Fatigue Enhancement in CIDI / HCCI Engine Components

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Acknowledgements

- Collaborative project between PNNL and Cummins Inc.

- 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
- 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

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*Illustration of LSP process*
- **LASER BEAM**
- **SAMPLE**
- **VAPOR PRESSURE**
- **WATER CURTAIN** (confining medium)
- **PAINT** or **TAPE** (ablative medium)
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

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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

![Bar chart showing the effect of LSP on surface roughness for different materials and conditions. The chart includes data for Ra and Ry & Rz.](chart.png)
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.