testing.
- After polishing or grinding of ~100 um, compressive stresses will still be 150-200 ksi.



Future Work

- Test matrix is established for LSP and WJP fatigue testing.
- Fabrication of steel and aluminum specimens for fatigue testing, control and characterization is underway.
- Fatigue testing expected to begin in June 2008 with initial test and characterization results completed in Sept 2008.
- Friction stir process investigation activities will include:
  - FSP parameter testing in cast iron with conventional tools (PCBN)
  - Characterization of FSP surface modifications
  - Establish industry partner for new tool design & materials

Technology Transfer

- Demonstrate process capability with an industrial engine manufacturer and utilizing commercial suppliers
- CRADA between Battelle and Cummins Inc.
- Commercial surface modification suppliers:
  - LSP Technologies (Dublin, OH)
  - Flow International (Kent, WA)
  - Lambda Technologies (Cincinnati, OH)
  - South Dakota School of Mines (Rapid City, SD)

Publications

A PNNL publication of related work referenced in the proposal for this project:

Title: "*The Effect of Laser Shock Peening on the Life and Failure Mode of a Cold Pilger Die*"

Source: Journal of Materials Processing Technology, Feb 2008

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Summary

- CRADA signed between PNNL & Cummins Inc. in Oct 2007
- Peening of engine component material surfaces shows potential to improve fatigue performance and increase engine efficiency and fuel utilization.
- LSP and WJP techniques will be used to impose deep residual stresses in materials for fatigue testing.
- FSP will be used to modify the microstructure of cast iron surfaces to improve fatigue performance.
- Initial modification of steel and aluminum specimens is underway and testing will be started this fiscal year.