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# Effects of Laser Peening, and Shot Peening on Friction Stir Welding



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# Outline

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- **Background**
- **Friction Stir Welding (FSW)**
- **Microstructure**
- **Laser & Shot Peening**
- **Residual Stresses**
- **Tensile Behavior**
- **Fatigue Life & Surface Roughness**
- **Fatigue Crack Growth**
- **Benefits**

# FSW Background

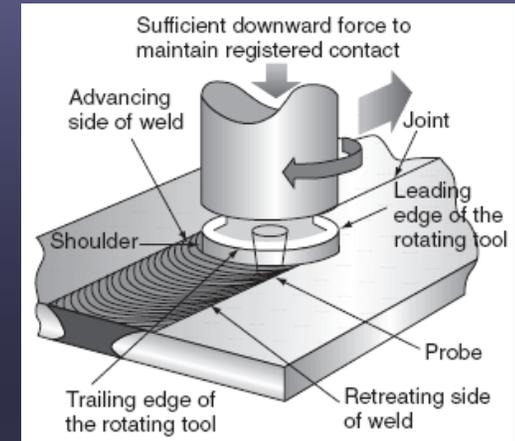


- **Friction Stir Welding (FSW) uses frictional heating combined with forging pressure to produce high strength bonds**
- **Attractive for aerospace applications**
  - Can result in considerable cost and weight savings, by reducing riveted/fastened joints, and part count
  - Can weld metals that are difficult to weld with conventional methods
    - Space shuttle external tank
- **Although residual stresses in FSW are generally lower when compared to conventional fusion welds, recent work has shown that significant tensile residual stresses can be present in the weld after fabrication**
- **Residual tensile stresses in the weld can lead to:**
  - Faster crack initiation
  - Faster crack propagation
  - Could also result in stress corrosion cracking (SCC)

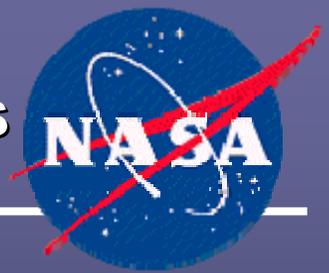
# Background



- **Nugget or the stirred zone**
  - The grain structure usually fine and equiaxed
    - Recrystallization from the high temperatures
    - Extensive plastic deformation
- **Thermo-mechanical affected zone (TMAZ)**
  - Less deformation and lower temperatures
  - Recrystallization does not take place
  - The grain structure is elongated, with some considerable distortions
- **Heat affected zone (HAZ)**
  - Unaffected by mechanical effects, and is only affected by the friction heat
- Use of FSW is expanding and is resulting in welded joints being used in critical load bearing structures



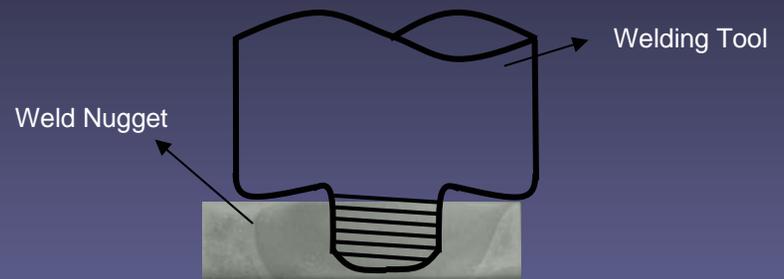
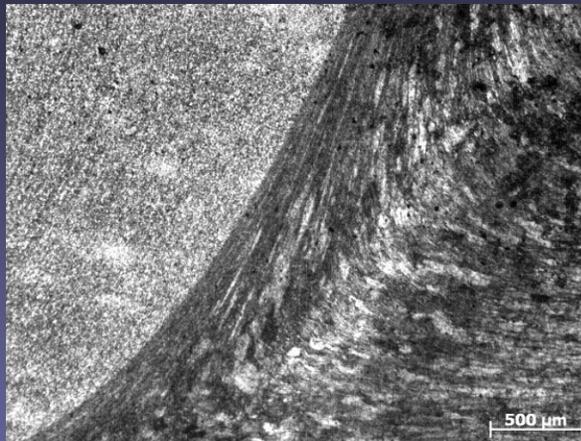
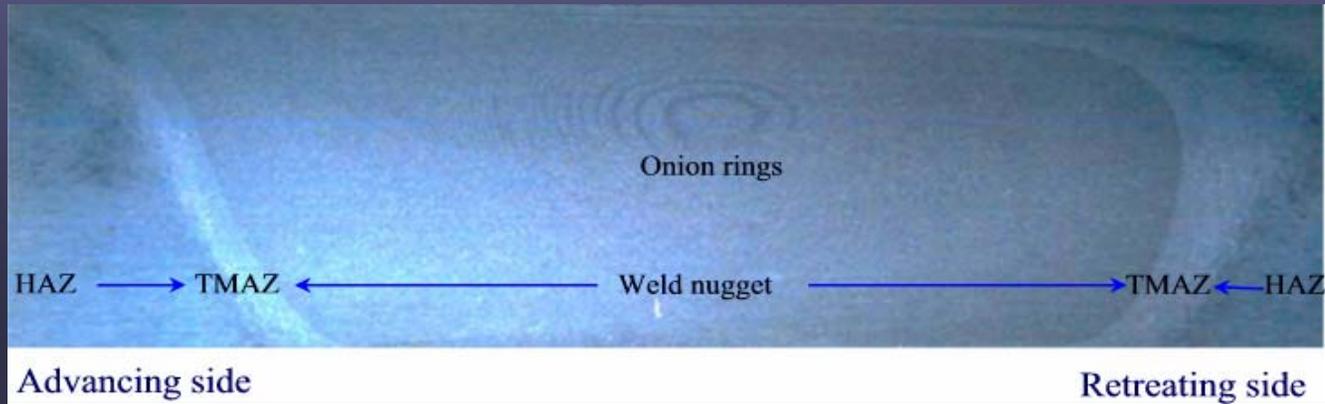
# Friction Stir Welding Test Specimens



- Aluminum Al-7075 specimens 122 cm x 40 cm x 0.635
- FSW specimens were made at the NASA- JSC using a 5-axis milling machine
- The plates were placed on the welding platform in a butt-weld configuration
- The welded plates were aged from the T651 condition to the T7351 condition in accordance with the SAE AMS-H-6088 requirements



# Microstructure of FSW



# Laser Peening

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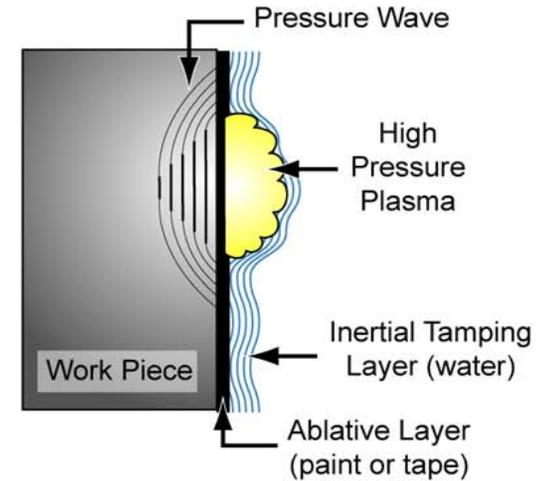
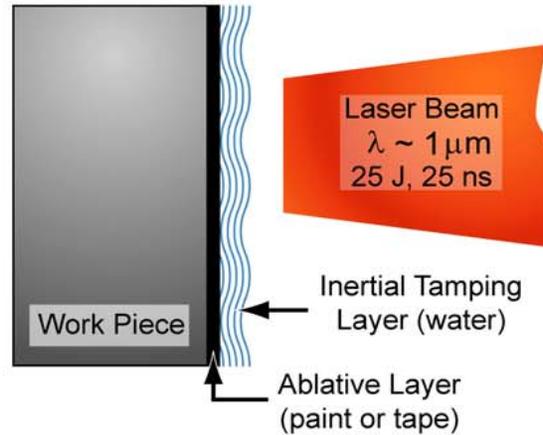
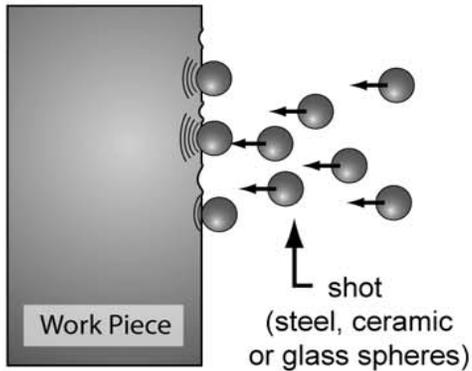
- Laser peening performed at Metal Improvement Company (Livermore-CA)
- The surface of the specimens intended for peening were covered with an aluminum tape 0.22 mm thick & tape was replaced between layers of peening
- The tamping layer consisted of an approximately 1mm thick laminar layer of flowing water
- A laser power density of 4 GW/cm<sup>2</sup> and 18 ns duration was employed
- Both faces of the fatigue crack growth specimens were peened

# Laser peening, a deterministic process, induces deep compressive stress to retard crack initiation and growth

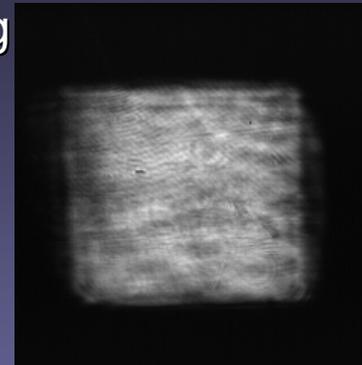
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- On a spot by spot basis ( typically 3 mm square) stress can be engineered for depth and surface intensity
  - Does not require physical contact with component
  - Strains the material with very short duration (25 ns) impacts
  - **Not a random stochastic process like shot peening**
  - **Indifferent to surface finish and surface geometry**
- Laser peening provides choices for system design
  - Enhances fatigue strength – thus performance
  - Eliminates Stress Corrosion Cracking (SCC)
  - Increases lifetime - reduces maintenance and replacement costs
  - Enables lighter weight components/structures

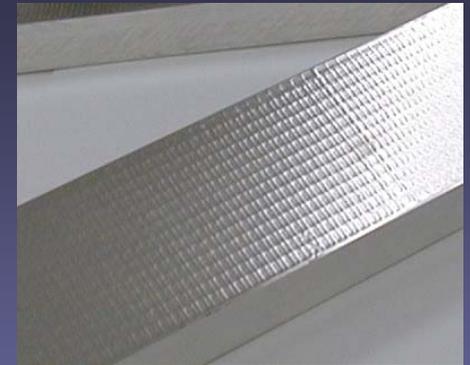
# Laser Peening Concept



- An extension of conventional peening
- Laser peening provides
  - Highly compressive surface residual stress
  - Deep layer of compressive residual stress
  - Smooth surface
  - Good process control



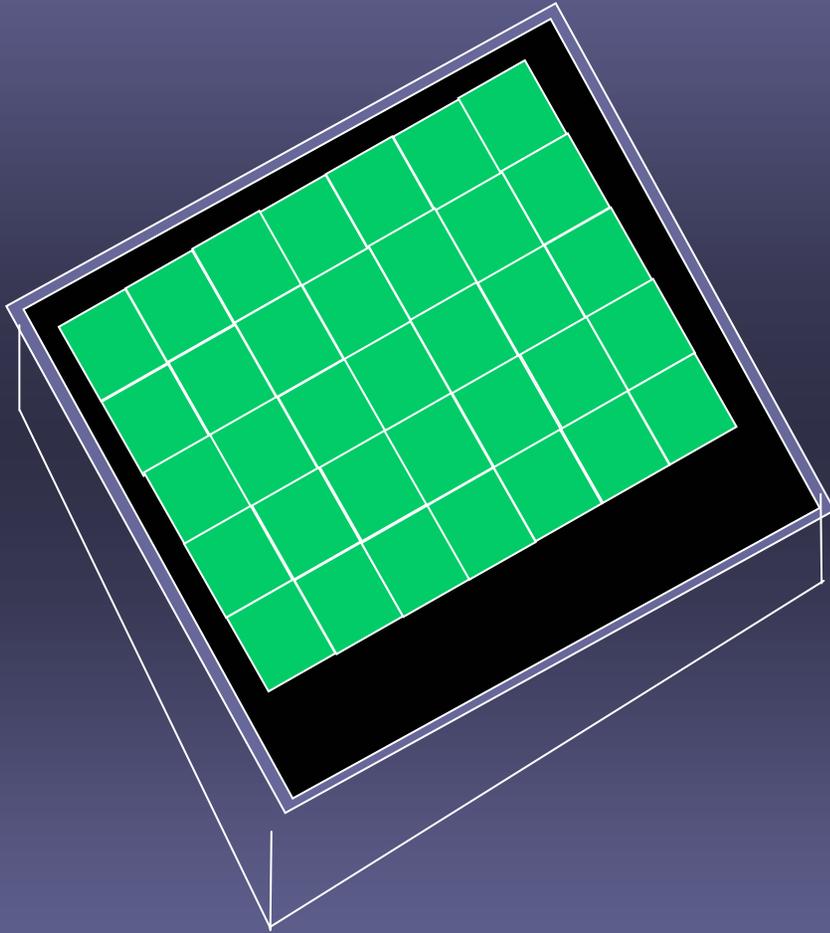
Laser near field image



Laser peened aluminum

# Laser Peening coverage build up

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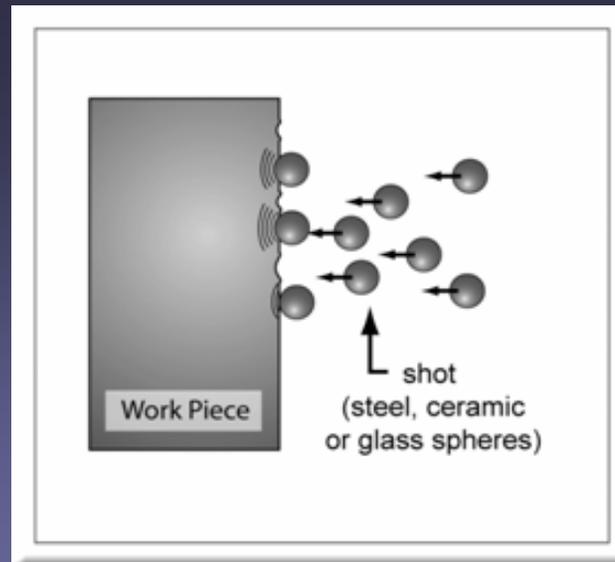


**Rectangular, highly uniform laser beam intensity distribution is coupled to the part using an optical delivery system that preserves the uniform intensity. Peening pulses are applied sequentially in complete rows without the need for re-coating the surface ablation layer**

# Shot Peening

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- To optimize the shot peening process, Peenstress which is a software developed at Metal Improvement Company was used
  - Based on this evaluation, the samples were shot-peened with 0.0234” glass beads, with an Almen intensity of 0.008-0.012A and 100% coverage

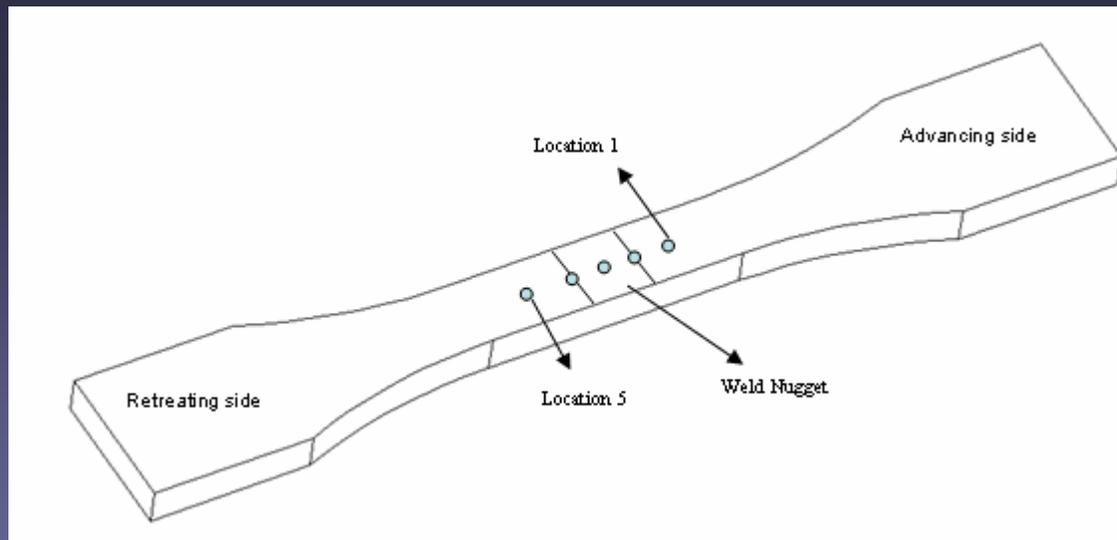


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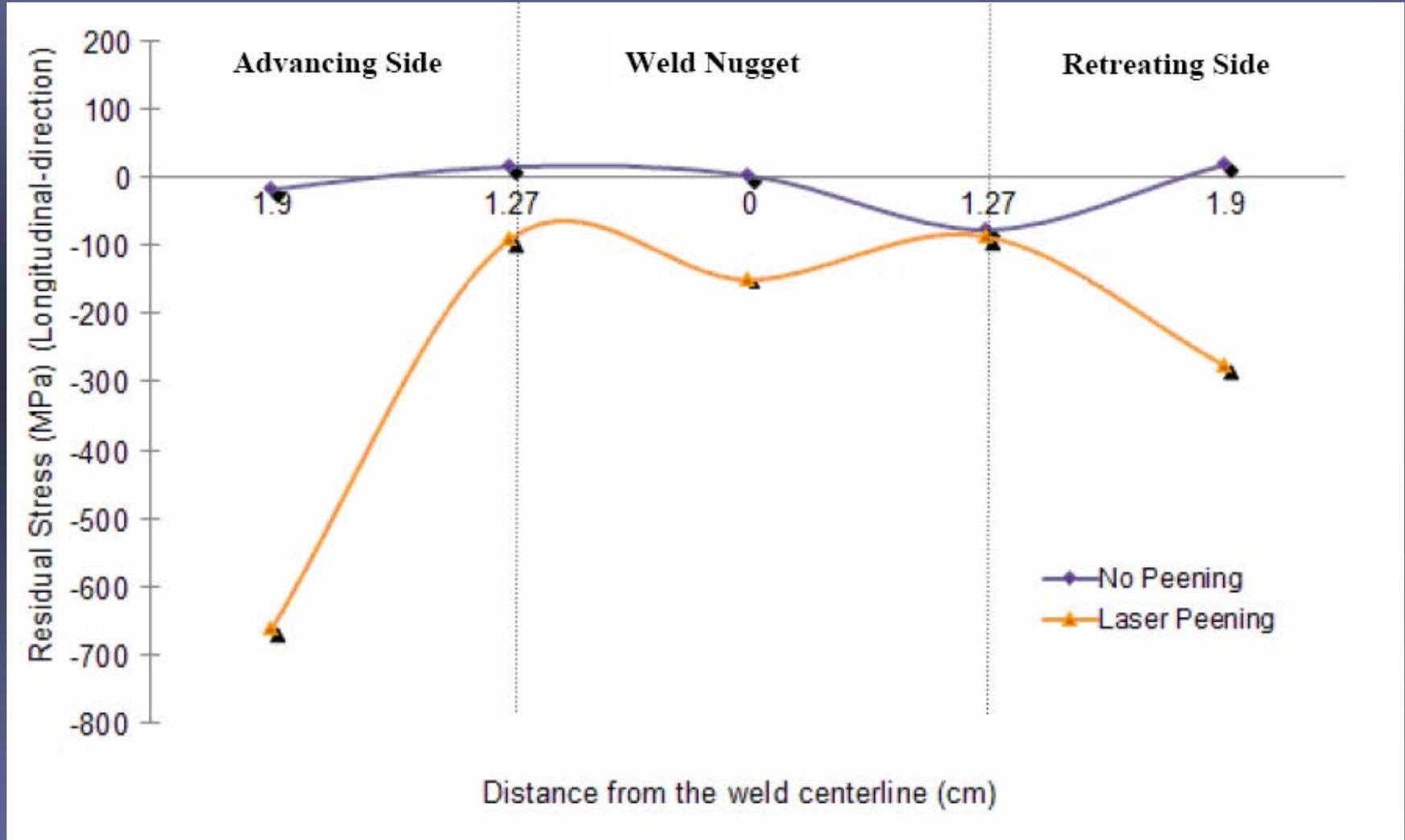
# Residual Stress

# Surface Residual Stresses Characterization for Peened Specimens

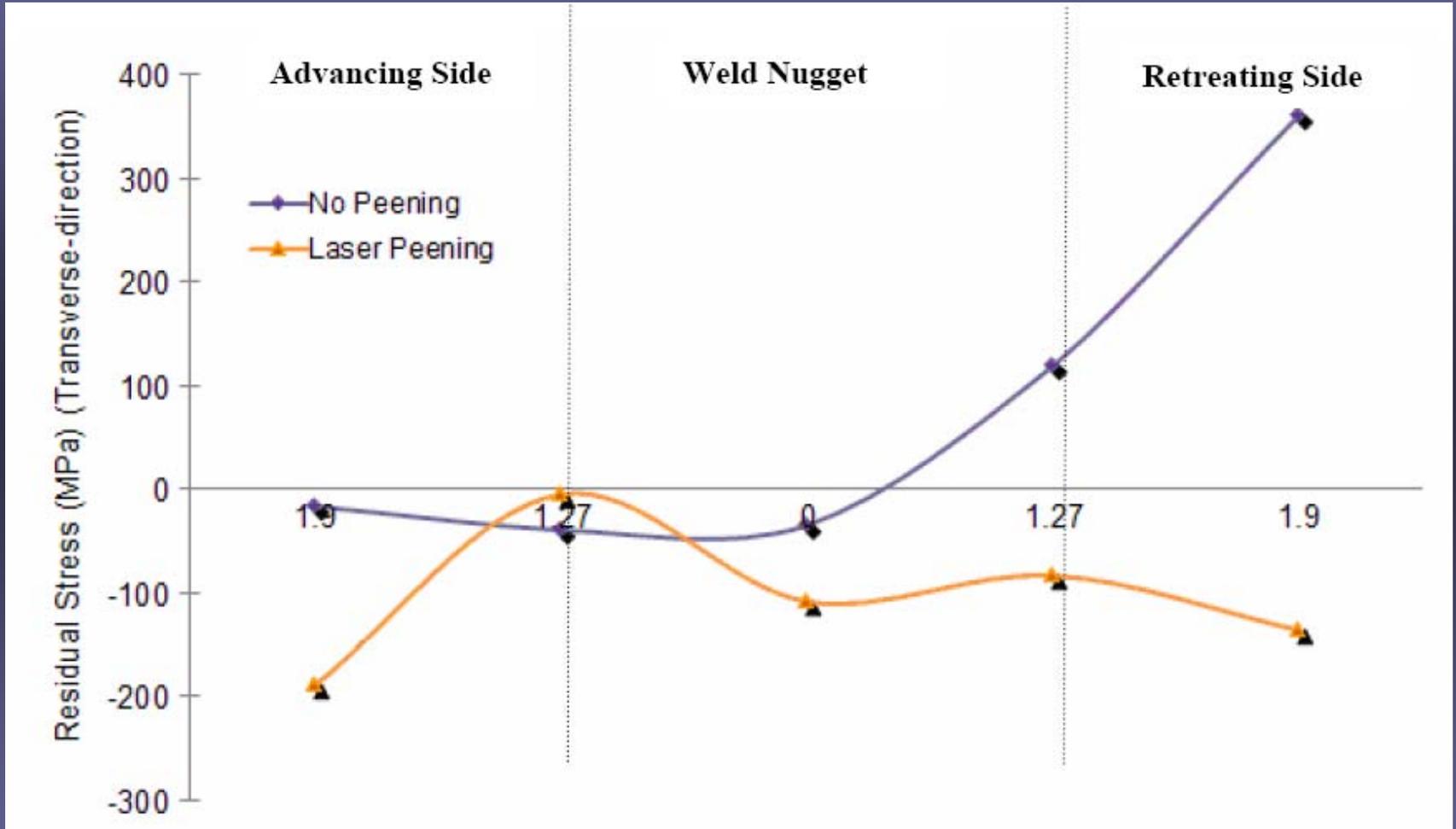
- The surface residual stresses for the peened FSW specimens were measured using an x-ray diffraction technique
- Residual stresses in both the transverse and the longitudinal directions were measured at five locations across the weld



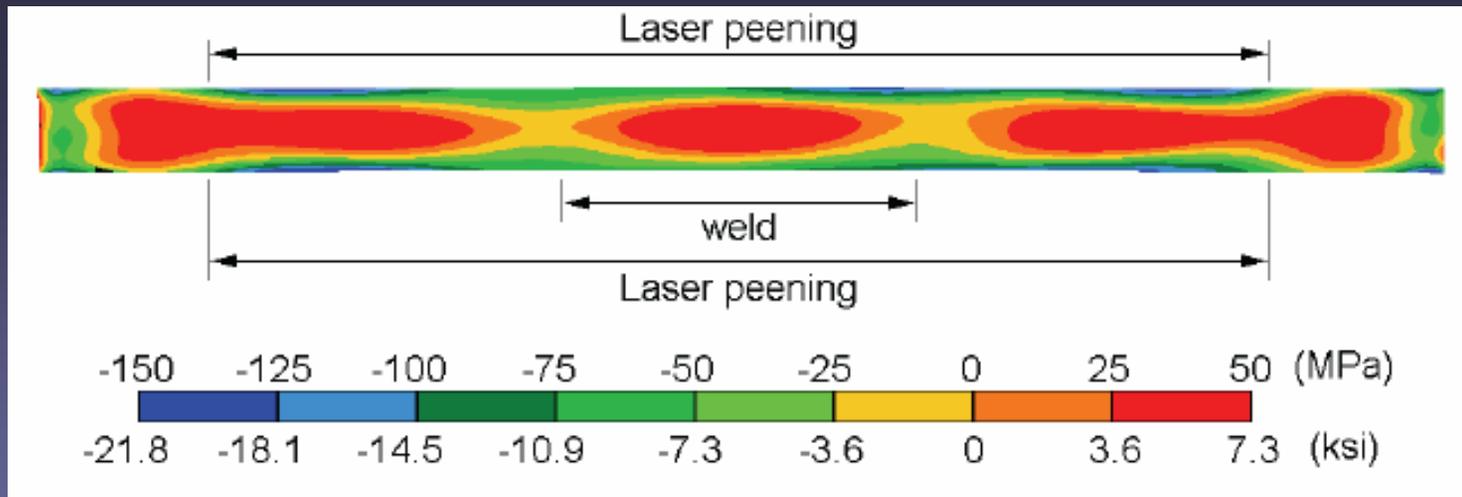
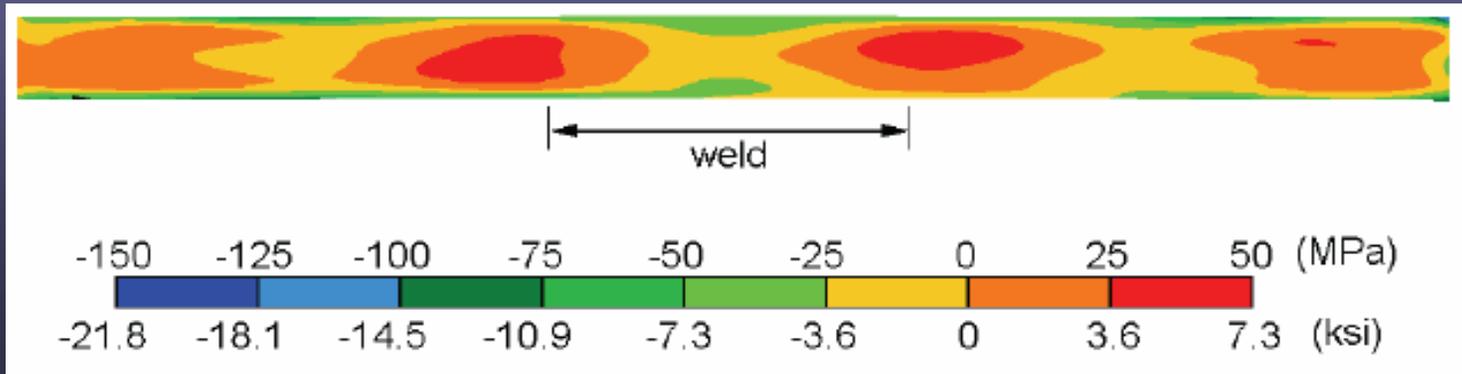
# Surface Residual Stresses (Longitudinal direction)



# Surface Residual Stresses (Transverse direction)



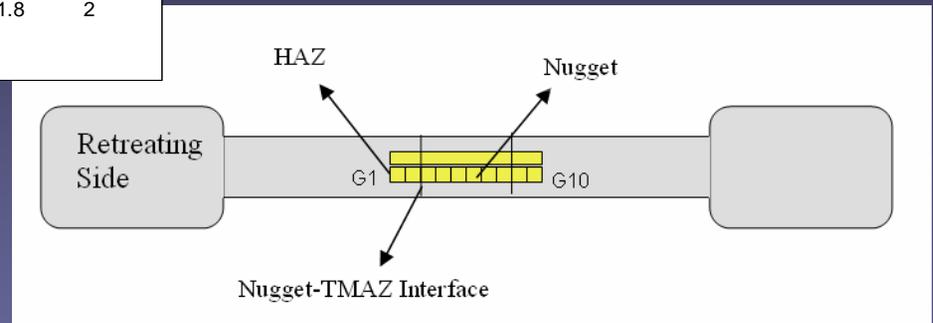
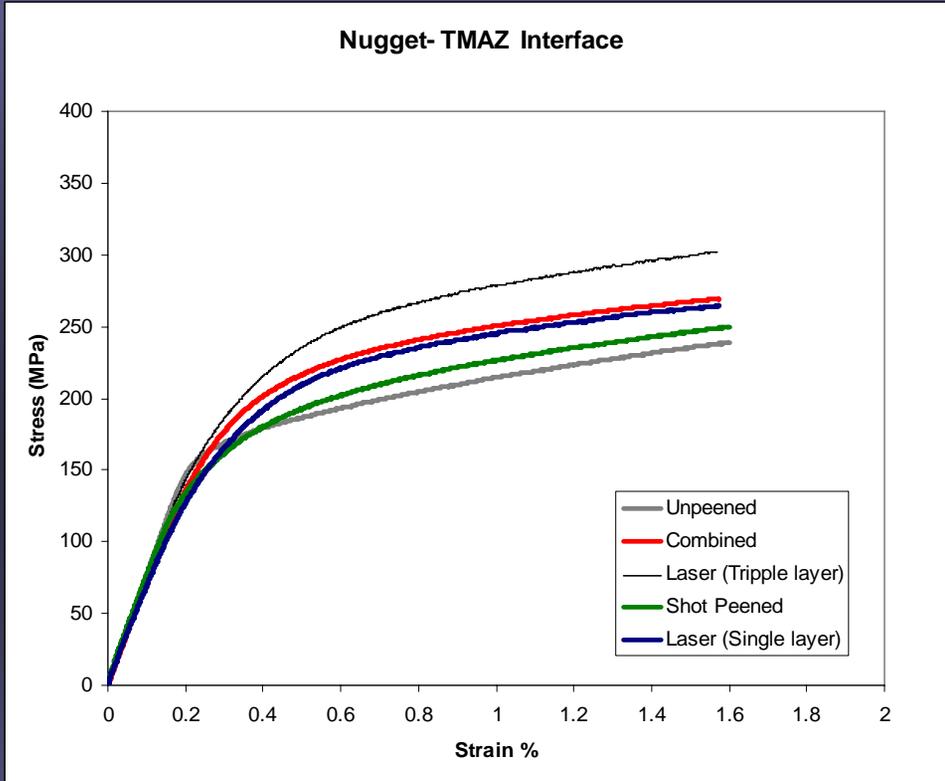
# Through Thickness RS (Contour Method)



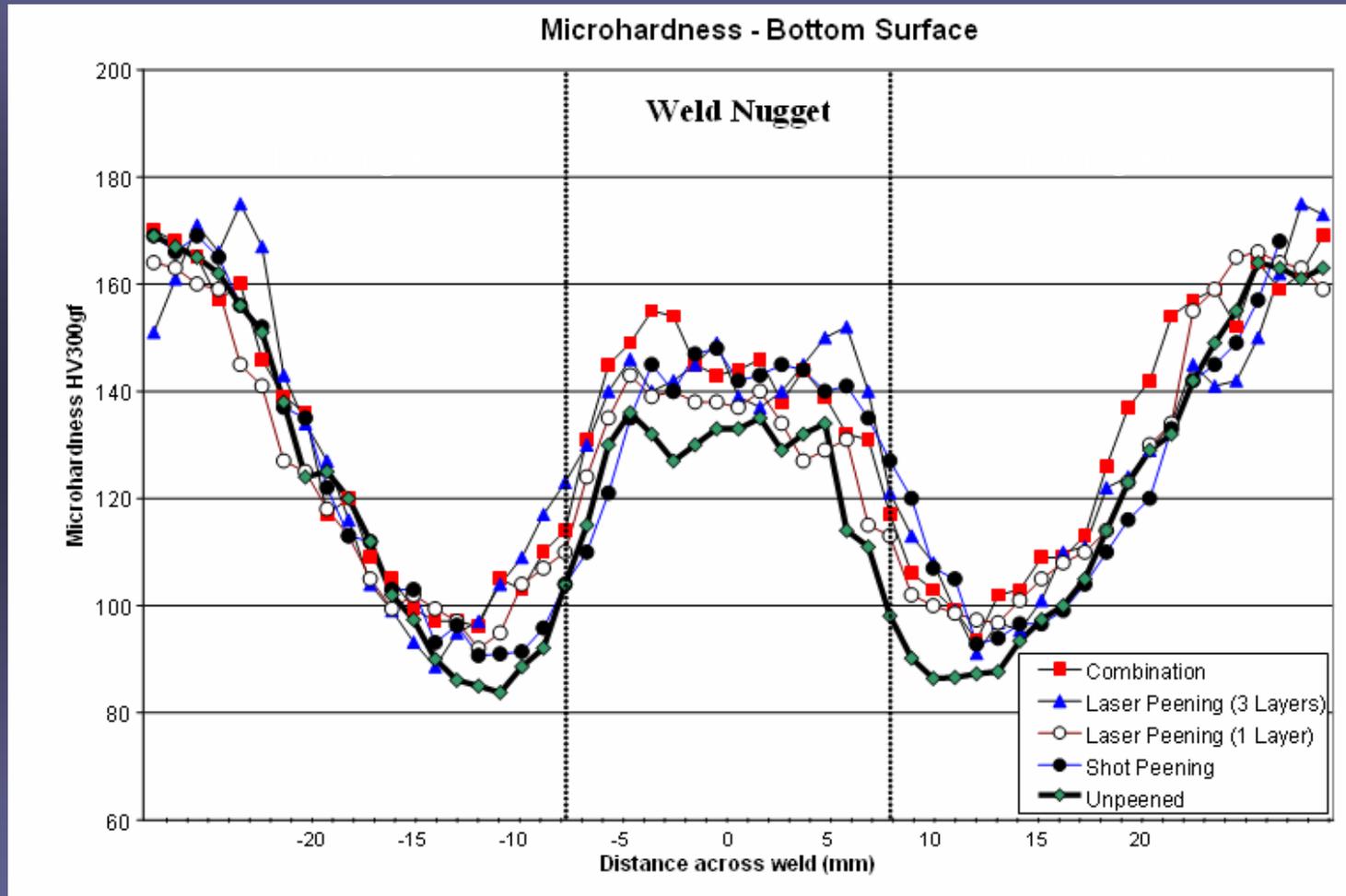
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# Tensile Behavior

# Tensile Behavior



# Microhardness



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# Fatigue Life

# Experimental Procedures

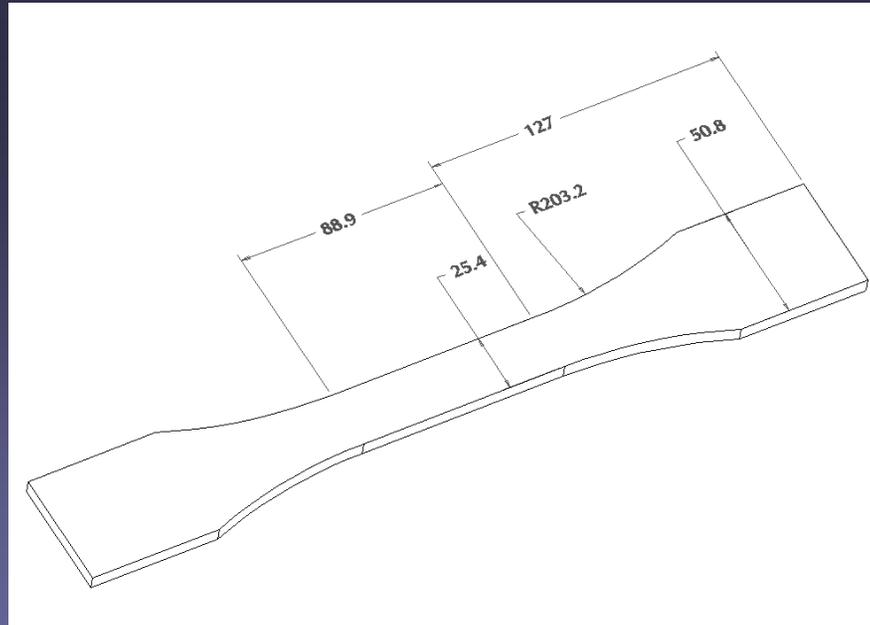
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- The fatigue testing performed under axial loading at constant amplitude at room temperature
- The maximum stress level was 190 MPa with stress ratio  $R=0.1$  at frequency of 22 Hz
- Prior to the peening process, the specimens were milled on the top side of the weld removing about 0.4 mm of material
- The coupons were oriented with weld in the center and the load applied perpendicular to the weld direction
- Several peening conditions were investigated
  - Laser Peening
  - Shot Peening
  - Combination (laser & shot peening)
  - Unpeened FSW material
  - Base unwelded material

# Experimental Procedures

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- Key laser peening parameters varied to optimize fatigue life
  - Peening intensity ( $\text{GW}/\text{cm}^2$ )
  - Duration (ns)
  - Number of layers



# Surface Roughness

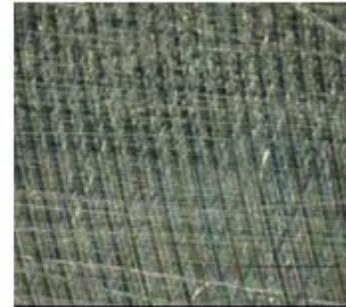
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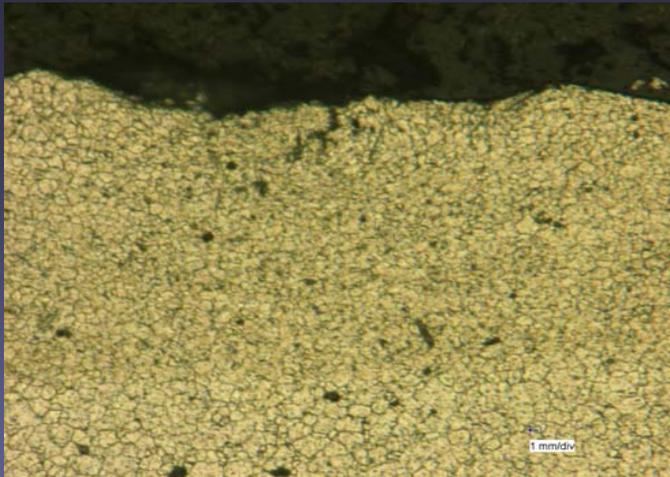
Base Material



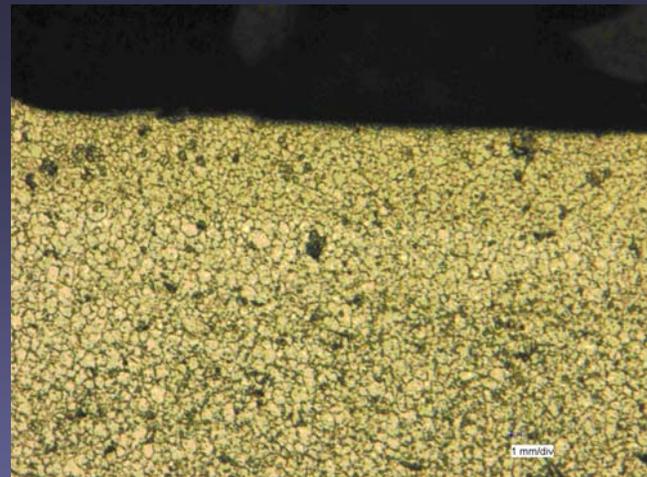
Shot Peening



Laser Peening



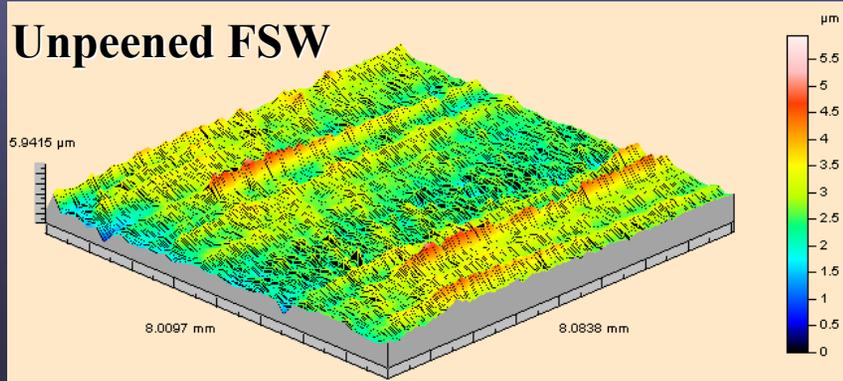
Shot Peening



Laser peening

# Surface Roughness

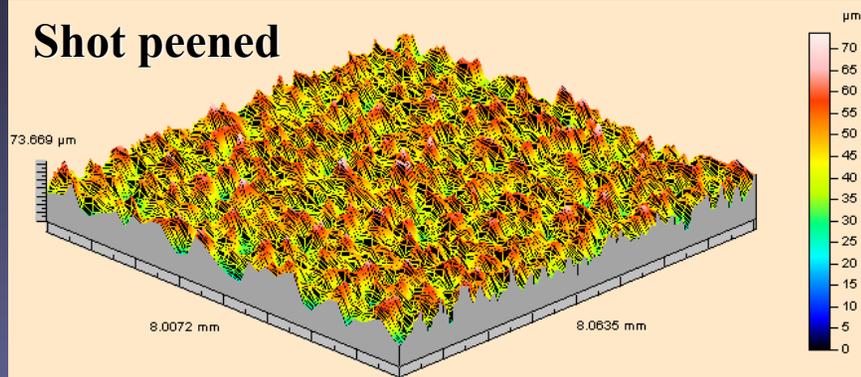
**Unpeened FSW**



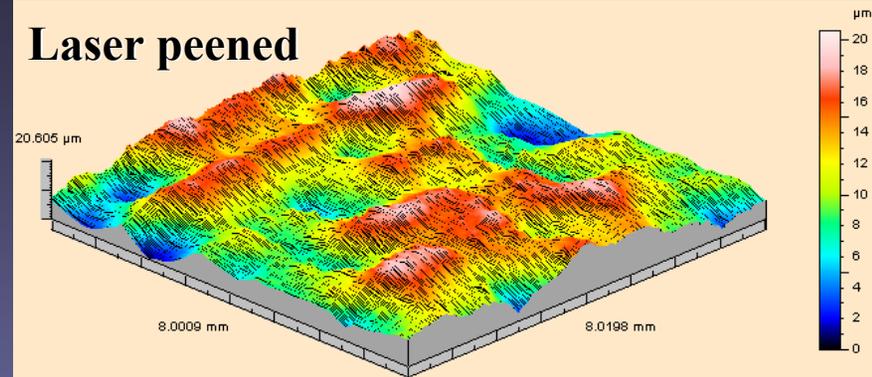
**Average and Peak surface roughness values**

Condition	Ra ( $\mu\text{m}$ )	Rt ( $\mu\text{m}$ )
Unpeened FSW	0.38	5.94
Shot Peened	7.59	73.7
Laser Peened	2.88	20.6

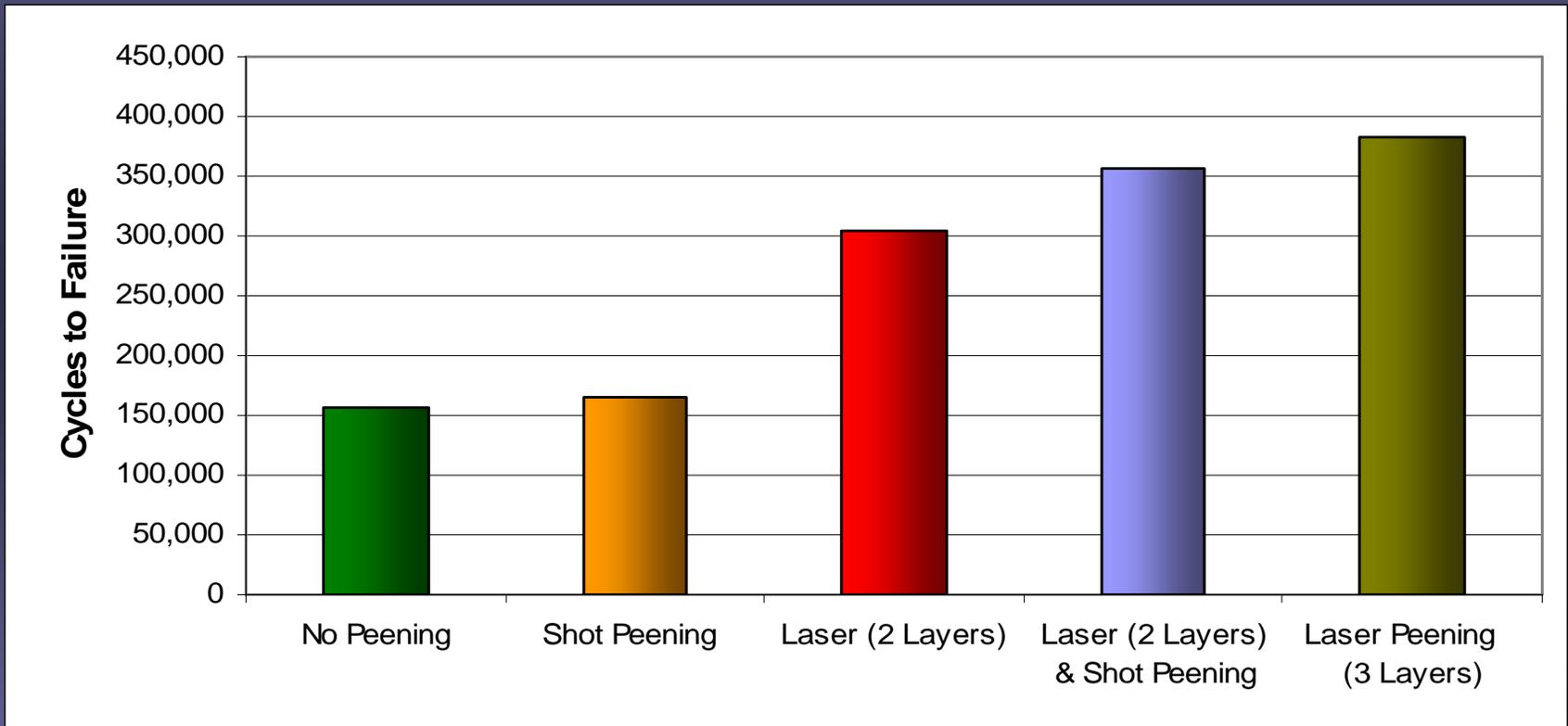
**Shot peened**



**Laser peened**



# Fatigue Life



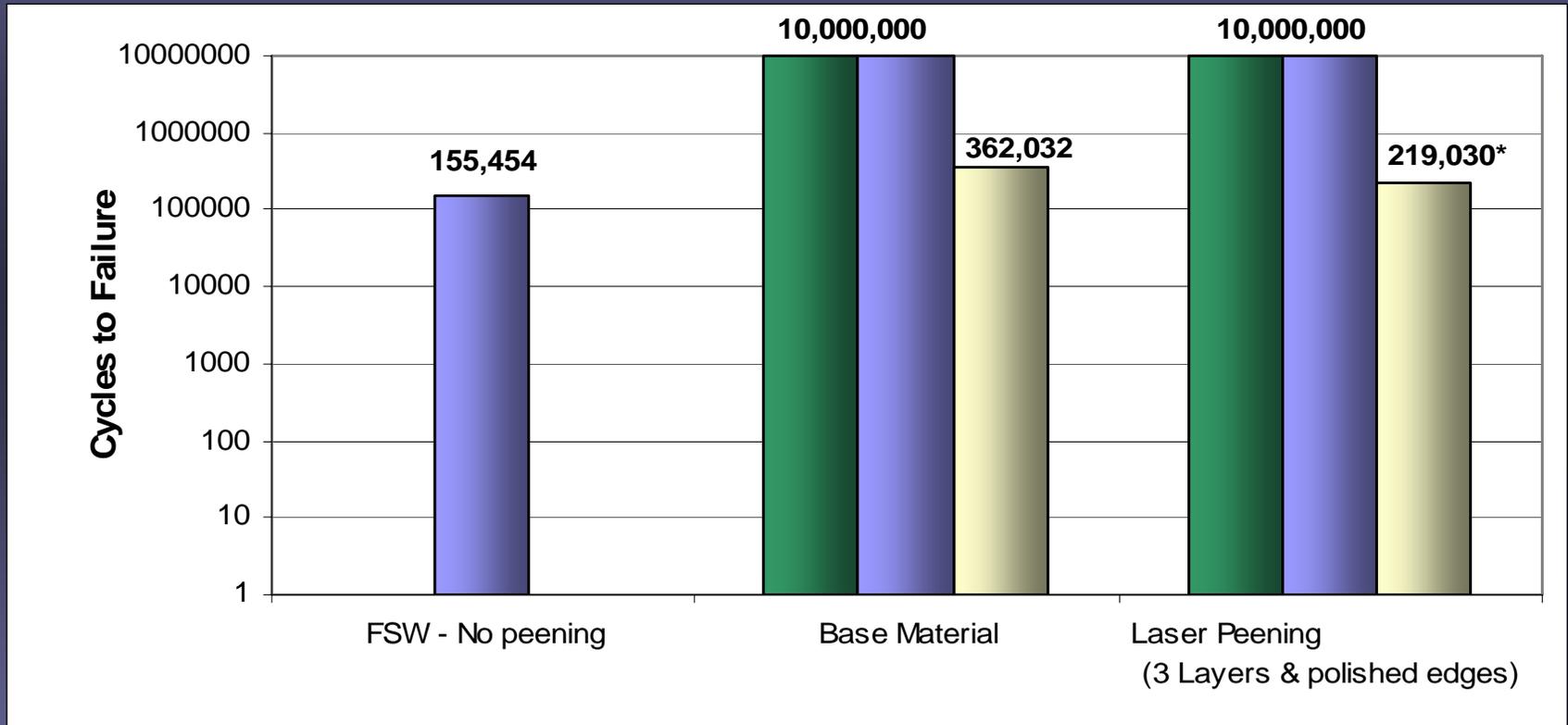
All samples were tested at a stress level of 190 MPa

# Fatigue Life

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- **It was noted from the fatigue tests that all laser peened specimens had cracks initiating at the edges, even though the corners of the specimen were rounded**
- **Therefore, it was decided to investigate the effect of the edge roughness on fatigue life of laser peened specimen**
- **A new set of laser peened samples was used in which the specimen's edges were hand polished after peening**
  - **A surface roughness similar to the unpeened samples was achieved**

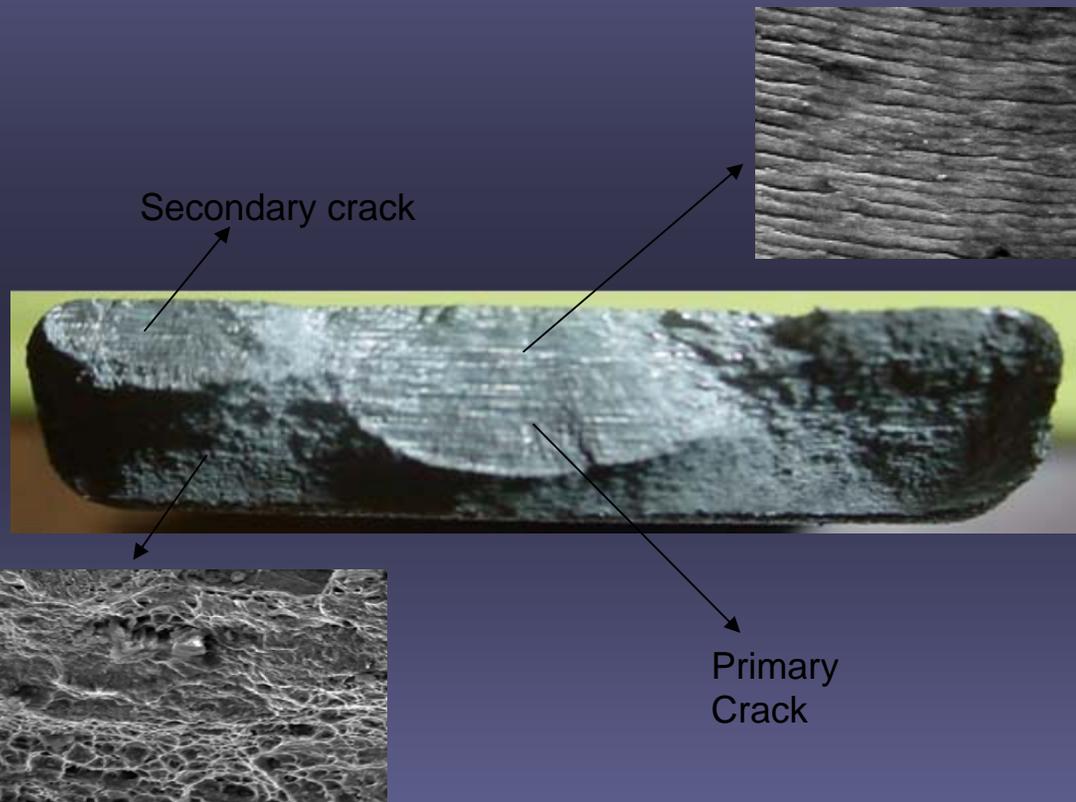
# Fatigue Life



\* Broke in the parent material away from the weld and peening zone

# Fracture Surface for a Shot Peened Specimen

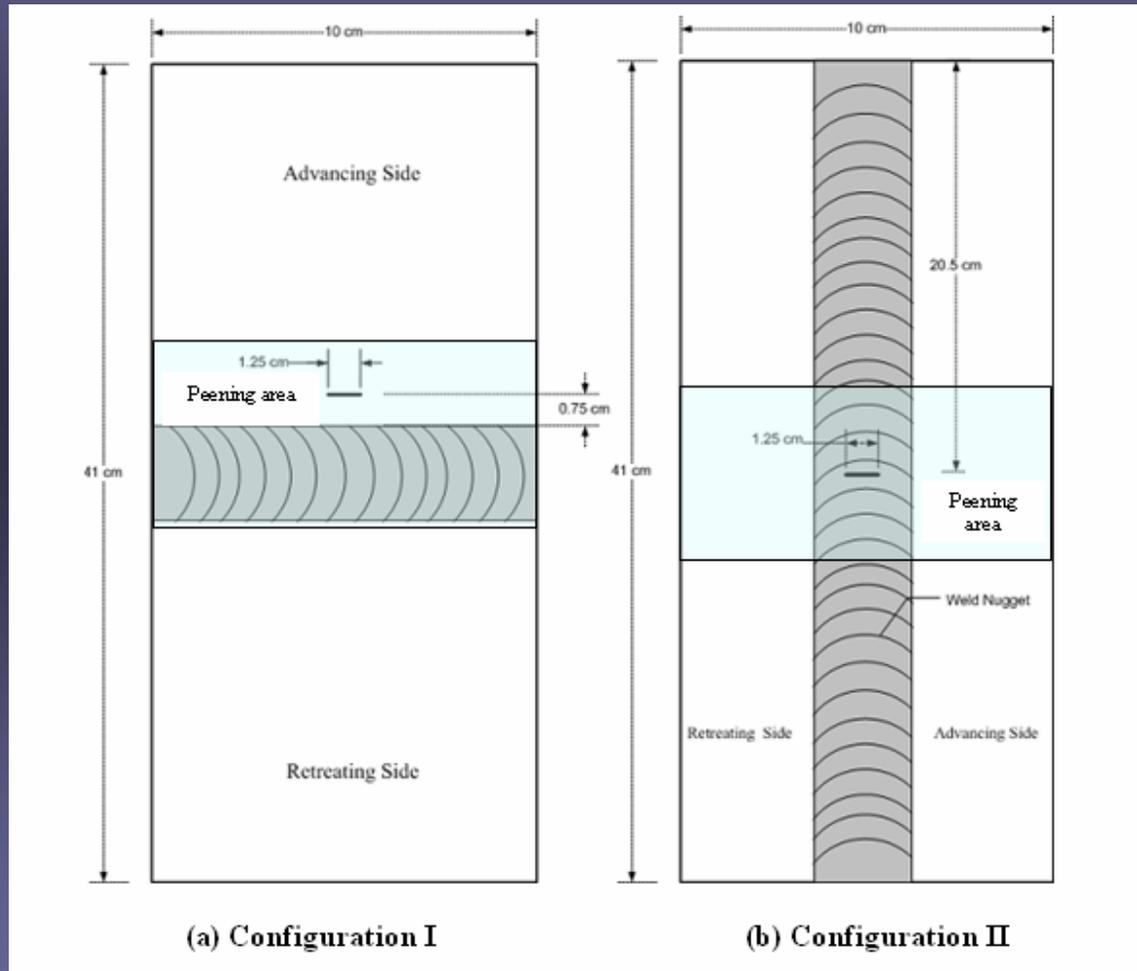
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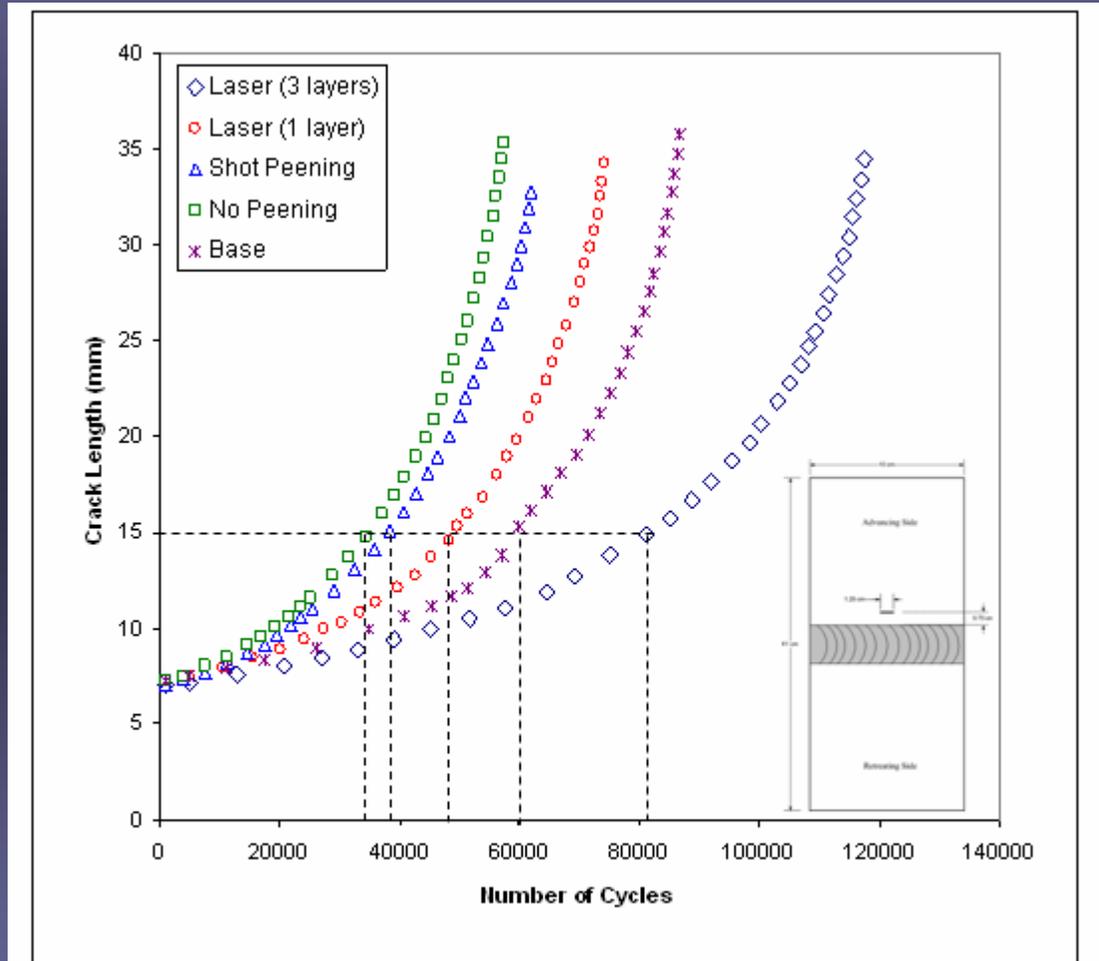
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# Fatigue Crack Growth

# Experimental Procedures



# Fatigue Crack Growth



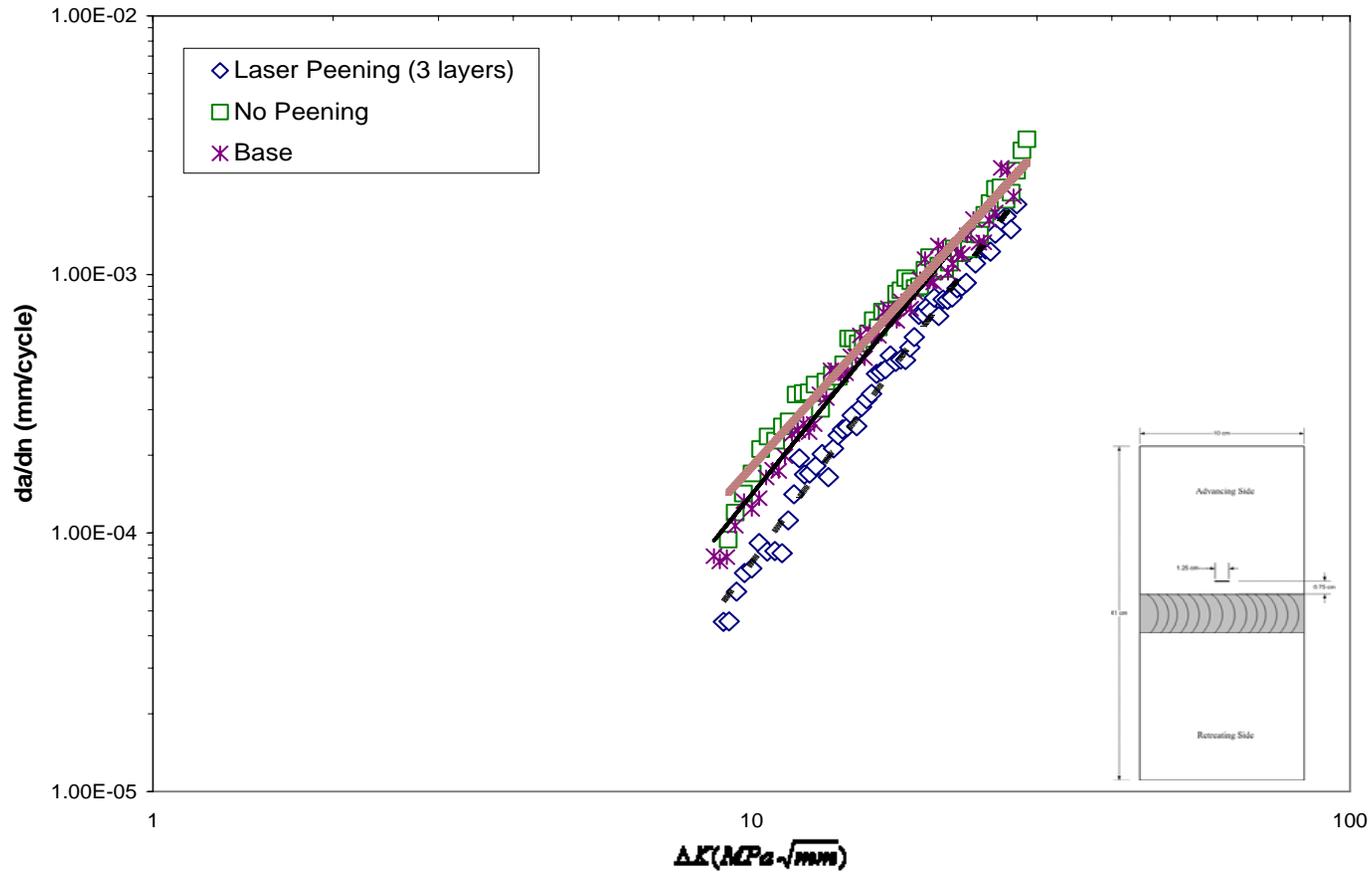
Results for crack length vs. number of cycles for FSW 7075-T7351 using Configuration I (T-L) Specimens

# Fatigue Crack Growth

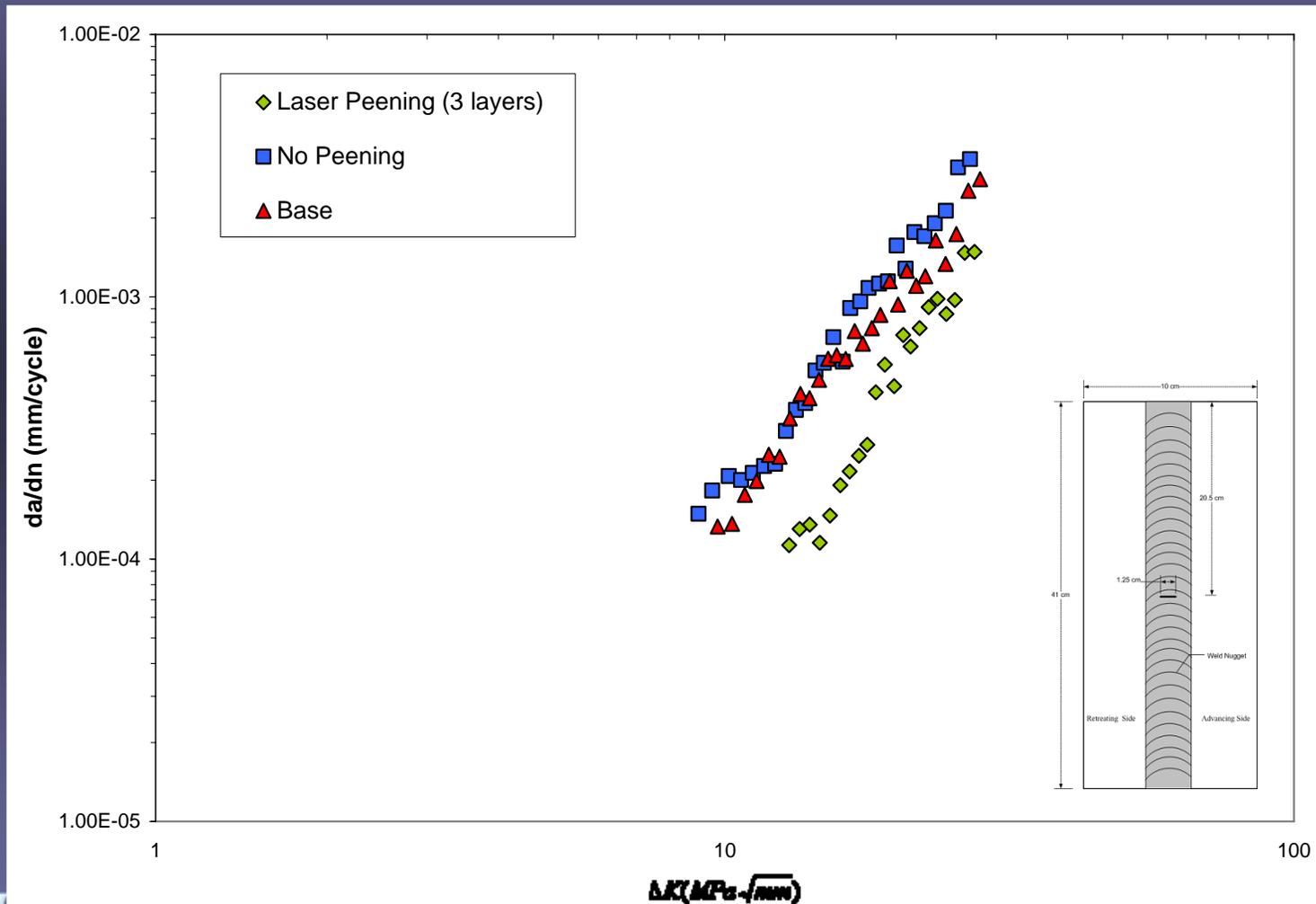
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- **Three layer laser peening significantly reduced FCGR compared to unpeened FSW specimens - especially at lower  $\Delta K$  values**
- **The differences in crack growth rates started to decrease and results started to converge at  $\Delta K > 20$** 
  - **This trend occurs because as cracks increase in length, the stresses are relaxed and crack growth rates reduced**
  - **This was attributed to the fact that residual stresses were leveled off by a large plastic zone ahead of the crack**
- **Noted that the unpeened FSW specimens had a higher fatigue crack growth rate when compared with the base material.**
  - **microstructure in the HAZ corresponds to one of an overaged structure**
    - **The resistance to fatigue crack growth should decrease in microstructures that are overaged**
  - **Difference in FCG between the FSW and the base material could also be due to the contribution from residual stresses, and not the microstructure**

# Fatigue Crack Growth



# Fatigue Crack Growth



# Benefits

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- **The proposed investigation will result in considerable improvement to crack initiation, and propagation in FSW process**
  - *Longer hardware service life*
- **Improve space hardware safety**
  - *By producing higher failure tolerant hardware, & reducing risk*
- **Lower hardware maintenance cost**
  - *Longer hardware service life, and lower hardware down time*

*Application of this proposed technology will result in substantial benefits and savings throughout the life of the treated components*

# Publications From This Research

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- **Effects of Laser and Shot Peening on fatigue life in Friction Stir Welds. 9th International Fatigue Congress. Atlanta- Georgia 2006**

- **Effects of Laser and Shot Peening on fatigue Crack Growth in Friction Stir Welds. International Conference on Residual Fatigue Life and Life Time Extension of In-Service Structures. Paris- France 2006**

- **Laser and Shot Peening Effects on Fatigue Crack Growth in Friction Stir Welded 7075-T7351 Aluminum Alloy Joints. International Journal of Fatigue 2006. Accepted for publication**

- **Evaluation of Surface Residual Stresses in Friction Stir Welds Due to Laser and Shot Peening. Journal of Materials Engineering and Performance 2006. Accepted for publication**

- **Laser and Shot Peening Effects on Fatigue Life and Surface Roughness in Friction Stir Welded 7075-T7351 Aluminum Alloy. Fatigue and Fracture of Engineering Materials and Structures. Accepted for publication**

12/29/2006

**The Effects of Laser Peening and Shot Peening on Mechanical Properties in Friction Stir Welded 7075-T7351 Aluminum. Journal of Materials Engineering and Performance. Under review**

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