2011 DOE Vehicle Technologies Program Review

Fatigue Enhancements by Shock Peening

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Project ID: PM002

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Overview

Timeline

Project start date:	October 2007
Project end date:	September 2011
Percent complete:	75%

Barriers

- Material limits
- Lack of investment in improving the traditional reciprocator platform
- Cost of advanced materials and their processing

Budget

Total project funding:

- DOE – $1,040 K
- Cost Share – 50%

Funding FY10: $325 K
Funding FY11: $150 K

Partners

Industrial CRADA Participant:
Cummins Inc.

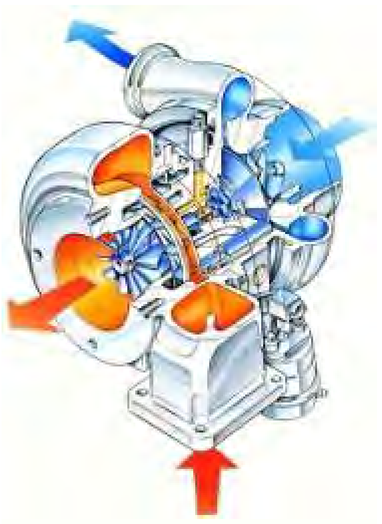
- Dr. Yong-Ching Chen
- Jeffrey Cooper
- Sanjay Thakur

Supplier Development:
LSP Technologies – Laser Peening
Flow International – Waterjet Peening

Support:
South Dakota School of Mines – Friction Stir Processing

Objectives of Project

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



- Evaluate the capability for surface modification techniques to improve fatigue performance of steel, aluminum and cast iron engine components
  - Potentially enabling a lower cost material to meet or exceed the performance of higher cost materials
- Surface modification techniques, which are non-traditional for engine manufacturers, include Laser Shock Peening (LSP), Waterjet Peening (WJP), and Friction Stir Processing (FSP)
- Materials of interest are steel used in fuel systems and aluminum alloy and cast iron structural components

Deliverables

- Demonstrate fatigue enhancements achieved by LSP and WJP for steel and aluminum components, including a comparison to traditional shot peening approaches
- Demonstrate enhancements achieved by FSP for cast iron components
- Prototype a component enhanced by a promising surface modification technique for full scale evaluation

FY11 Project Milestones

Milestone	Due	Status
Complete full systems evaluation of a waterjet peening processed aluminum component demonstrating an increased design stress by more than 15%.	7/15/2011	In progress

Technical Approach

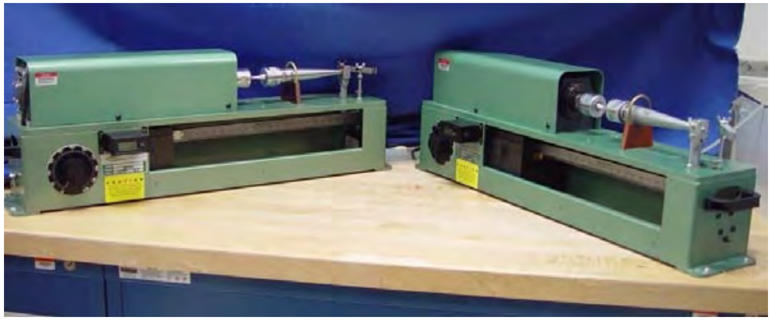
▶ Technology Development

- **Fatigue Enhancements in Steel and Aluminum**
  - Demonstrate LSP and WJP produce **deep** compressive stresses in steel and aluminum test specimens
  - Characterize stress distributions and compare to control specimens
  - Rotating beam fatigue (RBF) testing of surface modified and control specimens
  - Perform thermal stability tests of surface modified specimens
  - Develop cost model for process deployment

- **Friction Stir Process Development for Cast Iron**
  - Demonstrate FSP technique for processing of cast iron
  - Investigate new tool materials and designs for cast iron FSP

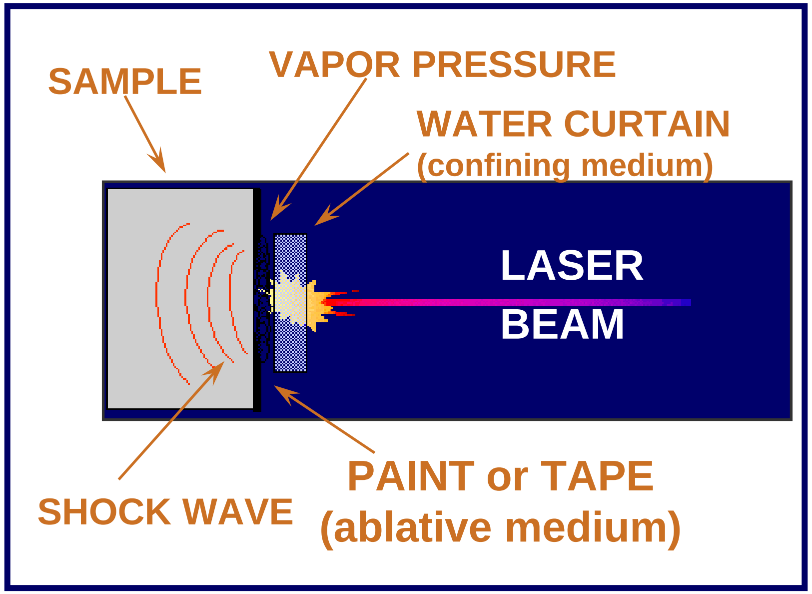
▶ Technology Deployment

- Demonstrate LSP and WJP surface modification approach on full-scale steel and/or aluminum component
- Develop a cost effective process sequence for LSP/WJP of a relative high volume production



Previous Accomplishments

- Fatigue life of Laser Shock Peened and ground 52100 steel showed significant increase in RBF life over the other populations
  - Cummins statistical analysis of the fatigue results showed ~12% increase in high cycle fatigue
- Fatigue life of Laser Shock Peened and ground 52100 steel showed significant increase in Rolling Contact Fatigue (RCF) life over the control population
  - Cummins statistical analysis of the fatigue results showed ~50% increase in RCF life
- Promising LSP results prompted Cummins Inc. to move to Technology Deployment
  - Cummins identified a series of components for full scale evaluation of LSP; prototype components were enhanced by LSP and testing initiated

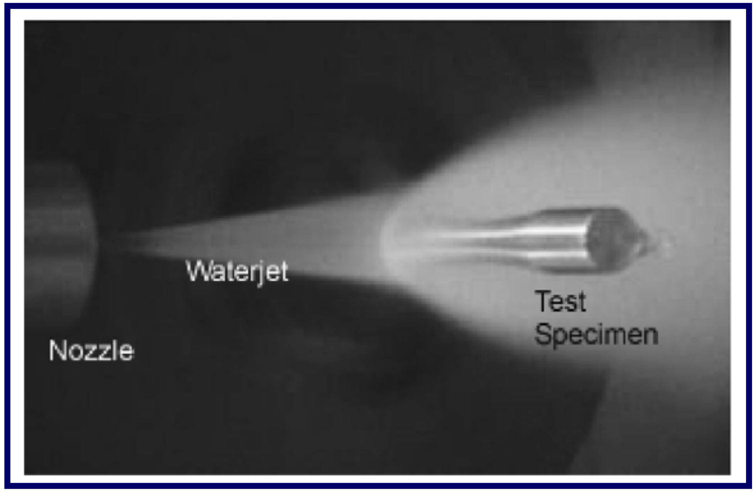


Accomplishments (FY10/FY11)

- Waterjet peening produced surface compressive residual stresses in cast aluminum alloy A354 while maintaining the surface finish
- WJP A354 specimens showed a significant improvement in fatigue life in comparison to the control
- Plasticization of cast iron was observed with the use of cover plates and no pre-heating when friction stir welding cast iron

Technical Progress – Waterjet Peening

- Task 1: Pre-screening of Waterjet Peening methods (previously reported) to determine most viable method for further evaluations
  - Peening method applied affected the depth of compressive stress and finish
  - Two methods, A and C, were selected for further evaluations
- **Task 2: Optimization of WJP processing parameters**
  - A quadratic model, DOE was applied, where the supply pressure (P), air pressure (P_A), stand-off distance, and traverse rate (u) was varied to determine optimum processing parameters for peening methods A and C
  - 26 runs were conducted; residual stress measurements and 3-d surface profilometry performed on each specimen processed
- **Task 3: Rotating beam fatigue test evaluations**
  - Fatigue test evaluations were performed on three selected processing conditions from Task 2 that provided high residual stress levels with minimum roughening of the surface

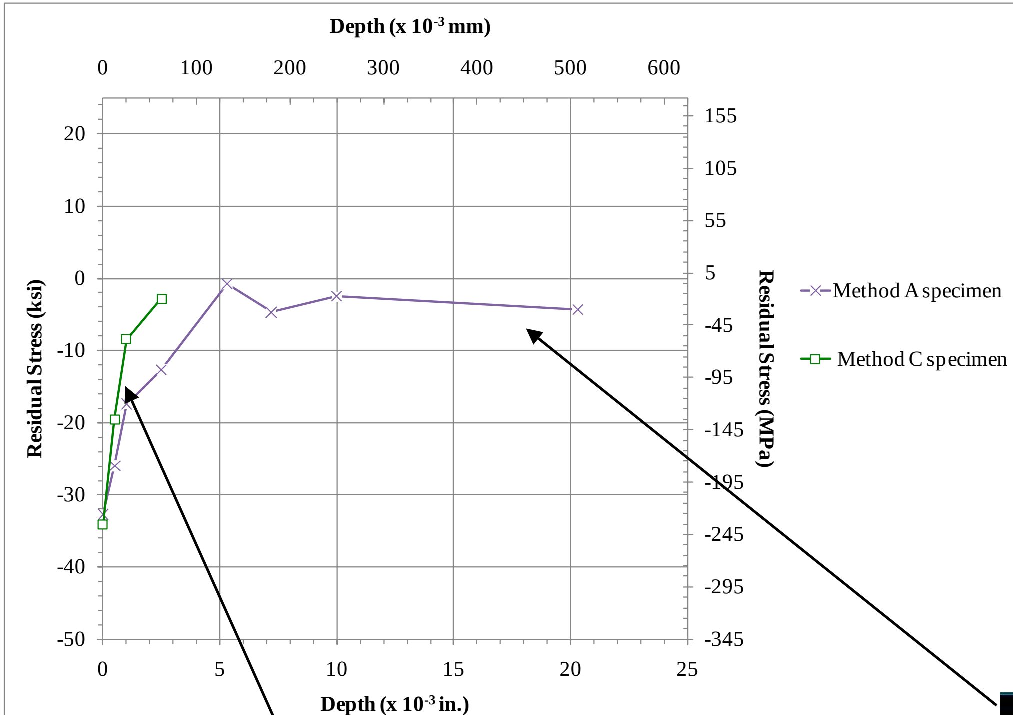


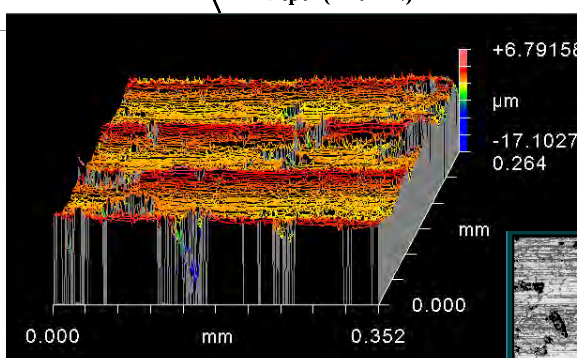
M. Ramulu et al, Fatigue Performance of High-Pressure Waterjet-Peened Aluminum Alloy, J. of Pressure Vessel Tech. Vol. 124 :118-123, 2002

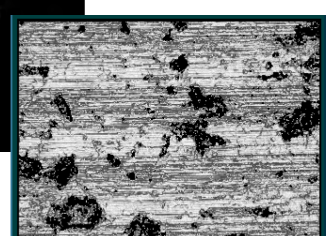
Specimen processed via waterjet peening

Results

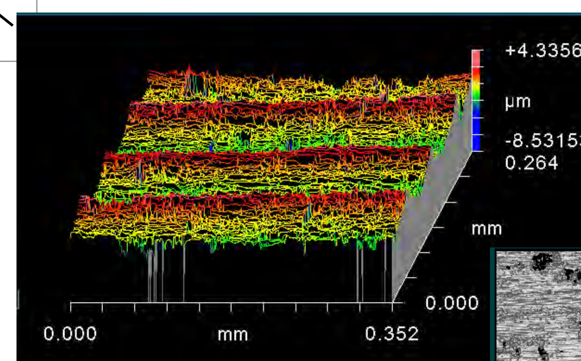
Comparison of residual stress measurements for Method A and Method C processed specimens, F24 and F18, respectively

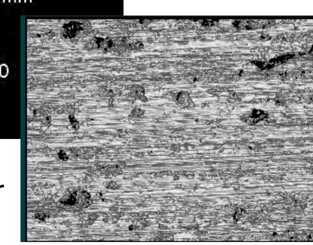






Representative surface image for spec. F18 where the ave. Ra measured was 43 µin.

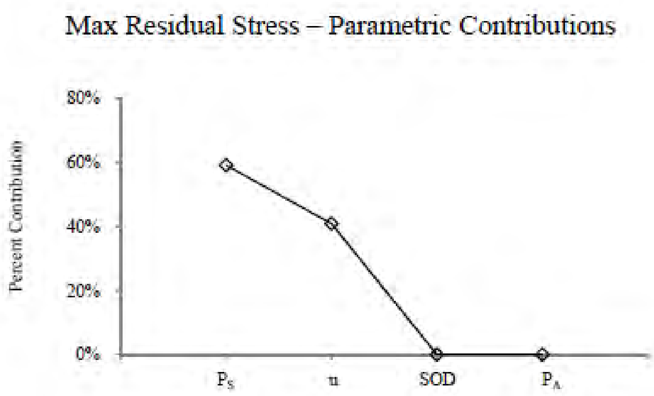


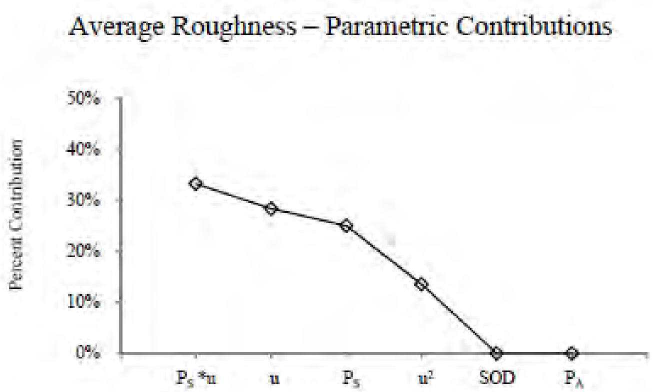


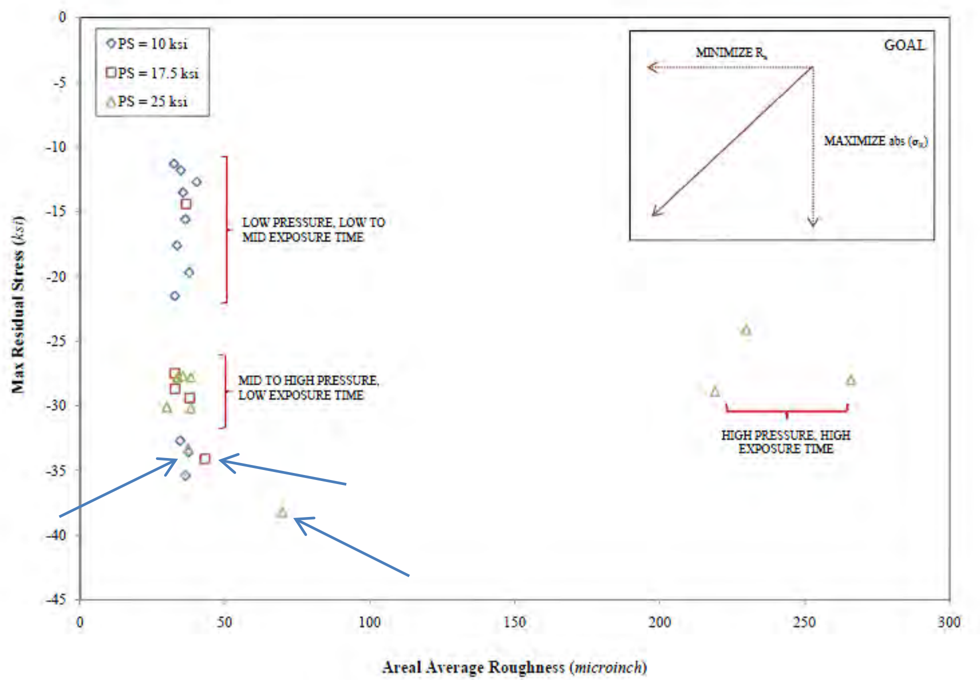
Representative surface image for spec. F24 where the ave. Ra measured was 35 µin.

- Measurements verified that waterjet peening can produce surface compressive residual stresses in A354 while maintaining the surface finish
  - Maximum compressive stresses observed ranged from 75 MPa to 275 MPa
  - Depths at max stress ranged from 0 to 0.070 mm
  - Average R_a surface roughness measurements observed ranged from 0.8 µm to 7 µm

DOE Results







- A Pareto analysis of the DOE results was performed to understand the parametric contributions to residual stress and surface roughness
  - Supply pressure and traverse rate determined to be important contributors

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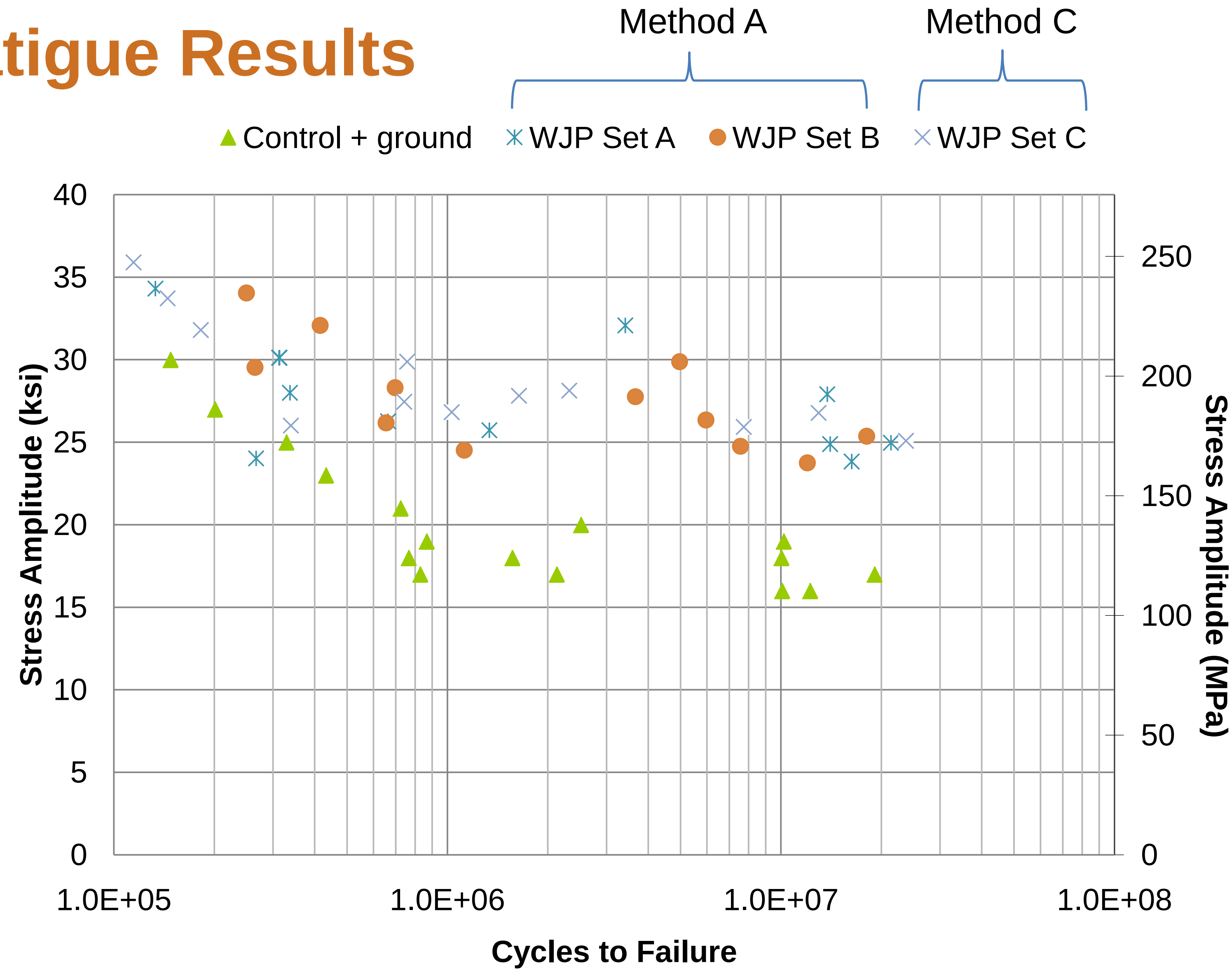
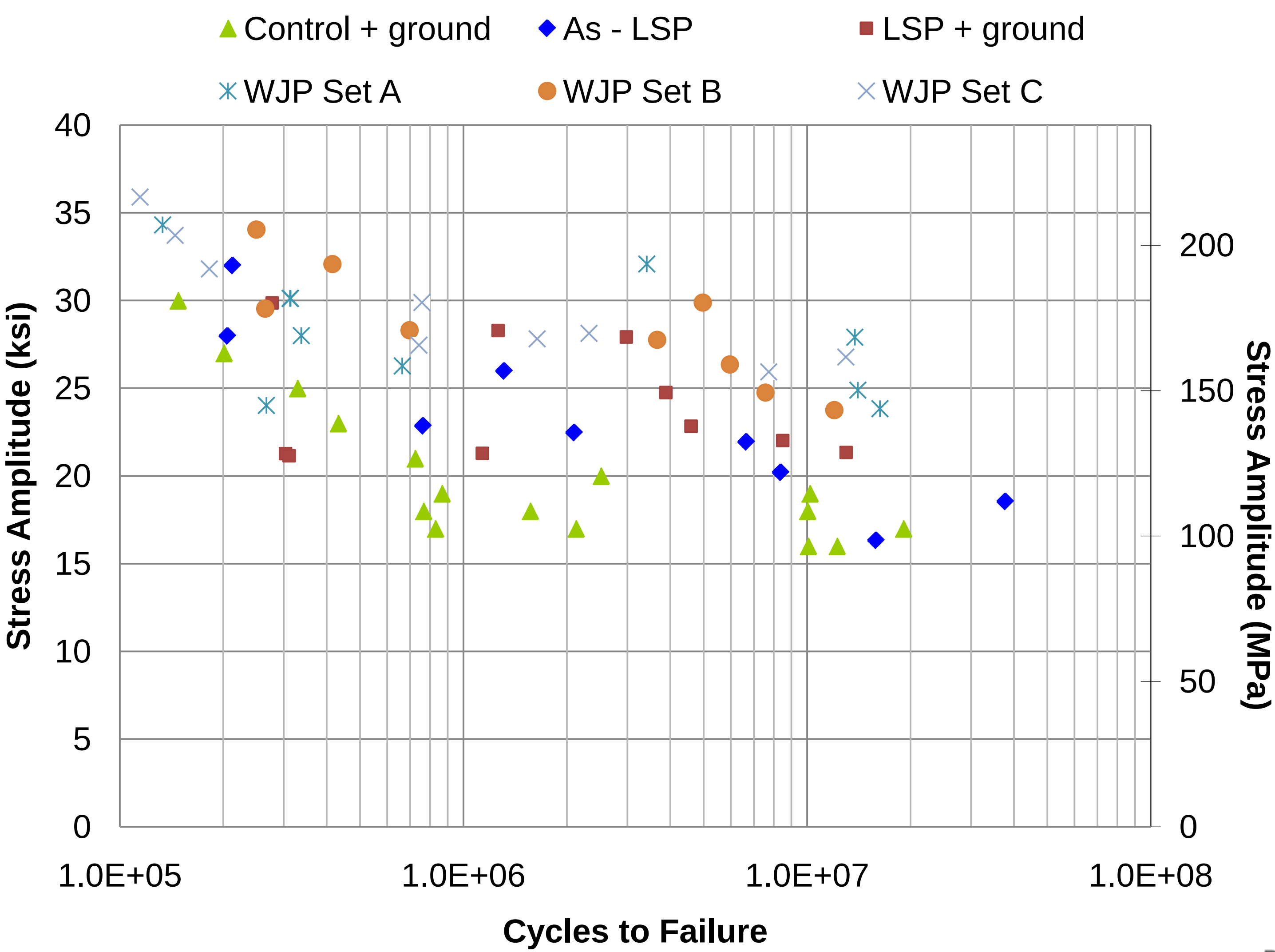
Fatigue Results



- Results to date indicate fatigue life improvement in comparison to control

Comparison of WJP Fatigue Results to other Peening Methods



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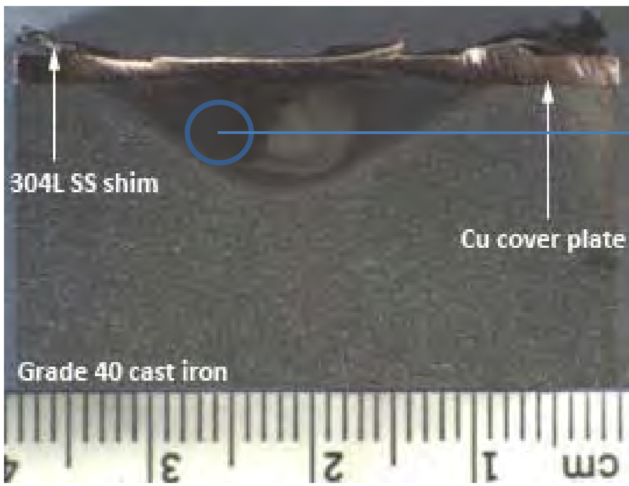
Technical Progress - FSP of Cast Iron

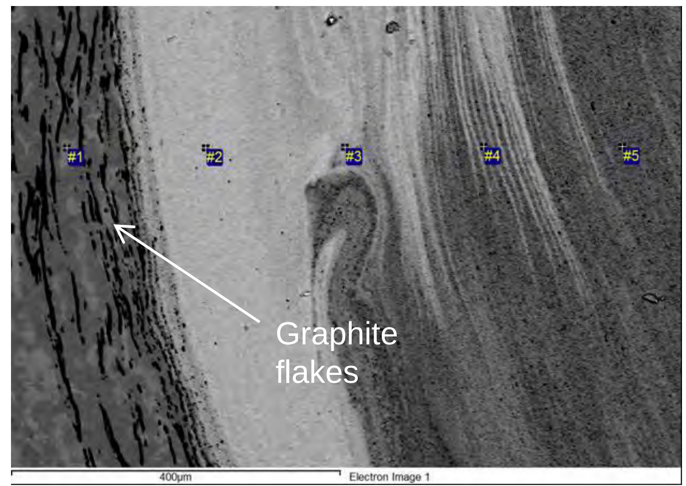
- Collaborative effort between Cummins Inc., South Dakota School of Mines and Technology, and PNNL
- Previously, work focused on evaluating challenges of friction stir processing/welding cast iron and investigating potential solutions to overcome these challenges (i.e. pre-heating, use of cover plates, cover plate thickness, etc.)
  - Evaluations occurred primarily on FSW plunges only
- Work progressed to translation of the tool and processing parameter development
  - From 0.5 to 1 IPM and 1000 to 1200 RPM at force control loads of 3300 and 5000 lb. with the use of cover plates (304L SS,1018 steel, & Cu)

Results

- Plasticization of cast iron achieved through the use of 304L shim/Cu cover plate
  - Full consolidation, on a 1-inch translation achieved
  - Hardness in majority of weld-zone ranged from 174 to 258 HV
  - However, segregation/alignment of graphite flakes observed
    - Previously, no segregation of graphite flakes was observed in plunge cross-sections



A 1-inch translation cross-section of the Cu cover plate on cast iron showing a consolidated joint.



SEM micrograph illustrating alignment of graphite flakes at the weld nugget interface.

Results

- Applying the same processing parameters to longer weld translations did not achieve the same results as observed in shorter, 1-inch weld translations
  - Thermally stable, 7.5 inch welds were still achieved with different processing parameters
  - However, graphite alignment still observed
- Low strengths attributed to graphite alignment
  - Tensile specimens prepared from the weld yielded longitudinal tensile strength of 33 ksi and no strength in the transverse direction

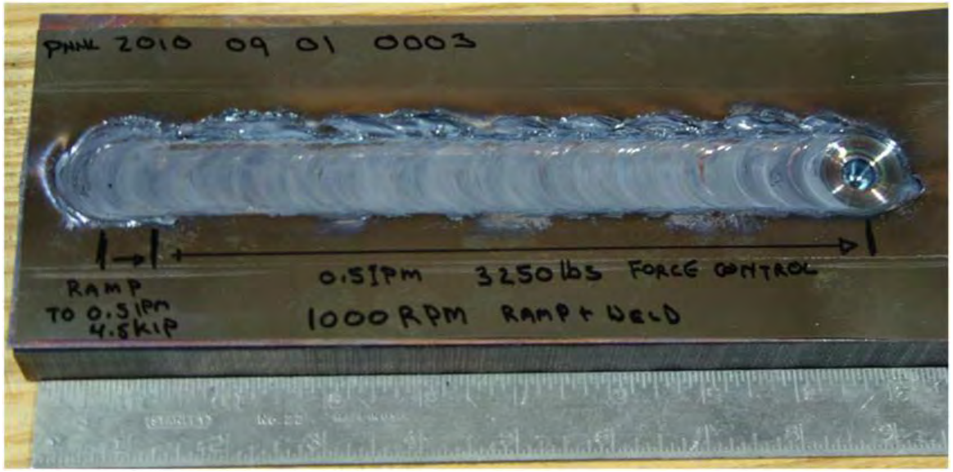


Image of a 7.5 inch weld translation of cast iron.

Technology Deployment

- Currently, Cummins Inc. has identified a component for full scale evaluation of WJP
  - Developing a work plan with Flow International outside of the CRADA

Future Work

- Testing of components enhanced by WJP
  - To be completed by Cummins Inc.
- Complete formal CRADA report and support Cummins implementation and documentation of components enhanced by LSP and WJP
- Produce repeatable, fully consolidated, defect free welds of FSP cast iron with same processing parameters
- Investigate potential tool designs to overcome graphite alignment observed in FSP of cast iron
- Complete FSP of cast iron final report

Summary

- WJP of A354 cast aluminum can produce surface compressive residual stresses while maintaining a required surface finish
- WJP A354 specimens showed a significant improvement in fatigue life in comparison to the control
- Thermally stable, consolidated friction stir welds (with the use of cover plates and no pre-heating) can be achieved for cast iron