Fatigue Enhancements by Shock Peening

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Pacific Northwest
NATIONAL LABORATORY

Overview

Timeline

Project start date: October 2007
Project end date: October 2010
Percent complete: 60%

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 FY08: $350 K
Funding FY09: $340 K

Partners

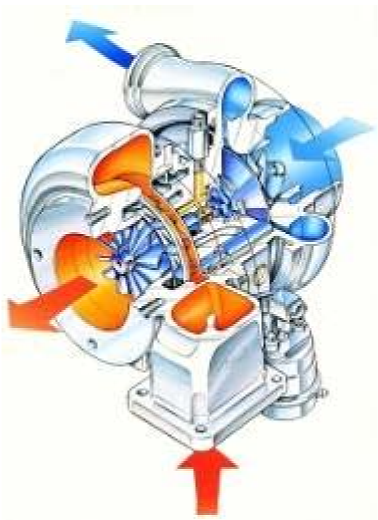
Industrial CRADA Participant:
Cummins Inc.
- Dr. Yong-Ching Chen
- Jeffrey Cooper

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

Technical Approach

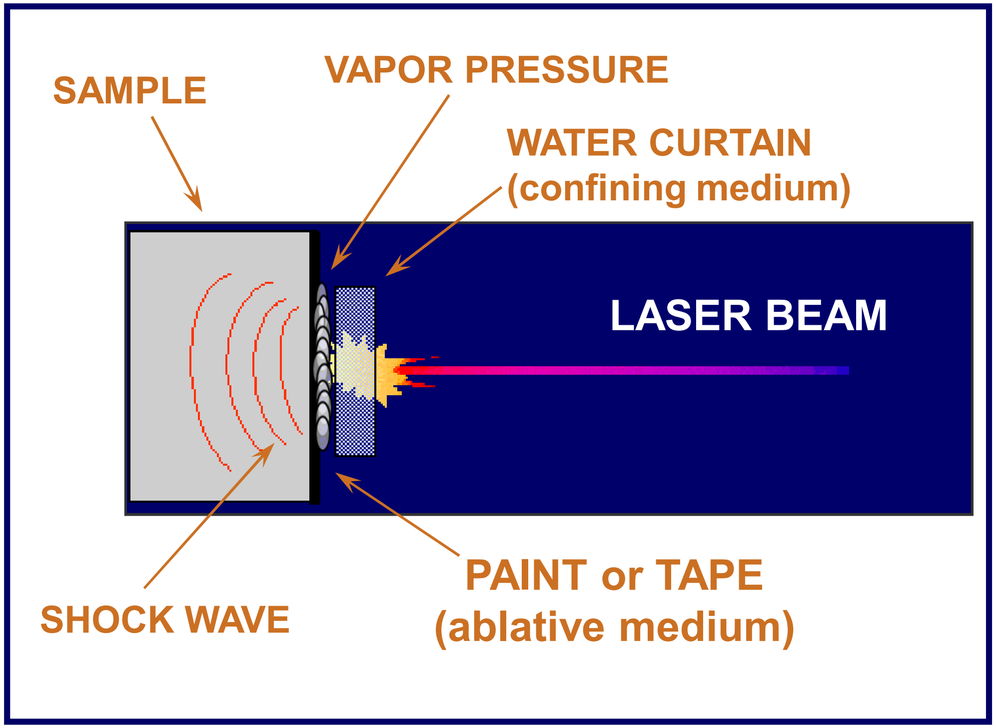
- **Technology Development**
  - **Fatigue Enhancements in Steel and Aluminum**
    - Demonstrate LSP and WJP produce **deep** compressive stresses in steel and aluminum test specimens
    - Characterize stress distributions and compare to control specimens
    - RBF testing of surface modified and control 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 joining 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

Technical Progress

- The last year of the project was focused on:
  - Laser shock peening to enhance the Rolling Contact Fatigue of M50 bearing steel and Rotating Beam Fatigue life of 52100 steel and A354 cast aluminum
  - Parameter development for waterjet peening of A354 cast aluminum
  - Selection of relevant test articles for friction stir processing/joining of cast iron

Technical Progress - LSP

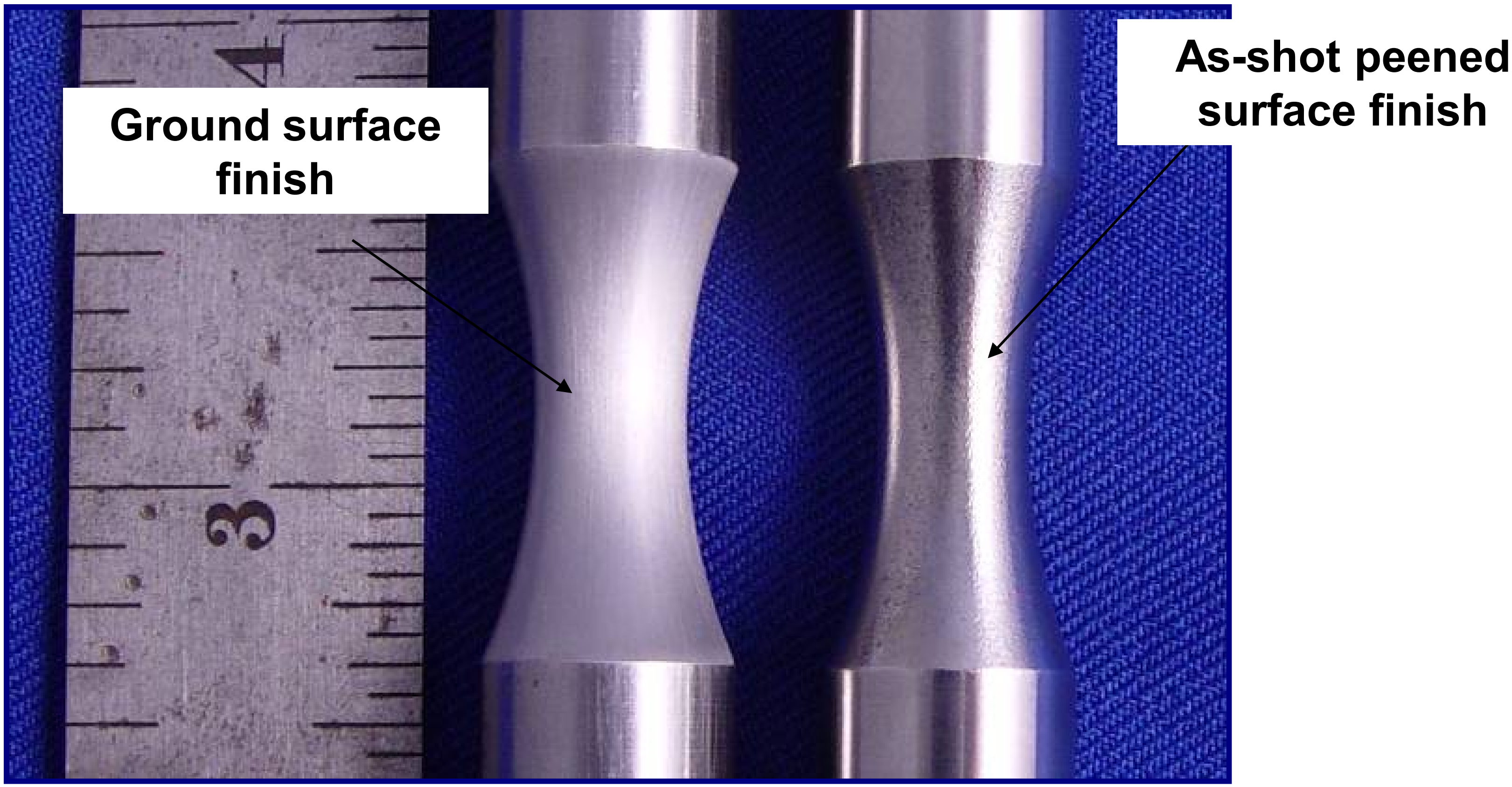
- Laser Shock Peening
  - Produces very deep compressive residual stresses
  - Large stand-off distances convenient for irregular geometry
  - Essentially not used in high strength steels prior to this project



Technical Progress - LSP

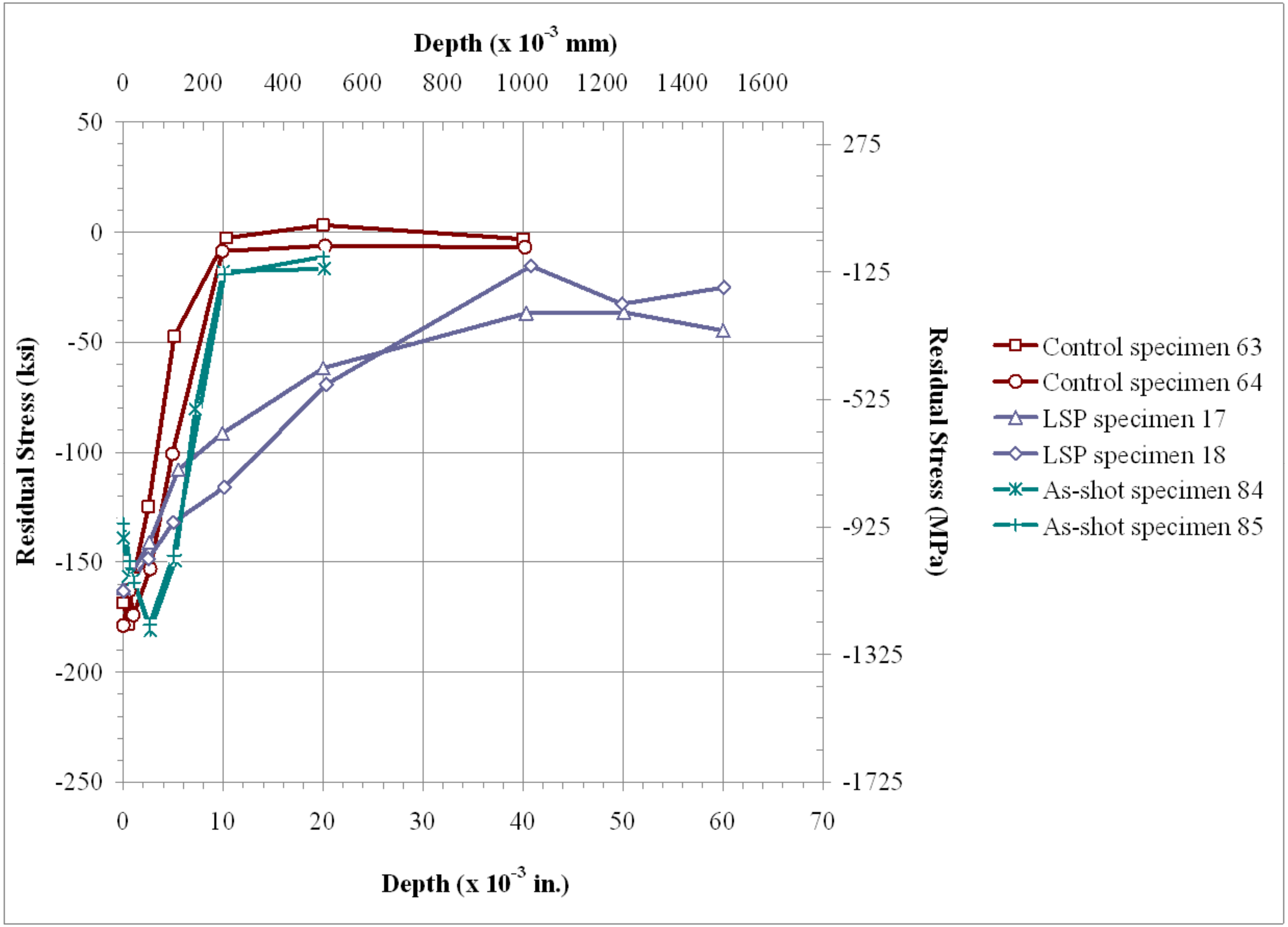
- LSP was expected to produce deep compressive stresses therefore unlike most surface peening methods post peening finishing can be used
- Rotating Beam Fatigue – tested at PNNL
  - 52100 Steel - 4 populations: 1) Control (ground), 2) LSP and ground, 3) as-Shot Peened, and 4) Shot peened and ground
    - Assumed that as-LSP roughness too high
  - A354 cast aluminum - three populations: 1) Control (ground), 2) as-LSP and 3) LSP and ground
    - Tested as-LSP to evaluate potential for peening areas that may not be accessible for post-peening finishing
    - Custom alloy prepared at PNNL
- Rolling Contact Fatigue – tested at Cummins Inc.
  - M50 bearing steel – tested 3 populations: 1) LSP and ground, 2) ground and 3) ground with finer finish
    - Observed a difference between population 1 and 2 where LSP was better than non-LSP; however, both were less than population 3
      - Attributed to finish where the production finish 3 was much finer than 1 and 2
    - Fourth population is being added; LSP and ground with finer finish

Alloy 52100 Steel Specimens Surface Finish Comparison

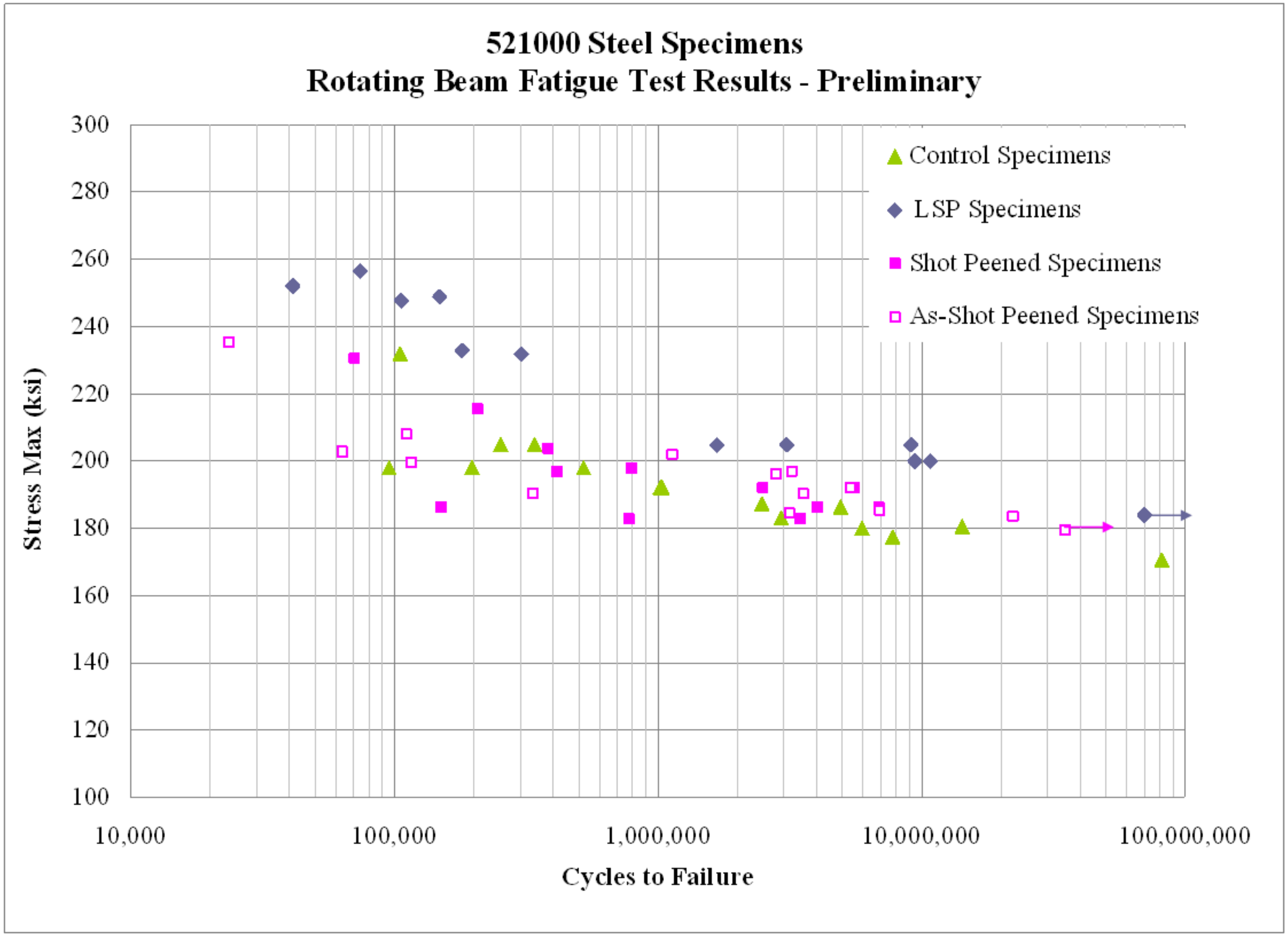


All samples ground after LSP have a ground finish similar to the control

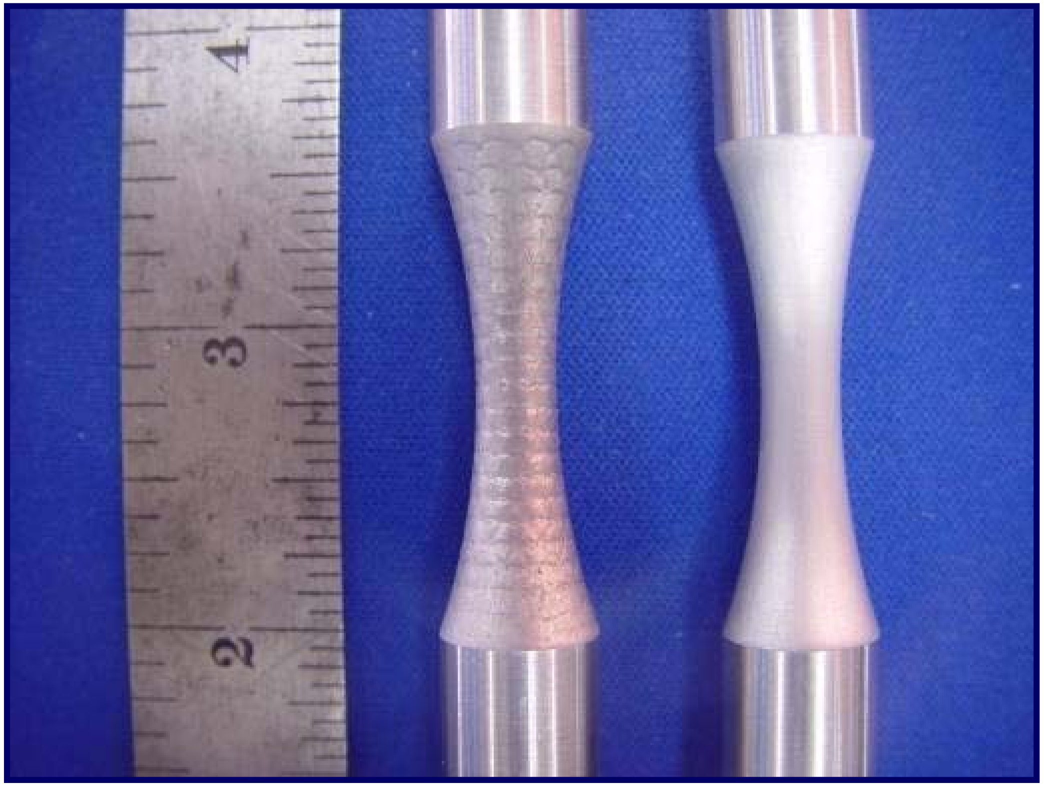
Longitudinal Residual Stress Distributions of Alloy 52100 Steel Specimens



Preliminary Fatigue Test Results of Alloy 52100 Steel Specimens

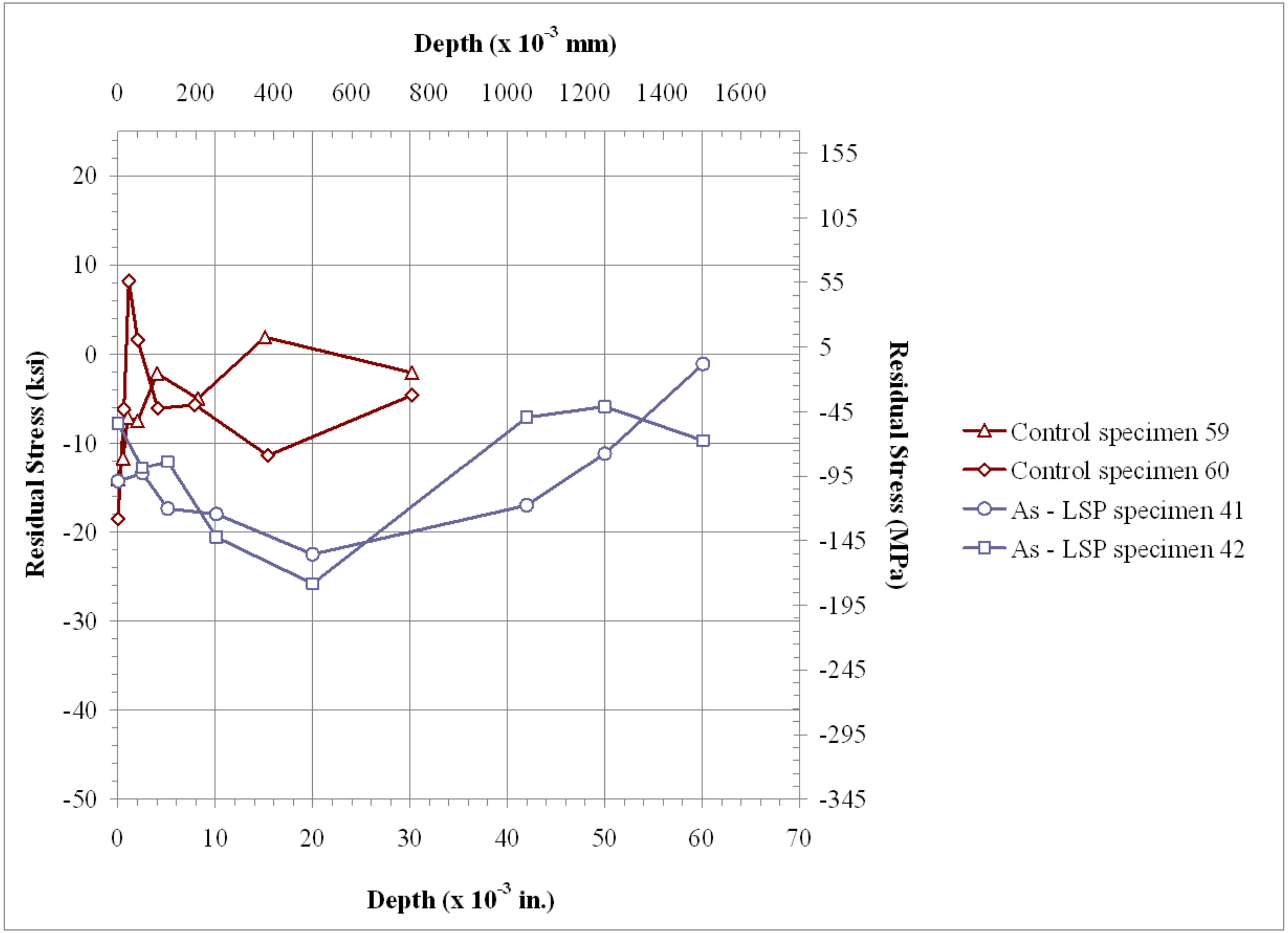


A354 Cast Aluminum Specimens Surface Finish Comparison

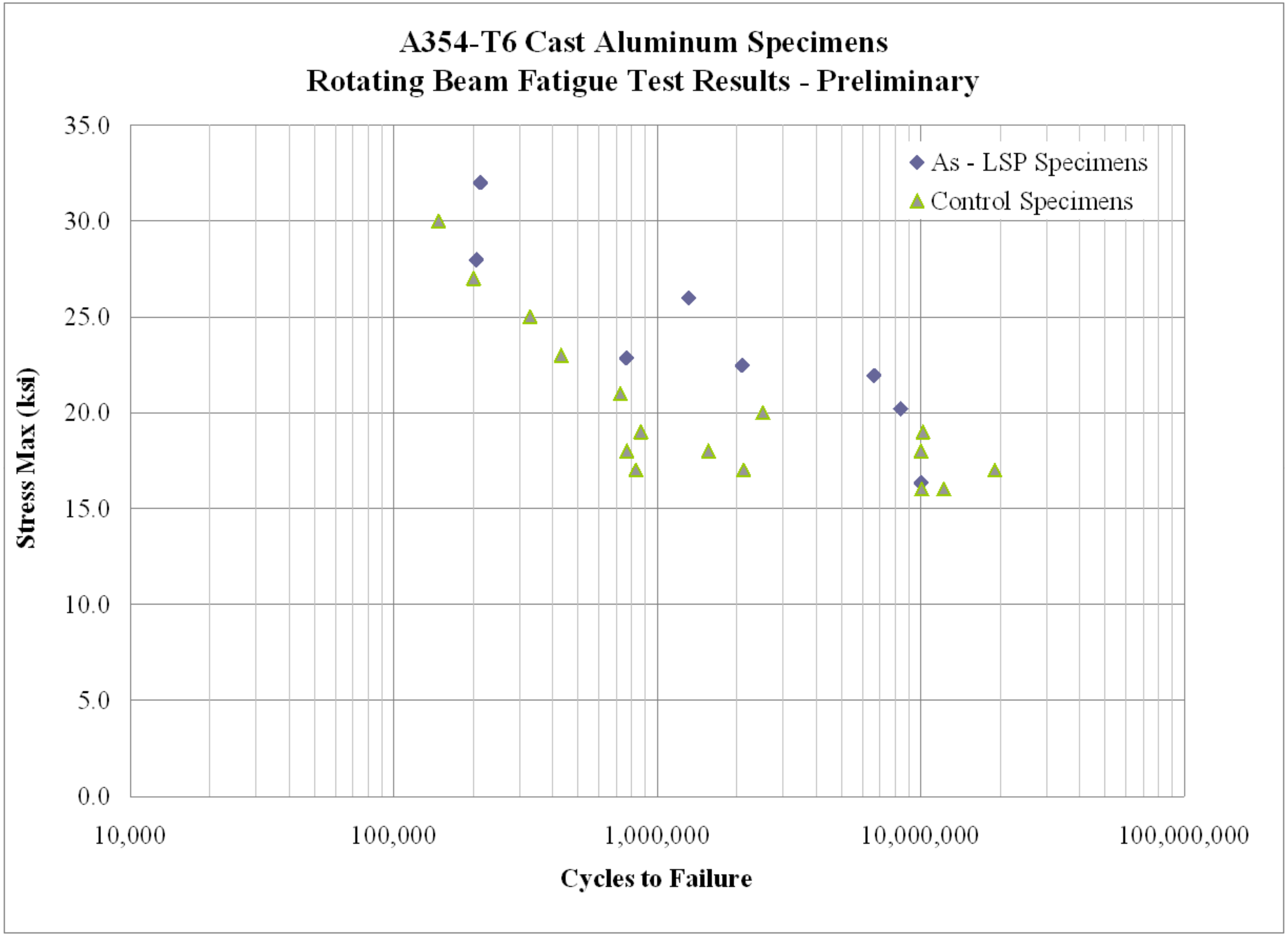


- Surface finish comparison of the as - laser shock peened (left) and the as-received ground (right) cast aluminum specimens
  - No final surface finish applied to LSP specimens
- Shock peened surface approximately 2.4 times rougher
  - 19 μin. vs. 8 μin

Longitudinal Residual Stress Distributions of A354 Cast Aluminum Specimens

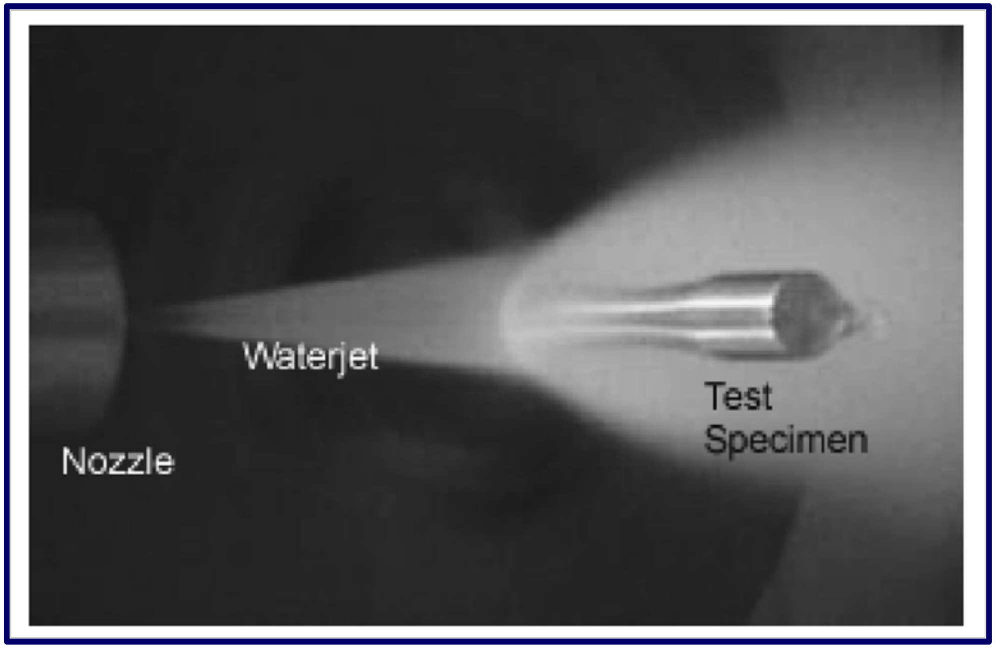


Preliminary Fatigue Test Results of A354 Cast Aluminum Specimens



Technical Progress - WJP

- Waterjet peening
  - Produces residual stress
  - Can improve finish
  - Large stand-off distances convenient for irregular geometry

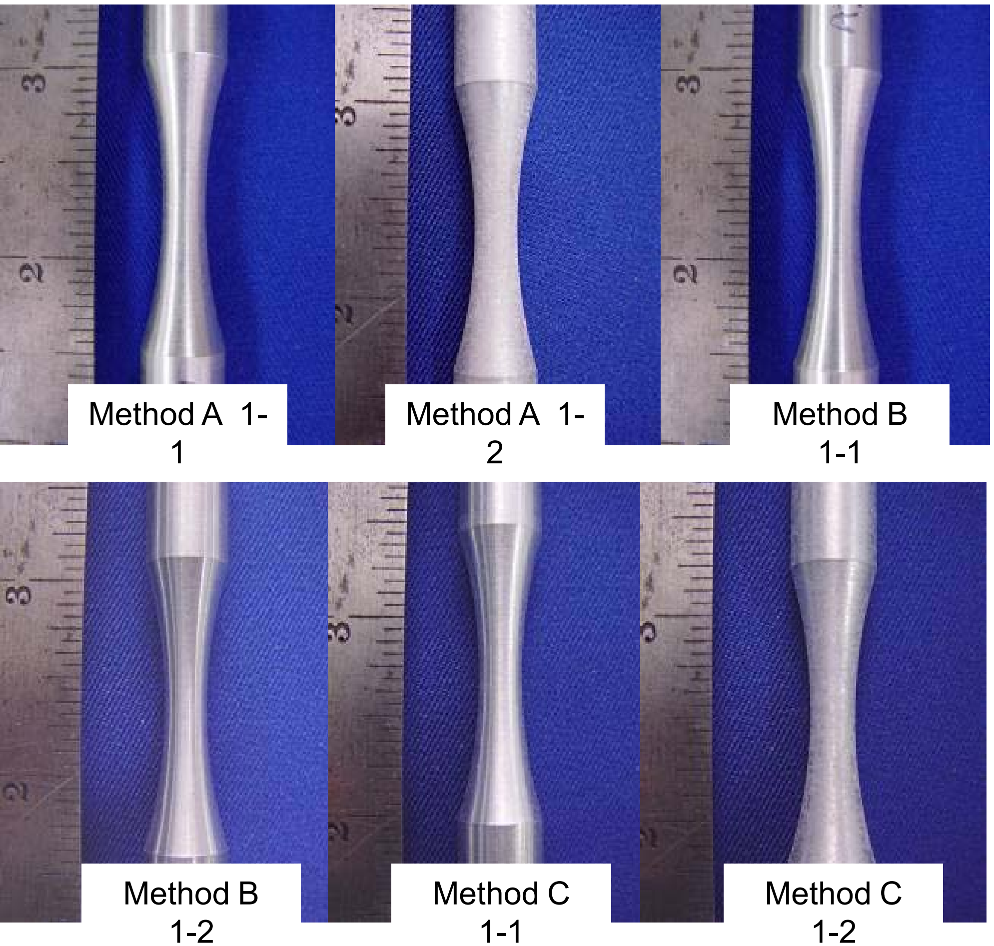


M. Ramulu et al, Fatigue Performance of High-Pressure Waterjet-Peened Aluminum Alloy, J. of Pressure Vessel Tech. Vol. 124 pp.118-123, 2002

Waterjet Peening of A354 Cast Aluminum

- Approach focuses on the use of waterjet technology for peening the A354 cast alloy to enhance its fatgiue life
  - Pre-Screening of waterjet methods to determine the best method to produce a set of samples for evaluation – methods A, B, C
  - A parametric study to determine the most optimum processing parameters from the most promising methodology will be evaluated by RBF
    - Pressure
    - Stand-off distance (the distance between workpiece and nozzle)
    - Speed/feed rate per unit area

Technical Progress - WJP



- Based on overall visual appearance, surface roughness, and surface residual stress
  - Methods A and C will subjected to further evaluation
    - Comparable compressive surface stresses (~35 ksi) and similar surface roughness were observed in specimens 1-1 for each respective method

Technical Progress - FSP of Cast Iron

- Cummins has initiated cast iron surface treatment project with South Dakota School of Mines and Technology under IUCRC grant (Leverages DOE and Cummins Inc. resources)
  - Completed procurement of PCBN-CS4 pin tools
  - Completed setting up the induction preheater - controller
  - Completed preliminary experiments on cast iron plates to identify the heating & cooling rates
  - Completed preliminary friction stir welding trials with CS4 pin tools

- PNNL initiating hybrid cast iron surface treatment and joining development using new PNNL FSW machine (high vertical force capability)
  - Induction coil purchased and installed
  - Microstructural analysis of friction joined cast iron parts in progress
    - Developing fundamental understanding of structures formed and optimization of the microstructure

Technical Progress

- Technology Deployment
  - Cummins Inc. has identified a series of components for full scale evaluation of LSP that obviously cannot be discussed here
  - Cummins Inc. has initiated work outside of the CRADA

Future Work

- Identify and test real components enhanced by LSP
  - To be done by Cummins Inc.
- Determine thermal stability of LSP induced compressive stresses in 52100 steel
- Complete RCF test matrix for LSP of M50 by evaluating peened and finer finish ground samples
- Complete RBF test matrix for LSP of A354 by evaluating peened and ground samples
- Down select waterjet peening method and complete RBF testing of cast aluminum alloy A354
- Perform friction stir joining screening trials of cast iron components

Summary

- Laser Shock Peening produces a residual stress that is deep enough for post-peen grinding
  - Combination of residual stress depth and surface finish would be very difficult to achieve with any other method
  - Will allow for increased fuel system performance and reduced mass reciprocating components without costly new materials and will enable new designs

- Promising results have prompted Cummins Inc. to move to Technology Deployment

- Fatigue life of Laser Shock Peened and ground 52100 steel showed significant increase in RBF life over the other populations
  - LSP enhanced fatigue over both low and high cycle fatigue ranges
  - Significant difference observed in fatigue life at high stresses among the four populations
  - As expected, the effectiveness of shallow peening methods like shot peening were removed by post peening grinding

- As-LSP fatigue life of cast aluminum alloy A354 was better than as-polished in spite of relatively rough finish
  - Deep stresses at nearly 70% of compressive and tensile yield strength
  - Greater than 20,000 psi at 0.020” depth should allow for polishing or machining while retaining residual stress

Summary, cont.

- Waterjet peening can produce surface compressive residual stresses while maintaining surface finish
  - More complete matrix to be initiated based on preliminary results
- Friction Stir Processing/Joining of cast iron is difficult and new developments will be required