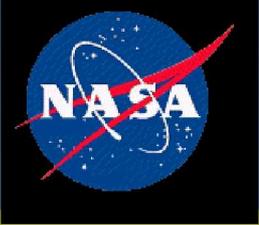




# *Laser Peening Effects on Friction Stir Welding*



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**NASA Johnson Space Center**



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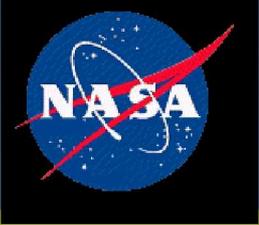
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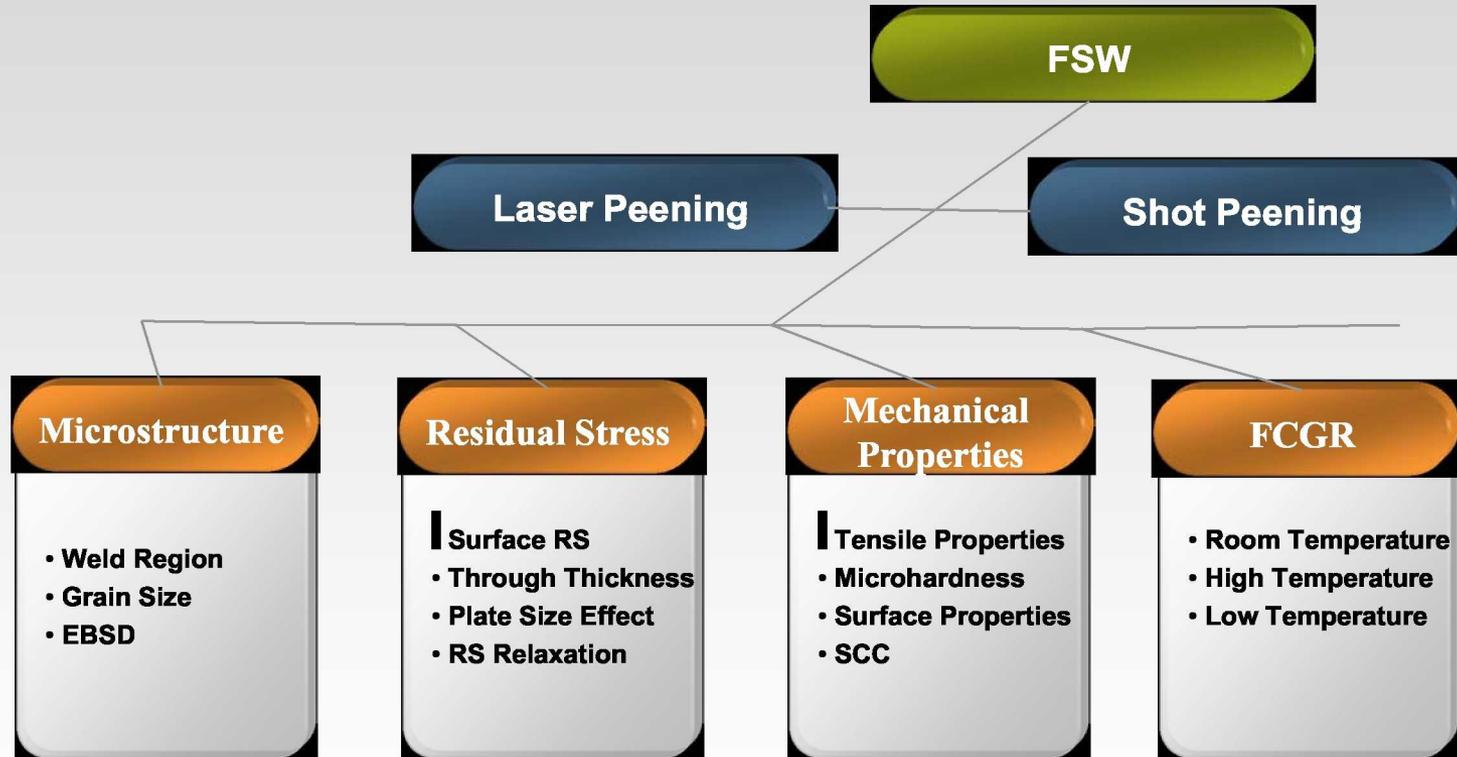
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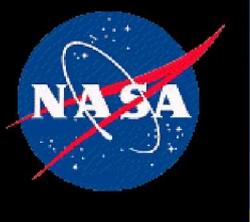
# Outline





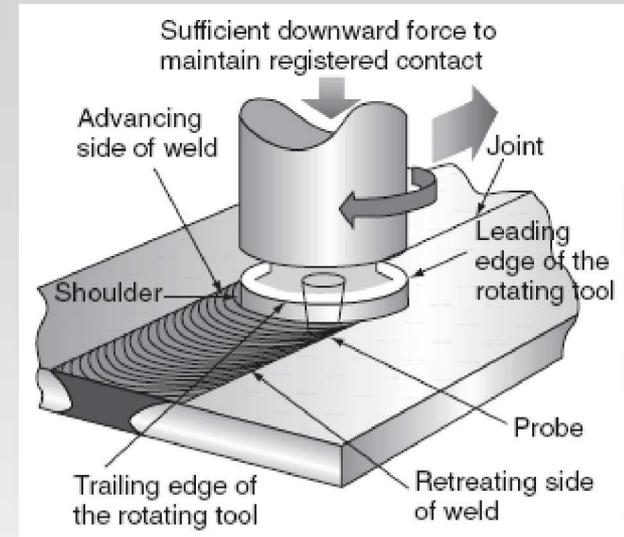
# Background

- Friction Stir Welding (FSW) is a welding technique that 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)
- Therefore, laser shock peening was investigated as a means of moderating the tensile residual stresses produced during welding



# 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)
  - Lesser degree of 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
- Therefore, laser shock peening was investigated as a means of moderating the tensile residual stresses produced during welding

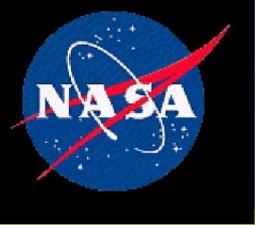




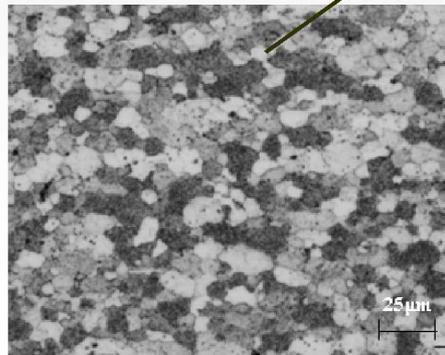
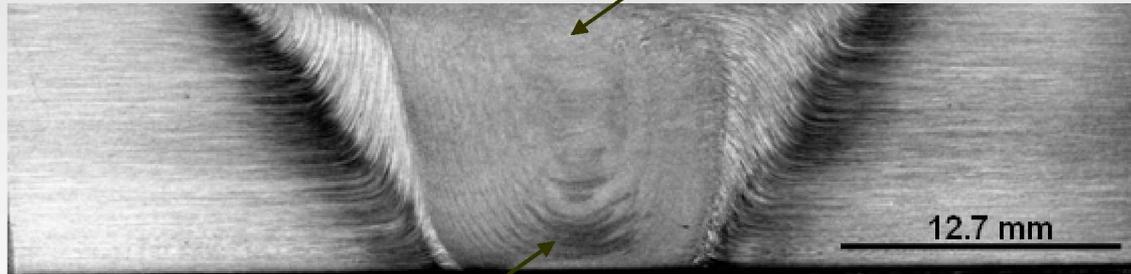
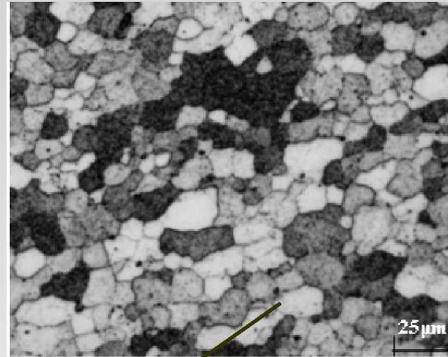
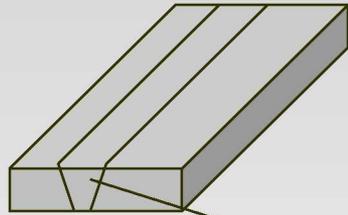
# Friction Stir Welding

- The alloy selected for this investigation was a 1.25 cm thick 2195-T8 aluminum lithium alloy.
- Possess many superior properties and is well suited for many aerospace applications due to its low density, high strength, and corrosion resistance.
- For the welding process, a rotational speed of 300 RPM in the counter-clockwise direction and a translation speed of 15 cm/min were used.
- The dimensions of the FSW panels were 91 cm x 30 cm x 1.25 cm.
- To verify the integrity of the weld, several bending tests using strip specimens were performed.
- The FSW specimens were inspected visually afterward with no crack indications revealed.



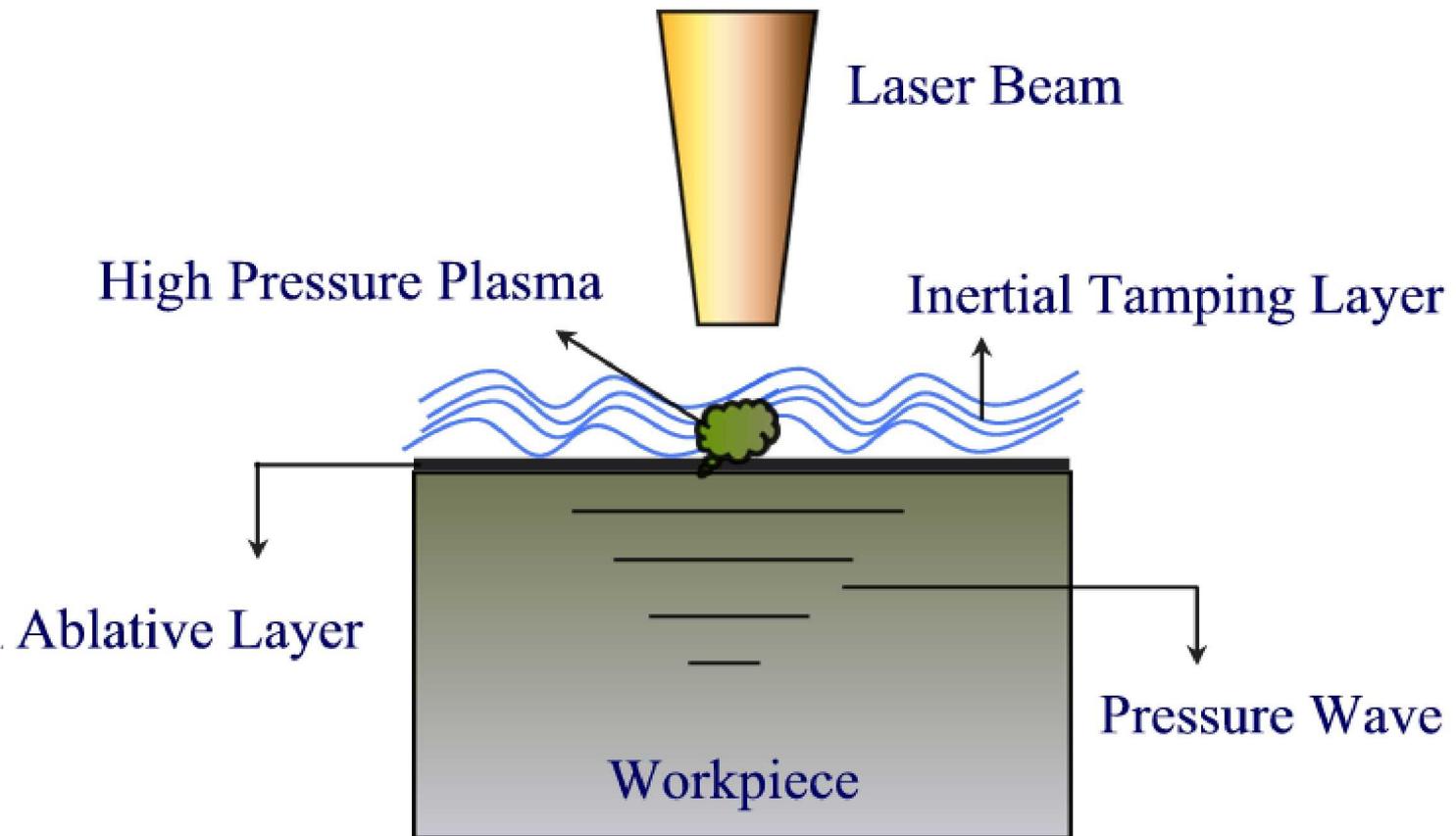


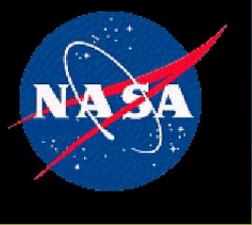
# Microstructure



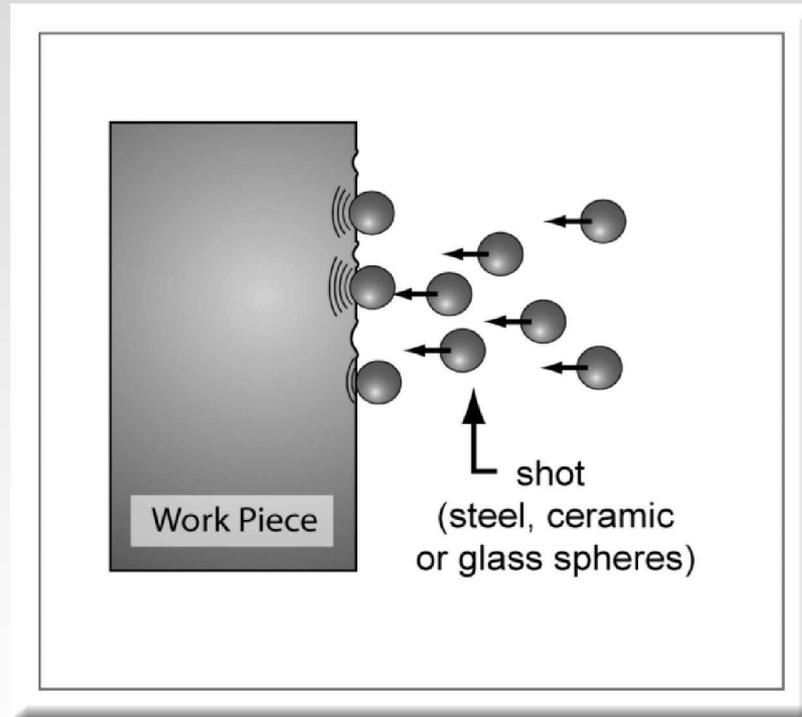


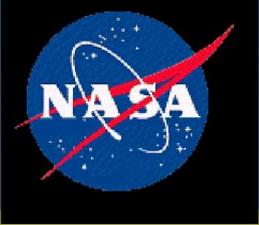
# Laser Peening





# Shot Peening





# Peening Methods

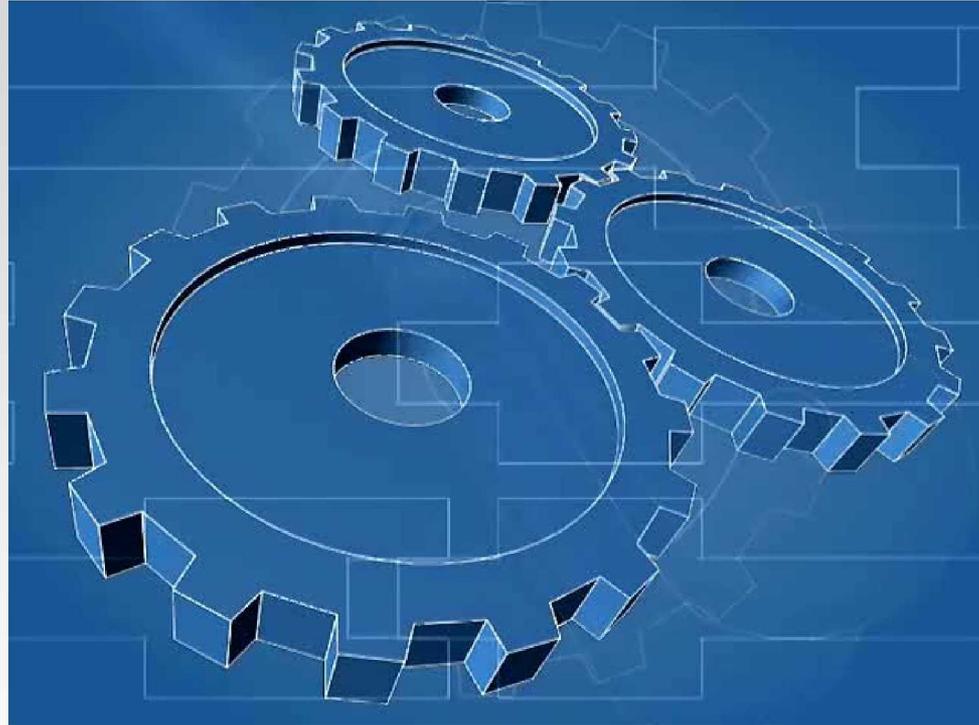


## Laser Peening

- 1 mm thick laminar tamping layer
- Samples covered using a 0.22 mm thick aluminum tape
- Applied using a square laser spot
- Laser power density of 5 GW/cm<sup>2</sup>
- 18 ns in duration
- Spots were overlapped 3%
- Applied at a frequency of 2.7 Hz
- Using a 1 micrometer wavelength
- Both faces of samples were peened

## Shot Peening

- 0.59 mm glass beads
- Almen intensity of 0.008-0.012
- Both faces of samples were peened



# Residual Stresses



# *Residual Stresses*

XRD

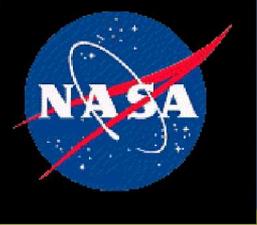
## **Surface Residual Stresses**

Determined by the x-ray diffraction technique

Contour

## **Through Thickness Residual Stresses**

Determined by the contour method



# Contour Method



## 1. Sectioning the Sample

- Sample is fixed to a rigid backing plate
- Sample is cut along the measurement plane with an EDM wire

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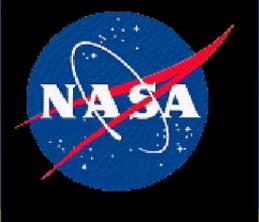
## 2. Measuring Deformation

- After sectioning a deformed surface shape is produced
  - Resulting from the relaxed residual stresses
- The displacement is measured on both sectioned surfaces using a coordinate measuring machine (CMM)

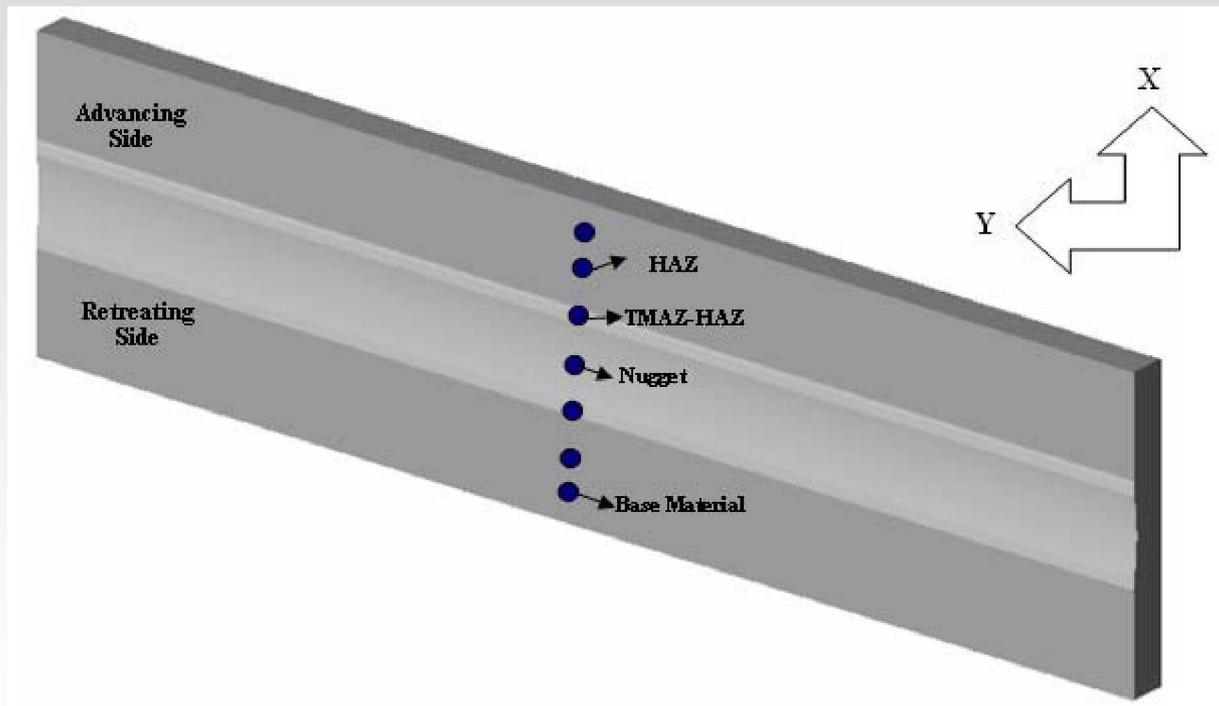
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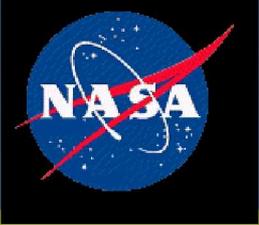
## 3. Estimating the Residual Stresses

- The displacements from both cutting surfaces is averaged
- The noise in the measurements is filtered
- The original residual stresses are calculated from the measured contour using a finite element model (FEM)



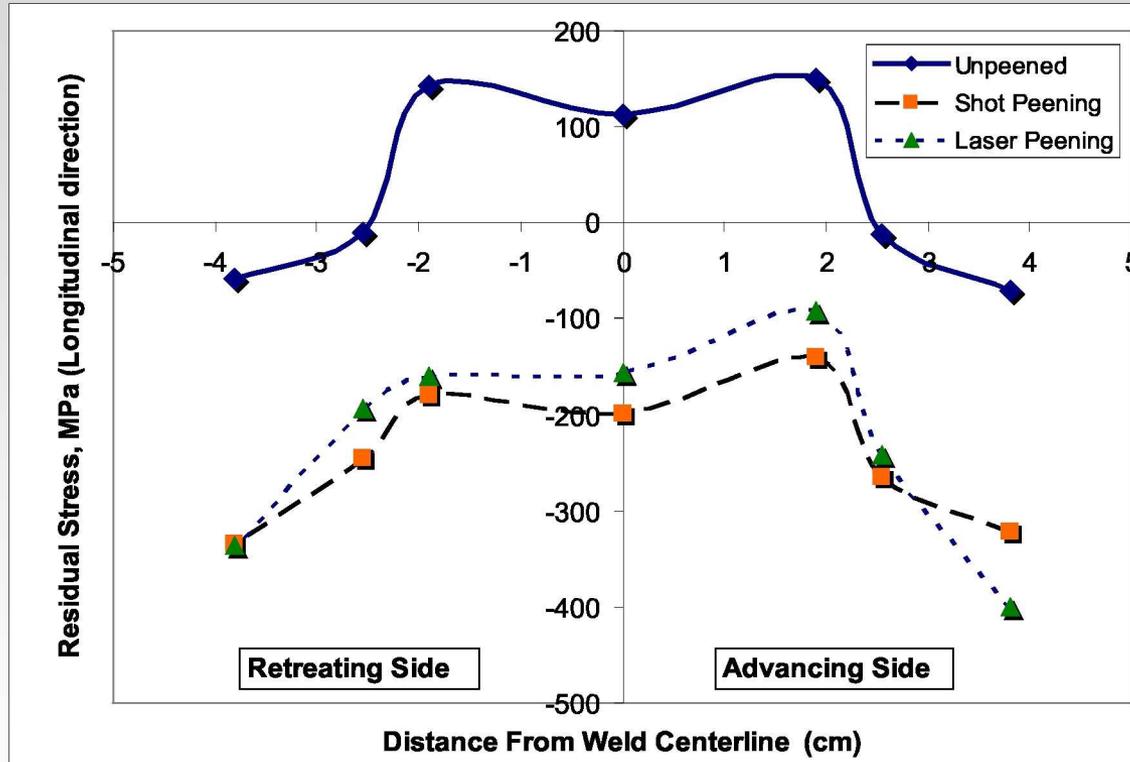
# Residual Stresses in FSW Specimen



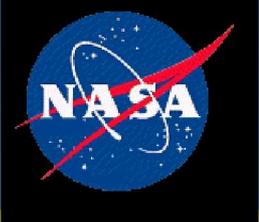


# Residual Stresses in FSW Specimen

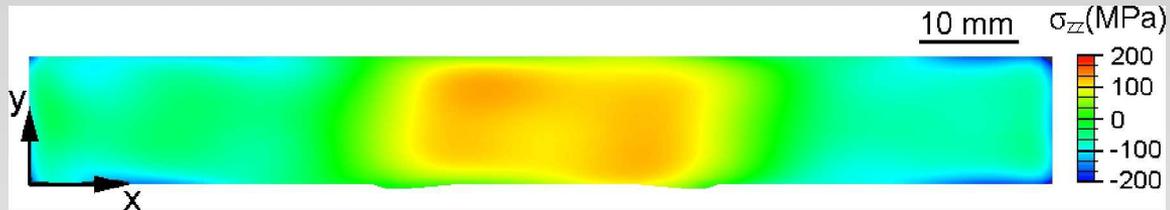
## Surface residual stresses



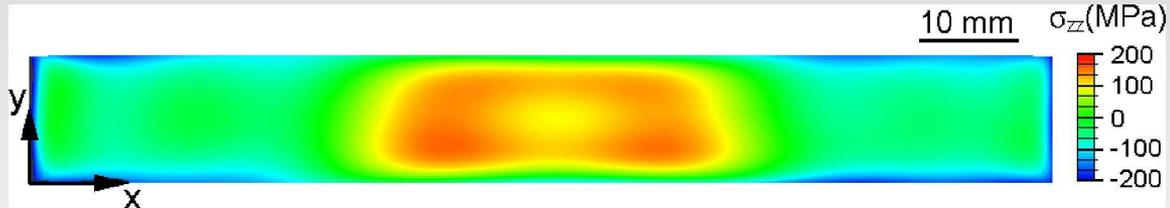
Residual stresses for the various peened FSW specimens



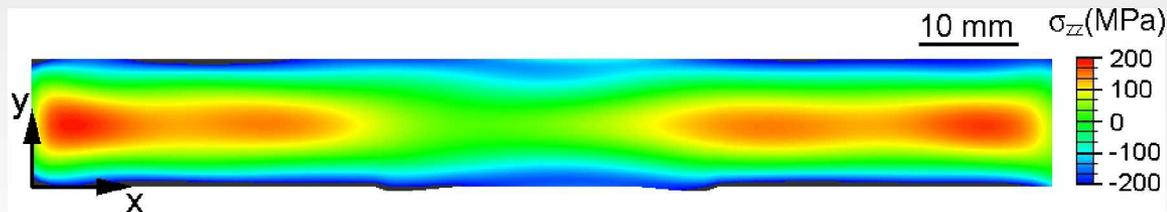
# Through Thickness Residual Stress



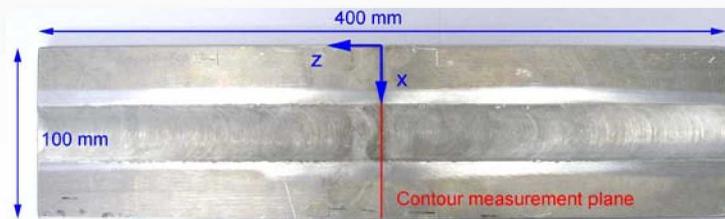
Two-dimensional map of the measured residual stress for the unpeened FSW specimen



Two-dimensional map of the measured residual stress for the shot peened FSW specimen

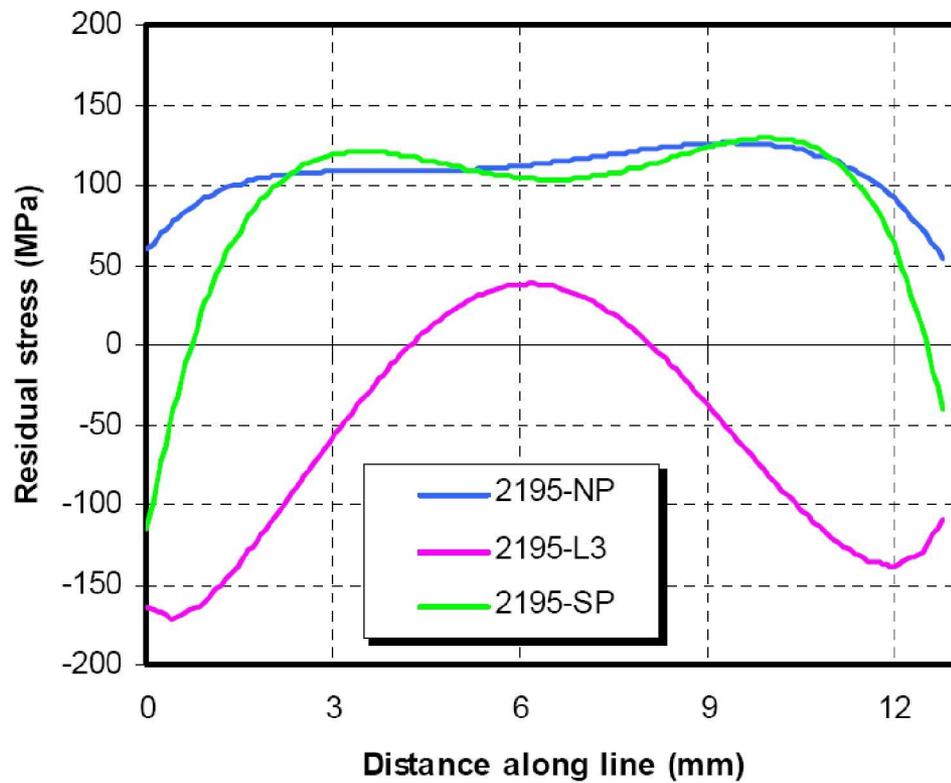


Two-dimensional map of the measured residual stress for the laser peened FSW specimen





# Through Thickness Residual Stress





# Mechanical Properties



# *Mechanical Properties*

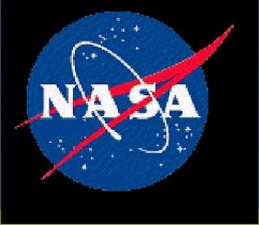
**Investigate the effects of peening**

The diagram illustrates the investigation of peening effects on mechanical properties. It features a central grey arrow pointing downwards from a yellow box containing the text "Investigate the effects of peening". This arrow branches into three paths, each leading to a circular icon with a square label. The first icon is grey and labeled "Tensile Properties". The second icon is blue and labeled "Microhardness". The third icon is green and labeled "Surface Effects".

**Tensile Properties**

**Microhardness**

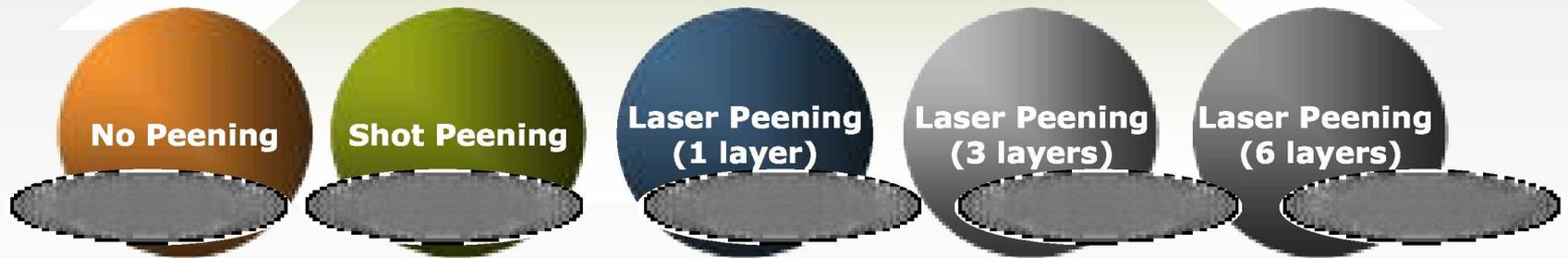
**Surface Effects**

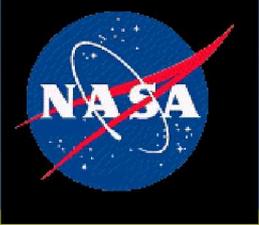


# Peening Conditions

*Mechanical Properties*

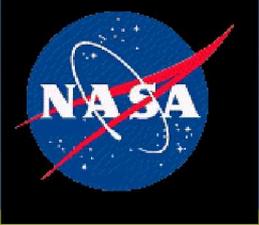
*Peening Conditions*



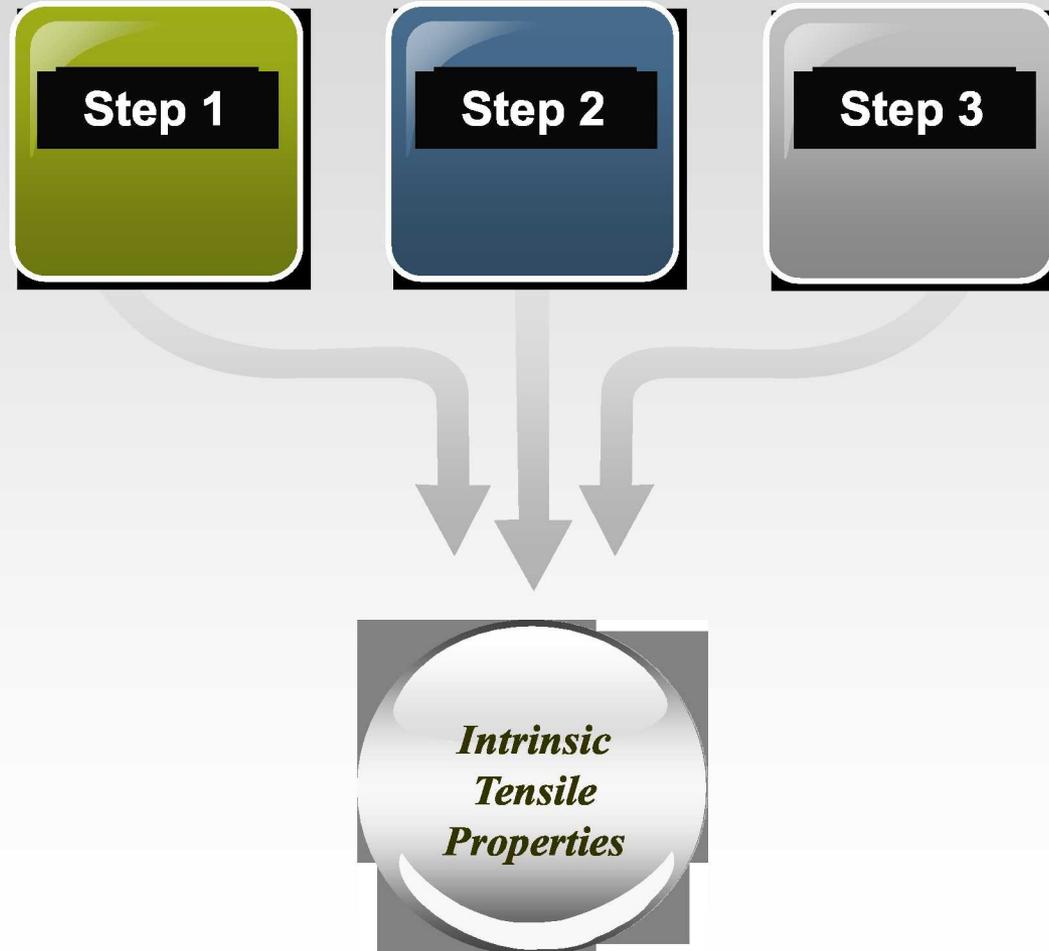


# *Tensile Properties*

- Conventional transverse tensile testing only provides the overall strain experienced by the sample
- It is necessary to determine local strains and equivalent tensile properties across the weld
  - Evaluated at different regions of the weld using an ARAMIS system



# ARAMIS System



## Step 1:

- A random or regular pattern with good contrast is applied to the surface of the test object and is deformed along with the object.

As the specimen is deformed under load, the deformation is recorded by the cameras and evaluated using digital image processing.

## Step 2:

- The initial image processing defines a set of unique correlation areas known as macro-image facets, typically 5-20 pixels across.

## Step 3:

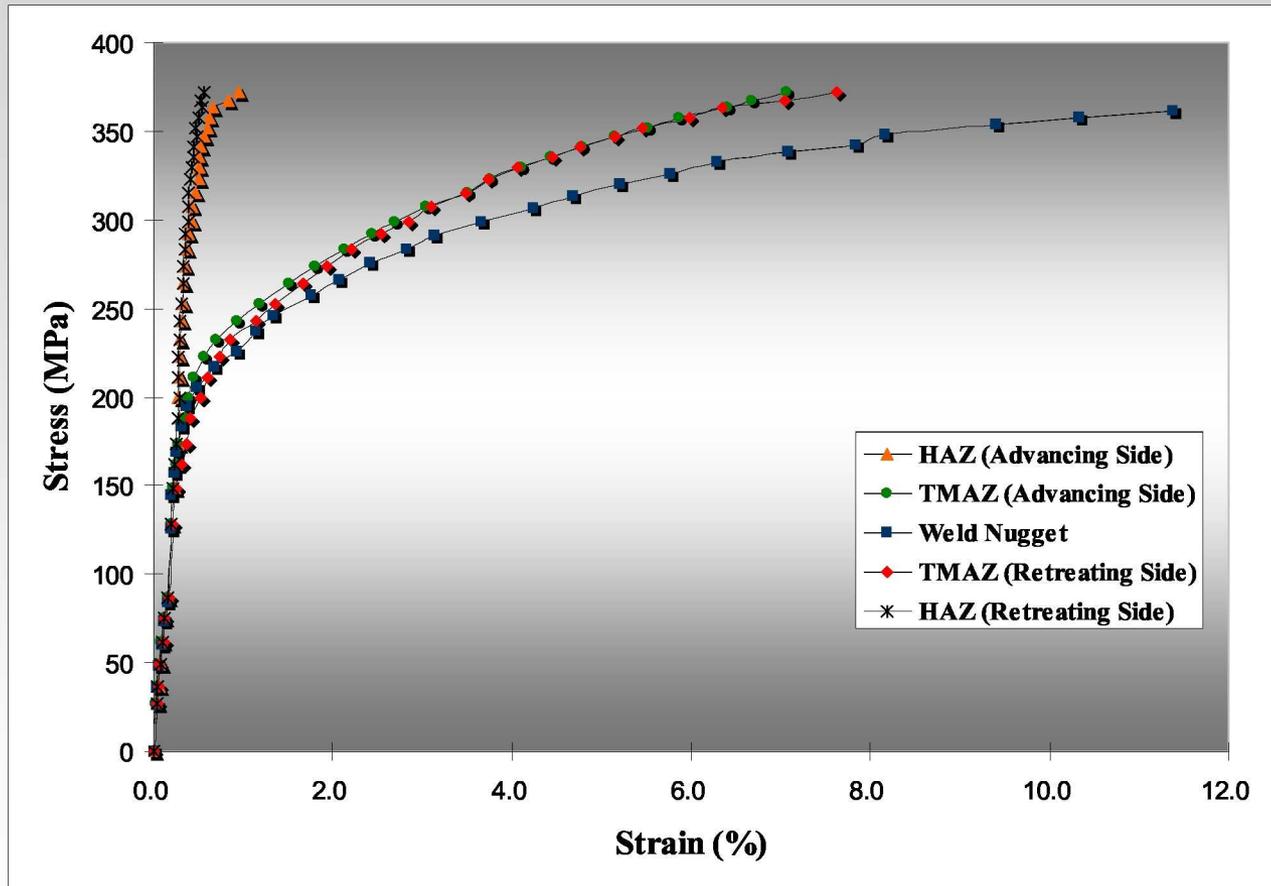
- These facets are then tracked in each successive image with sub-pixel accuracy.

- Strains are calculated at different regions across the weld region.

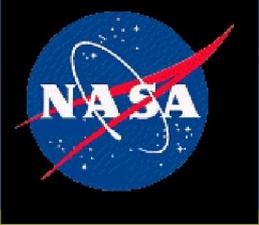


# Tensile Properties for 2195

As welded condition



Tensile properties at different regions of the weld for a FSW 2195 AA

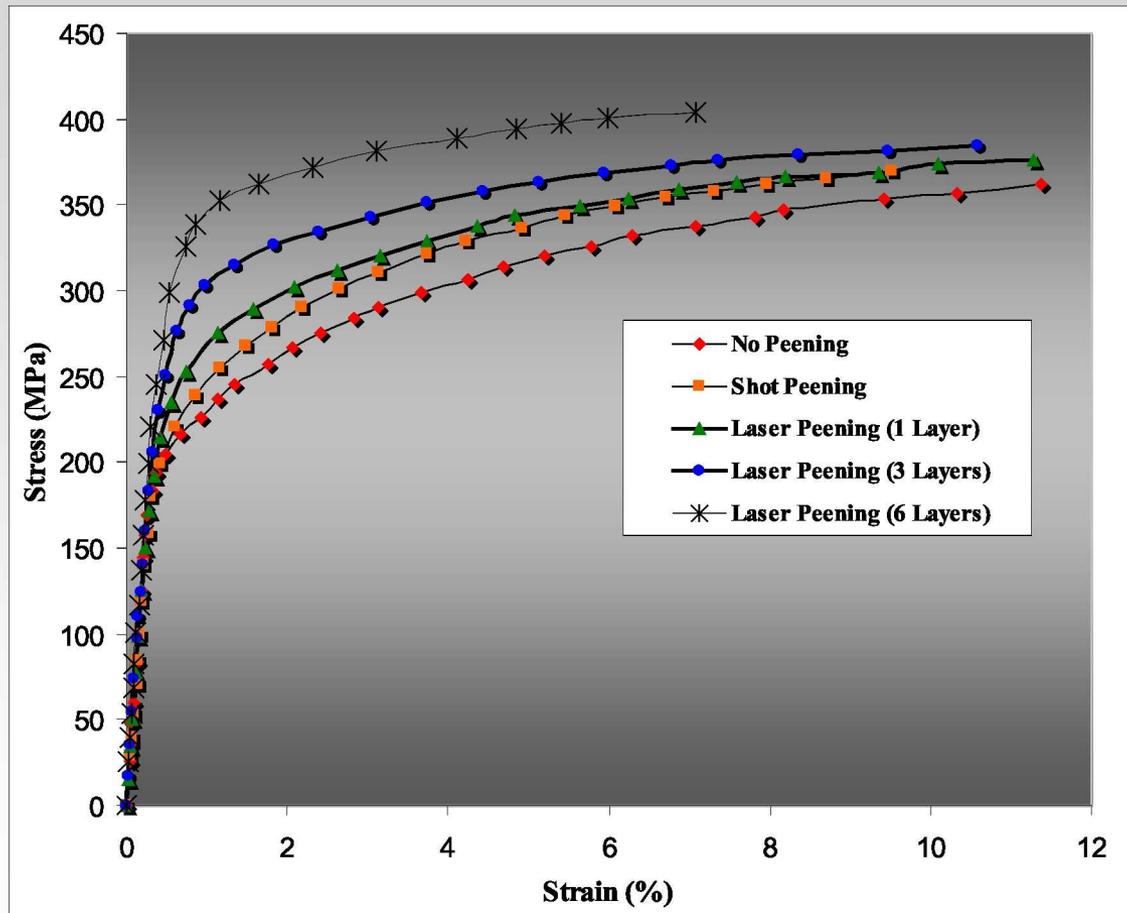


# *Tensile Properties*

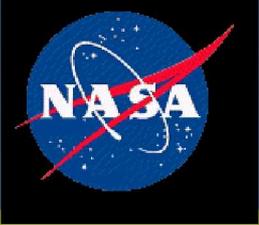
- The weld nugget exhibited the lowest tensile properties when compared to other locations across the weld
  - Strengthening precipitates in 2195 AA were no longer present in the weld nugget
    - Temperature during joining was above the solution temperature of the hardening precipitates
  - This region of the weld will therefore be relatively ineffective in inhibiting dislocation motion
    - The localized strain in the softened area of the weld will result in lower mechanical properties



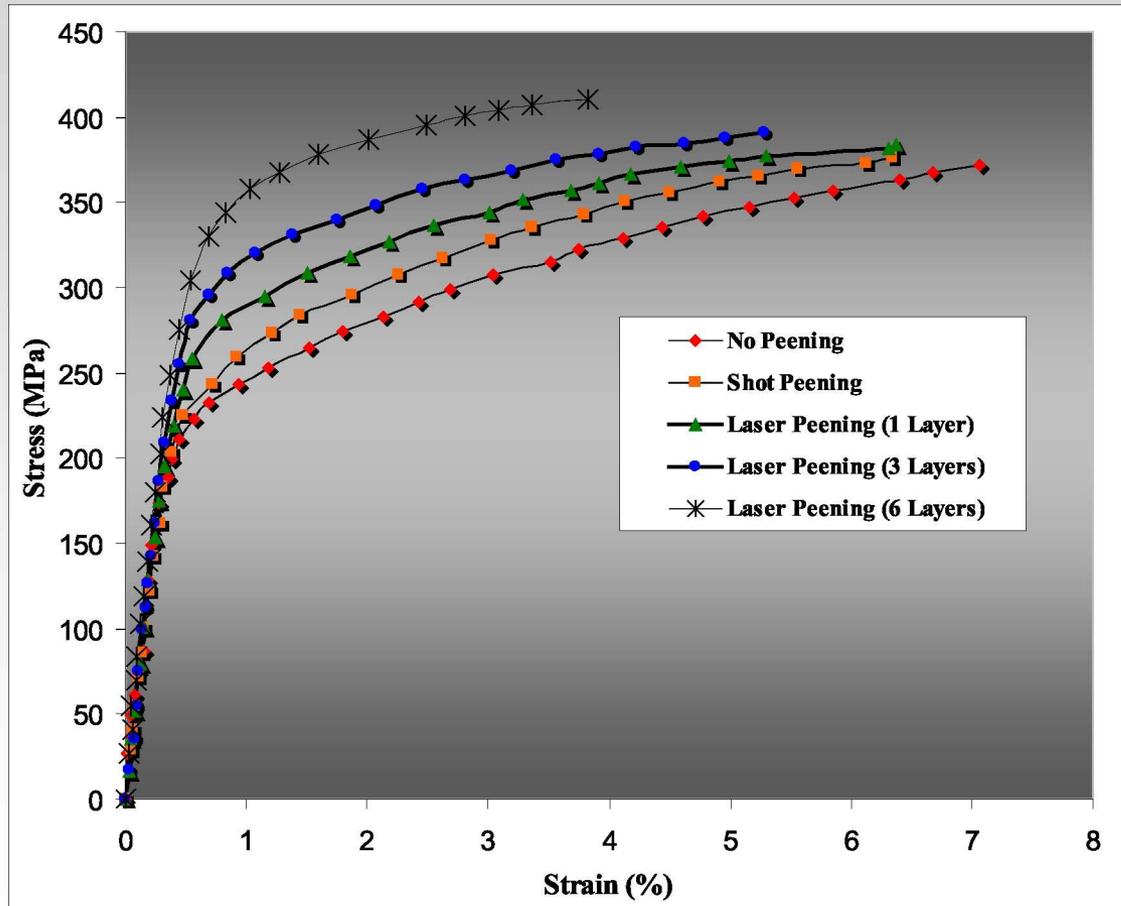
# Tensile Properties at Weld Nugget



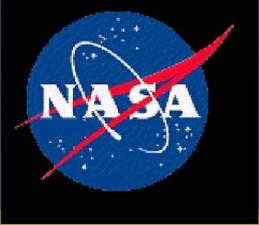
Tensile properties at the weld nugget under different peening conditions



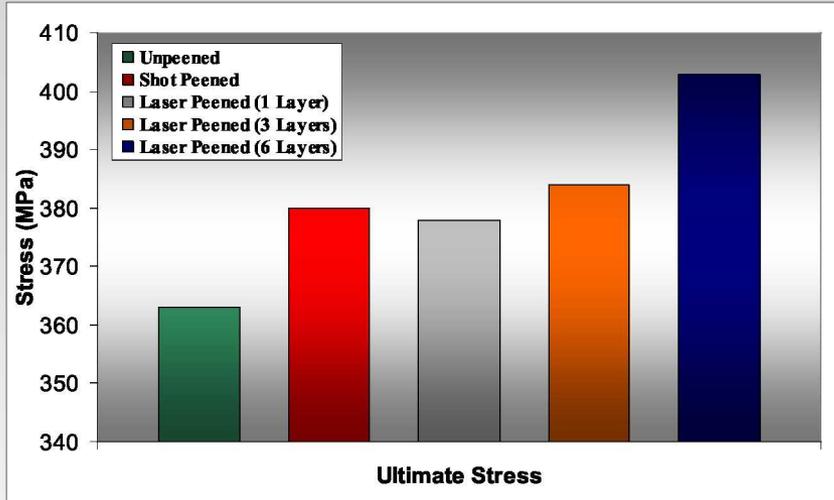
# Tensile Properties at TMAZ



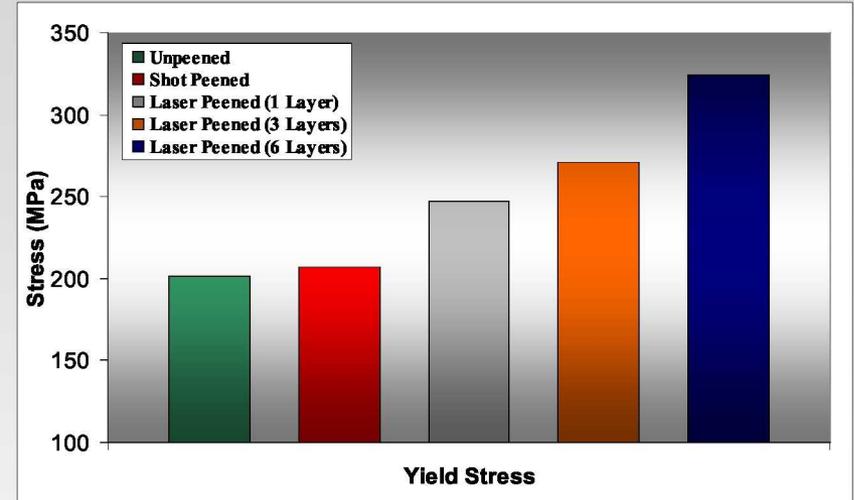
Tensile properties at the TMAZ under different peening conditions



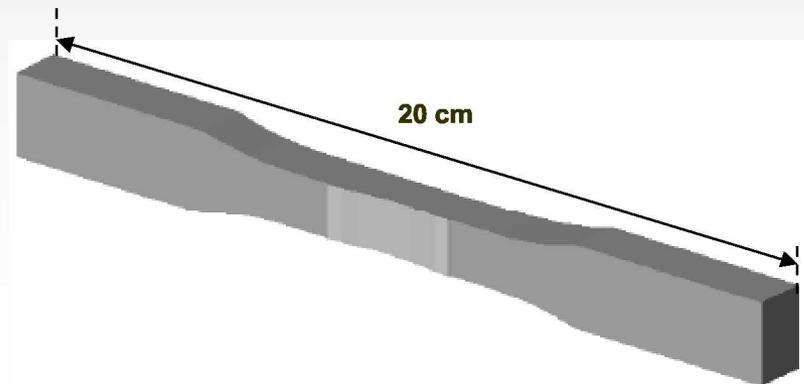
# Global Yield and Ultimate Stresses

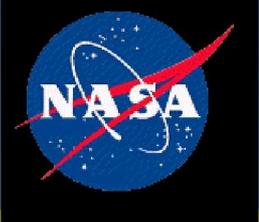


The ultimate tensile strength for different peening conditions

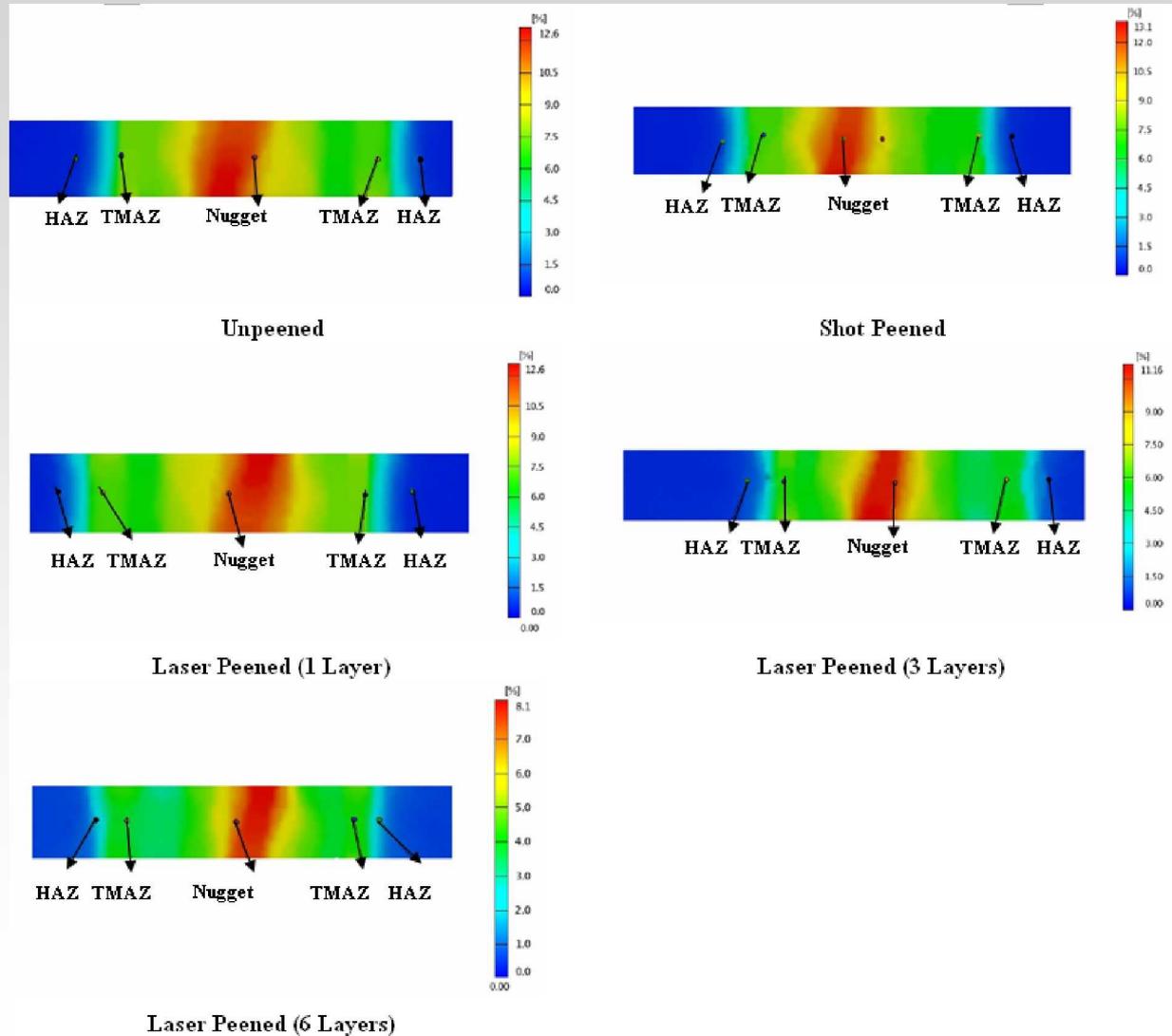


The yield stress (0.2% offset) for different peening conditions



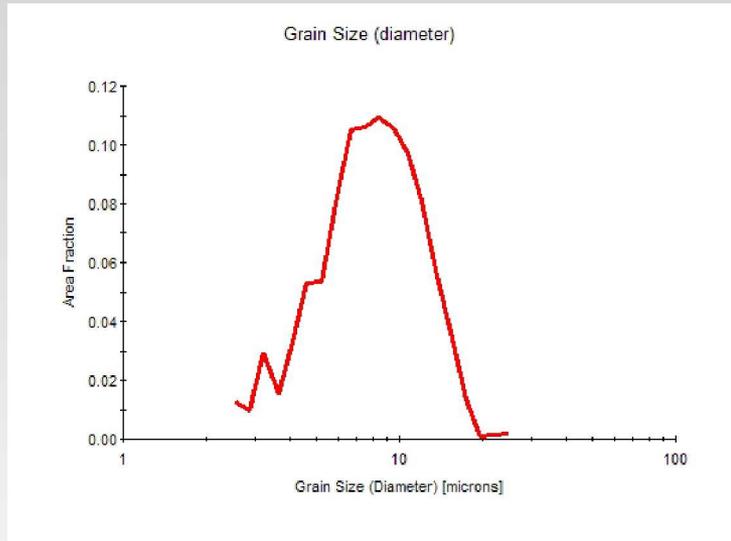


# Strain distribution across the weld

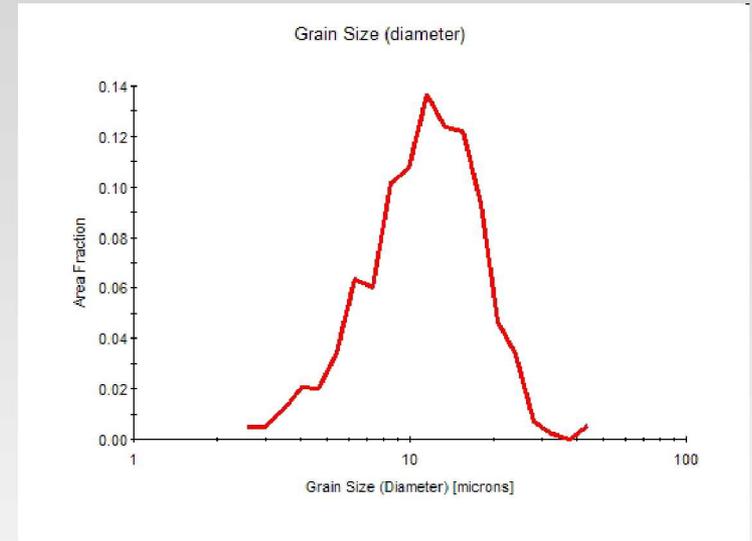




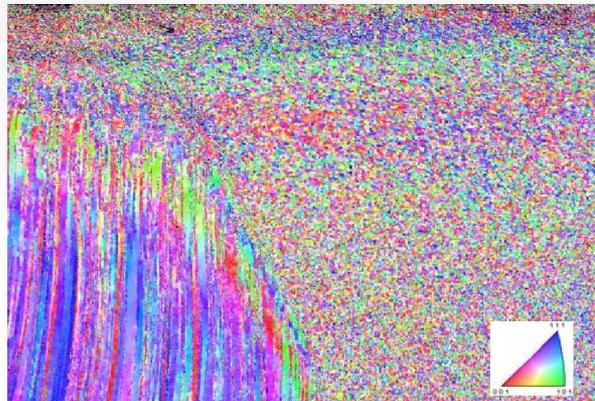
# EBSD Grain Size Difference

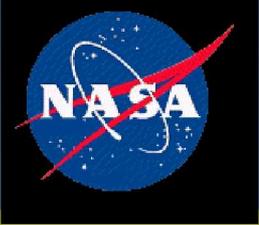


**Grain size histogram for laser peened specimen**



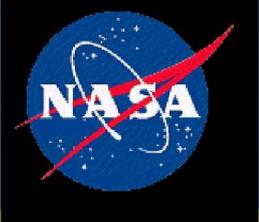
**Grain size histogram for unpeened specimen**



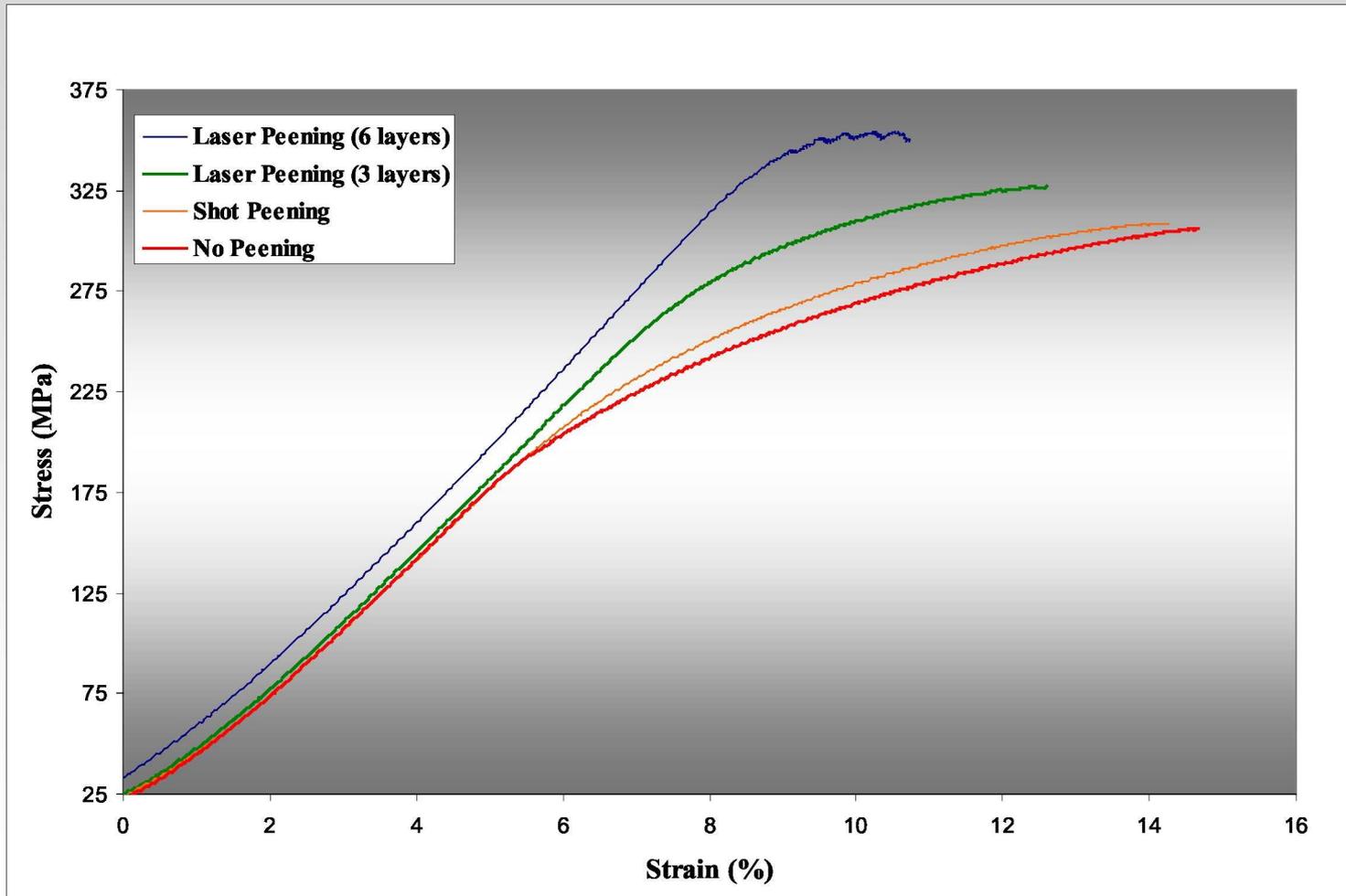


# Tensile Properties

- Laser peened demonstrated:
  - 60% increase in the yield strength in the weld nugget in the FSW joint
  - 11% increase to the ultimate tensile strength in the weld nugget in the FSW joint
  - In contrast, shot peening exhibited only modest improvement to the tensile properties (3%)
- The increase in mechanical properties from the laser peening was mainly attributed to:
  - High levels of compressive residual stresses introduced during the high energy peening that can reach significantly deeper than shot peening
  - Increase in dislocation density from the peening
- Laser peening using six layers resulted in a 35% reduction to ductility

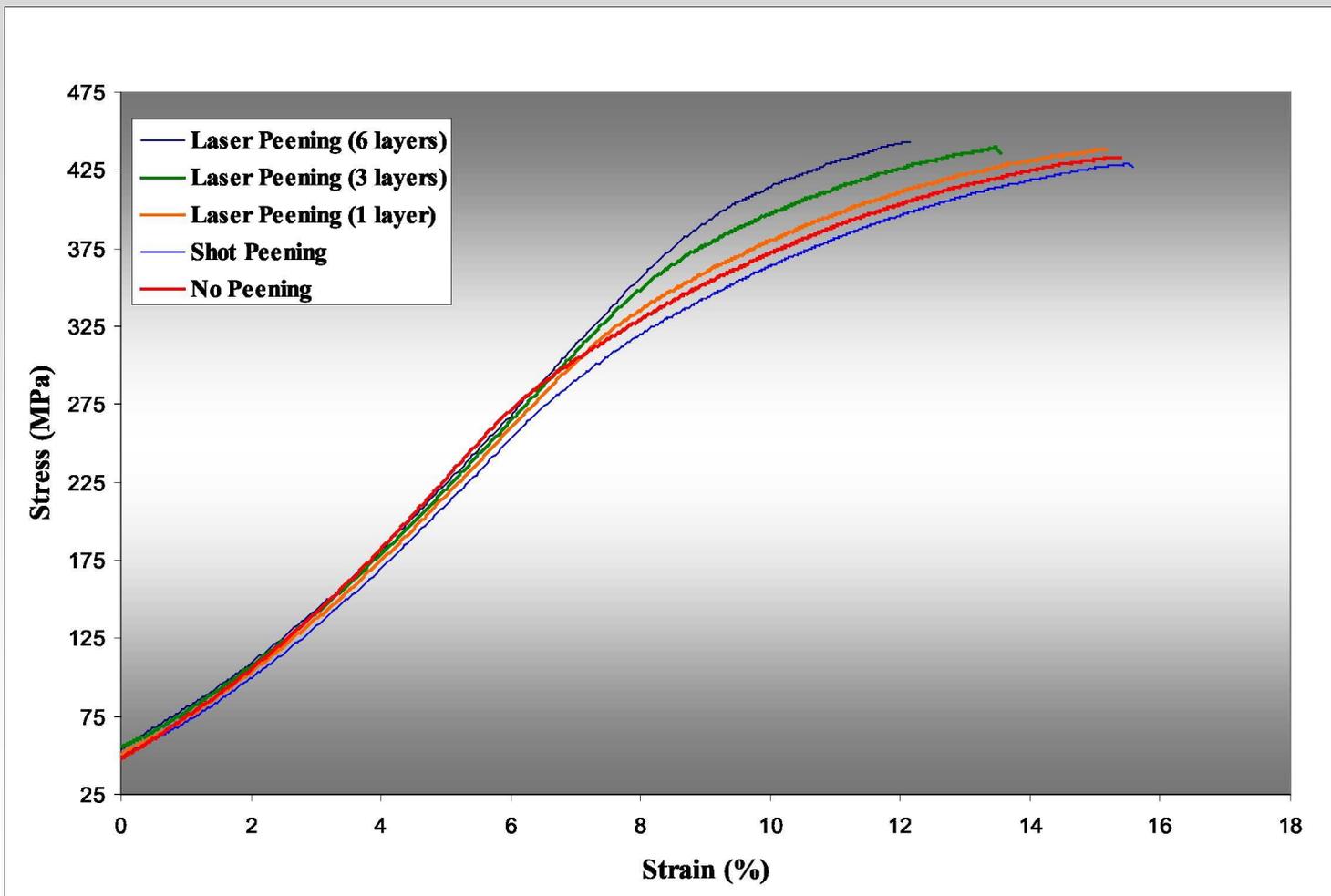


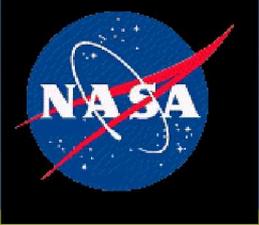
# Tensile Properties (360 F)



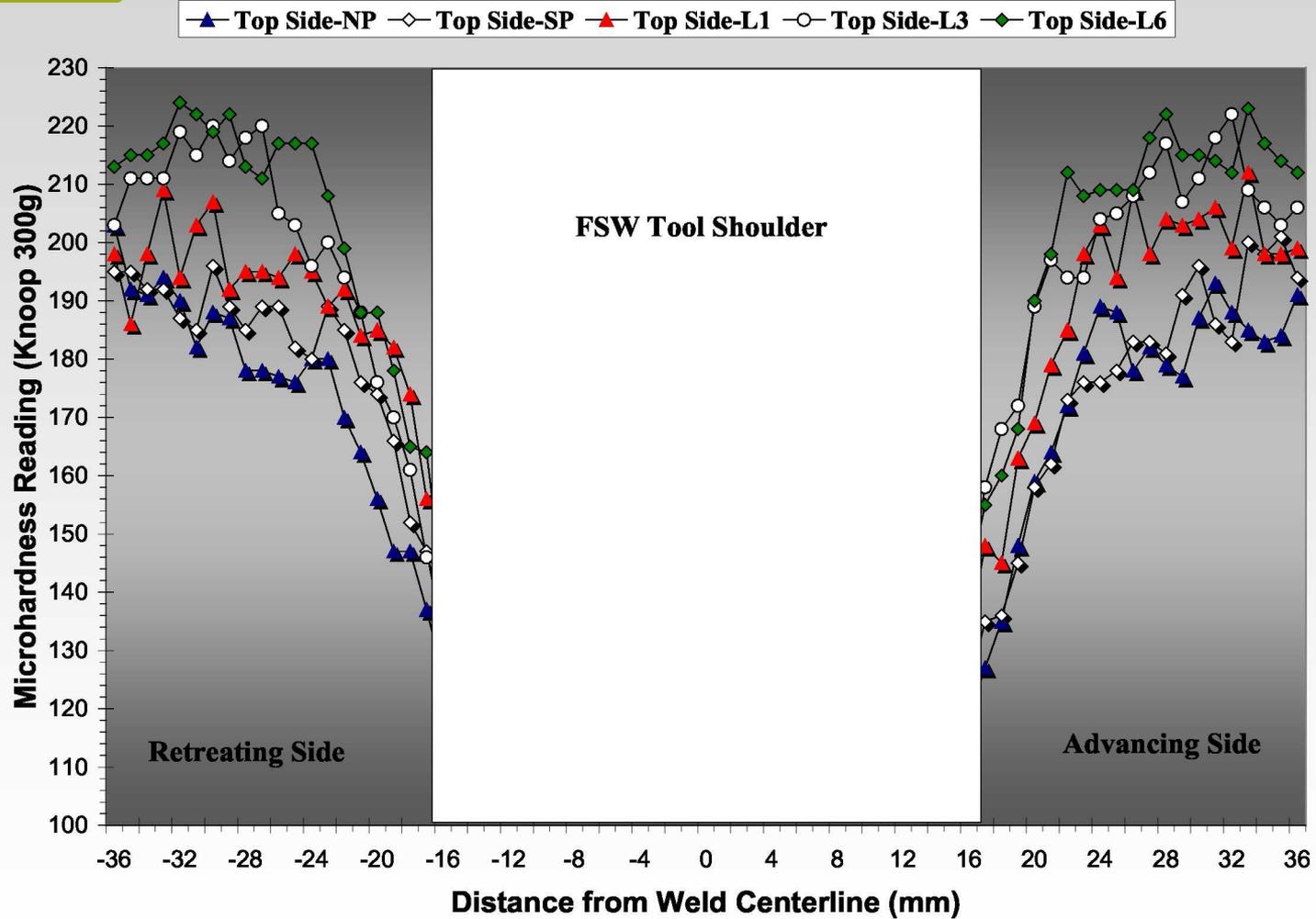


# Tensile Properties (-150 F)

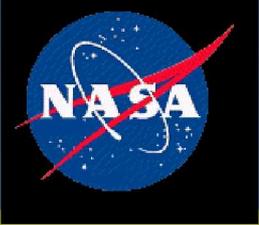




# Microhardness (Top)



Microhardness profile across the top side of the weld for different peening methods



# Microhardness

- Significant hardness was achieved by processing the FSW 2195 AA samples with laser peening
  - Hardness increase around 28% in the top surface
  - Hardness increase around 21% in the bottom side of the weld nugget region
- Hardness levels due to laser peening increased proportionally with the number of peening layers in the 2195 aluminum alloy
- The polishing that takes place prior to microhardness measurement can wipe out all the hardness effects produced by the shot peening.
  - This is because the hardening effects from shot peening only affect a shallow depth in the material.
- Hardness profiles across the weld were wider on the top side of the weld compared to the bottom surface.
  - That was attributed to bottom plate contact with the backing plate which acts as a heat sink, therefore reducing the metallurgical transformations that take place at high temperatures.



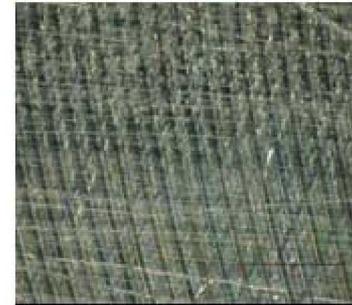
# Surface Roughness



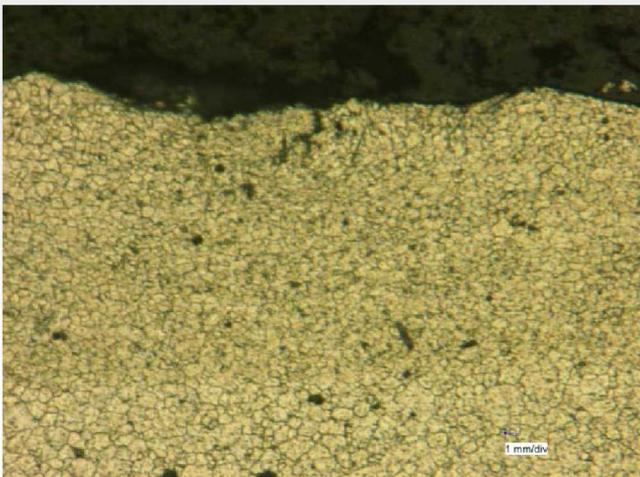
Base Material



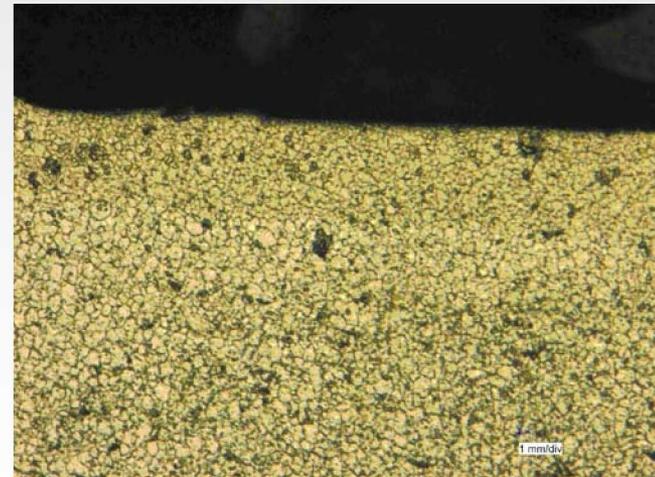
Shot Peening



Laser Peening



**Shot Peening**

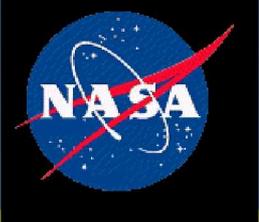


**Laser peening**

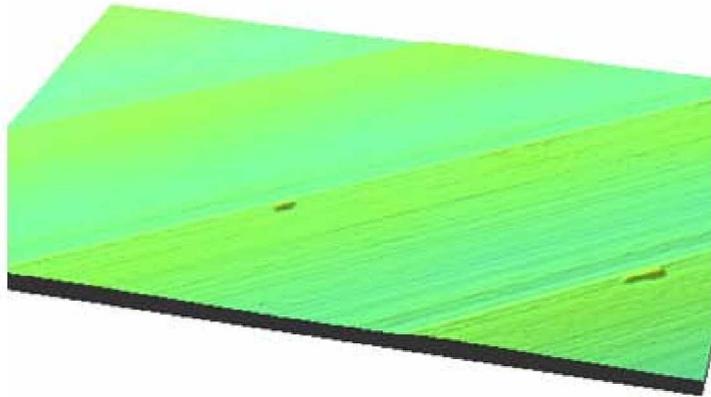


# Surface Roughness

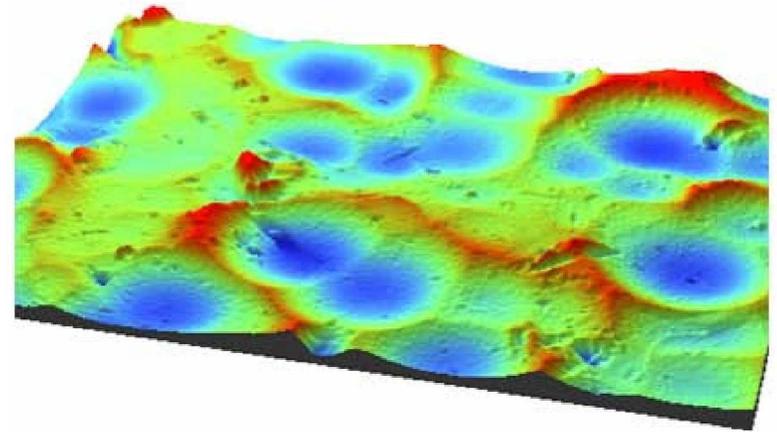
Condition	Ra	Rpk	Rvk	Nomenclature
Unpeened	1.087 $\mu\text{m}$	1.429 $\mu\text{m}$	0.93 $\mu\text{m}$	<b>Ra:</b> Roughness average <b>Rpk:</b> Maximum peak height <b>Rvp:</b> Maximum valley depth
Shot Peened	5.029 $\mu\text{m}$	5.761 $\mu\text{m}$	2.884 $\mu\text{m}$	
Laser Peened (6 layers)	1.336 $\mu\text{m}$	1.815 $\mu\text{m}$	1.328 $\mu\text{m}$	



# Surface Roughness

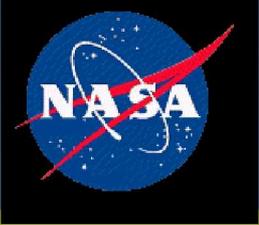


No Peening

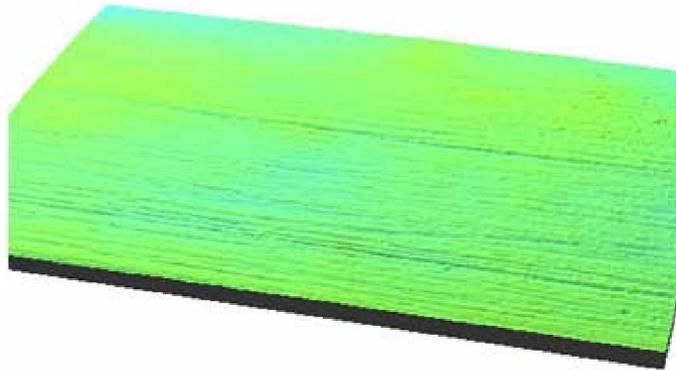


Shot Peening

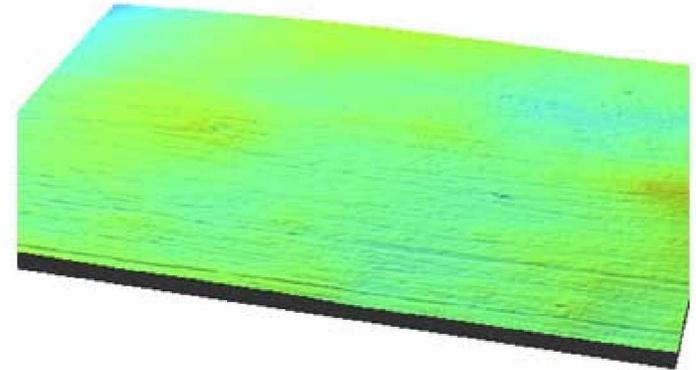




# Surface Roughness

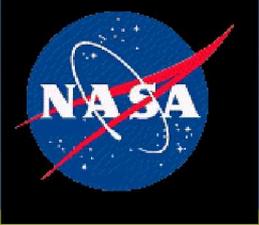


Laser peening (Three layers)

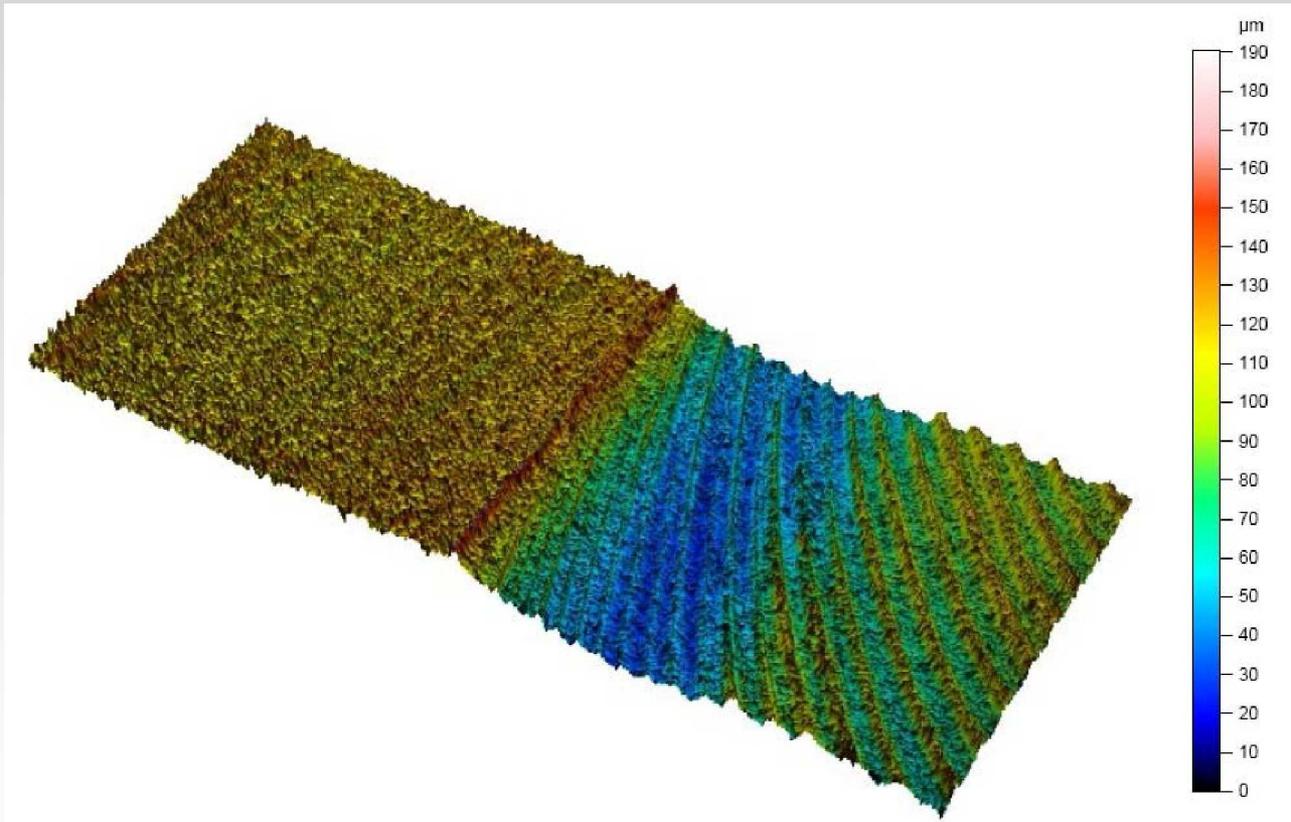


Laser Peening (Six layers)



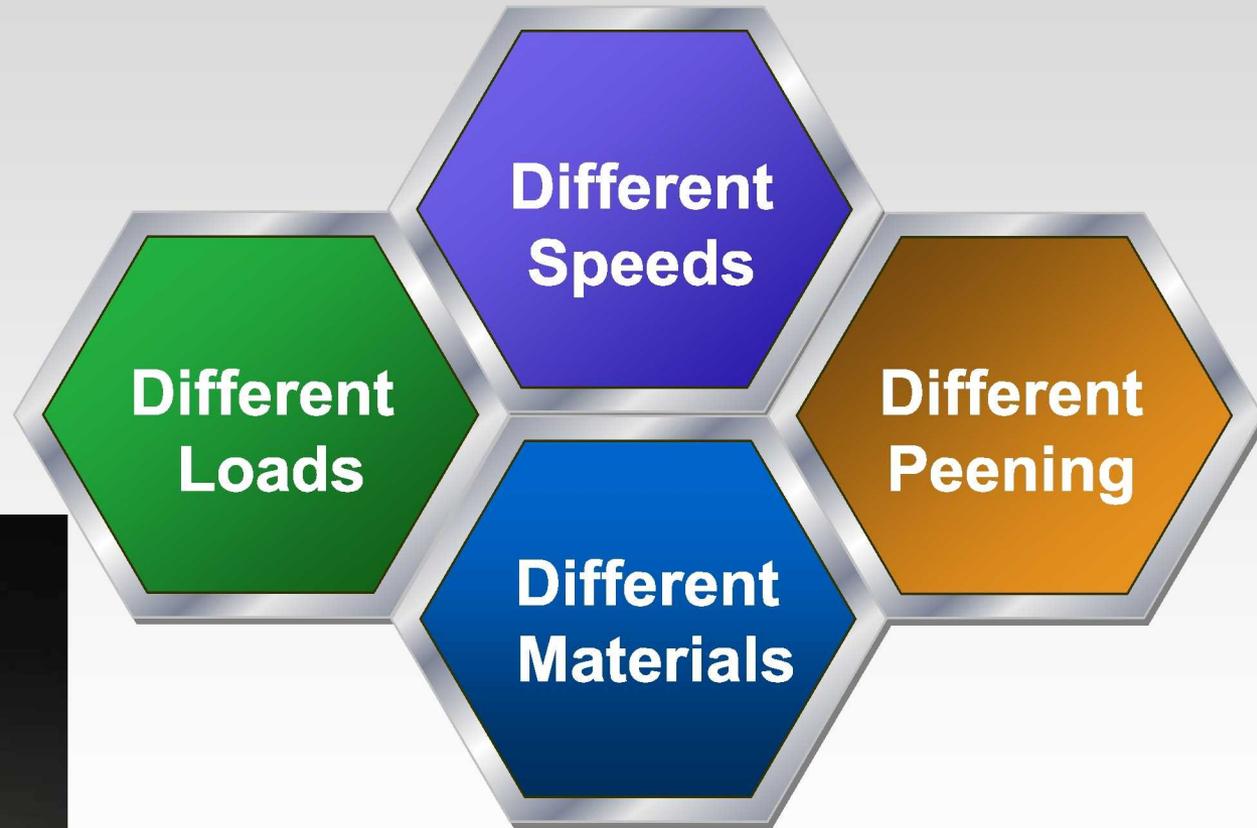


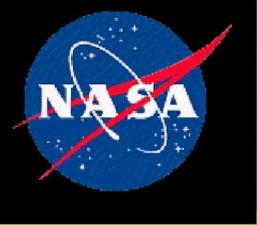
# Surface Roughness





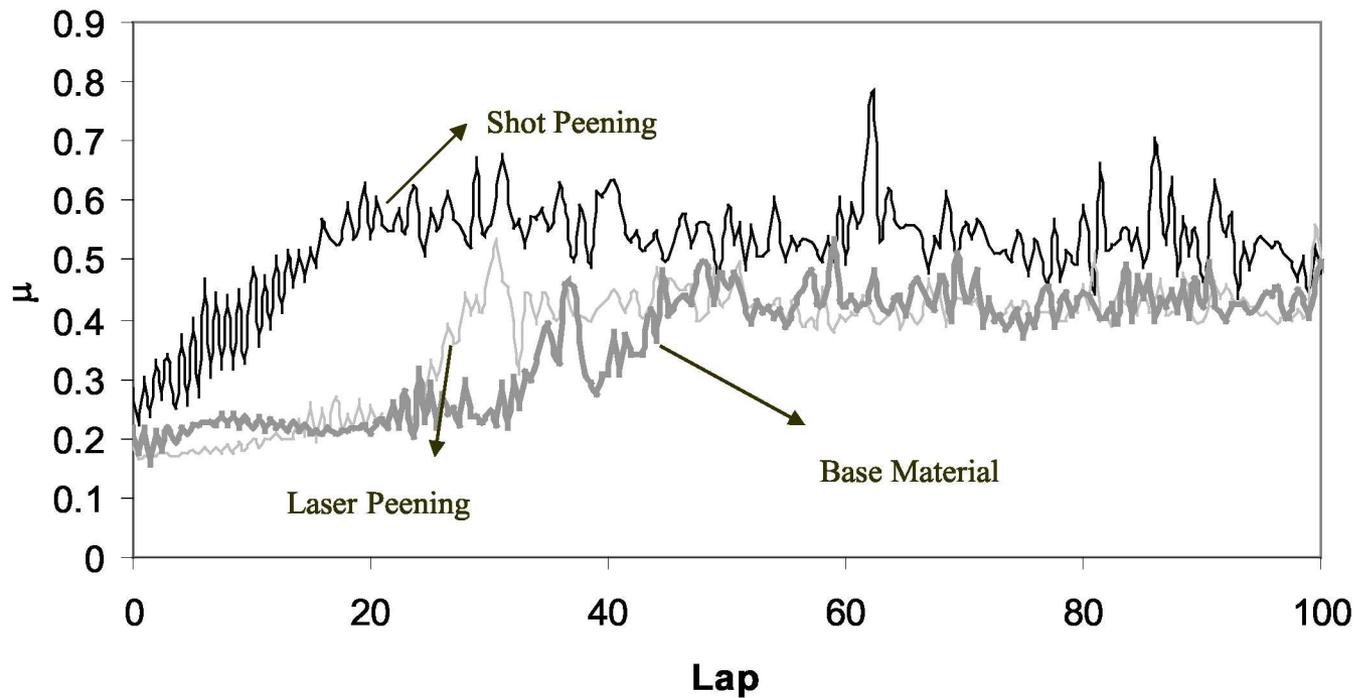
# Surface Wear/Friction





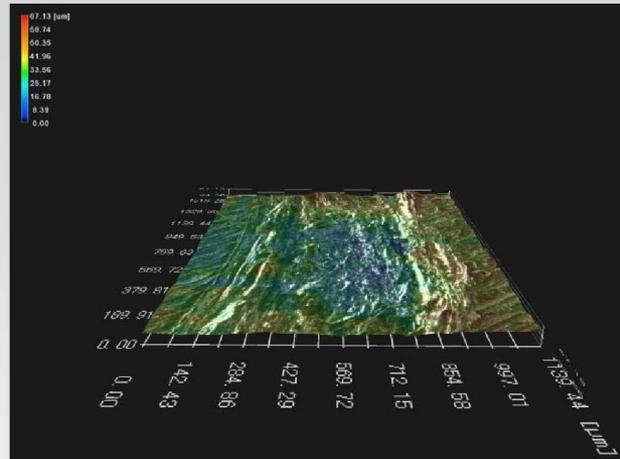
# Friction

- Testing done with identical contact force (10 N) and speed (0.5 cm/sec)
- Shot peening appears to provide higher steady state friction coefficients.
- Long term friction coefficients for laser peened and bare surfaces were comparable.

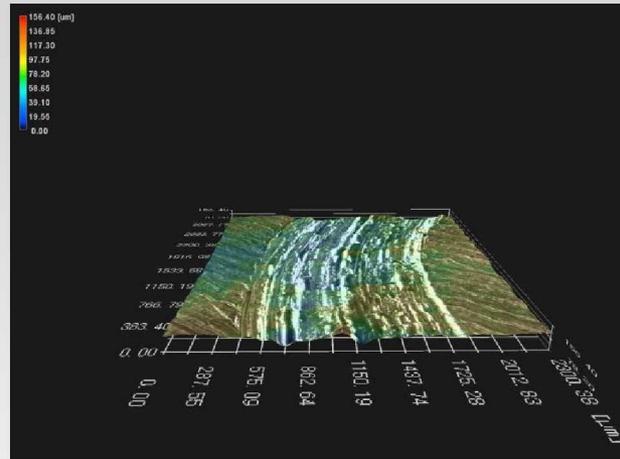




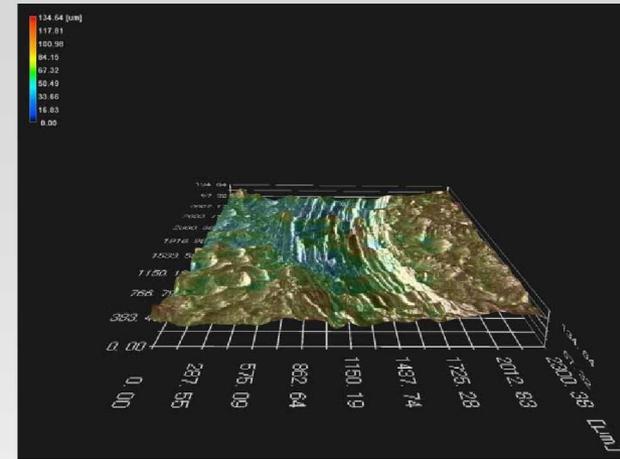
# Wear



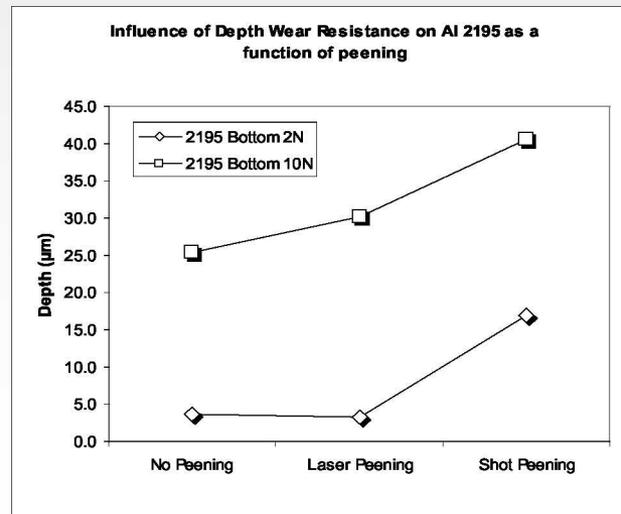
No peening



Laser peening

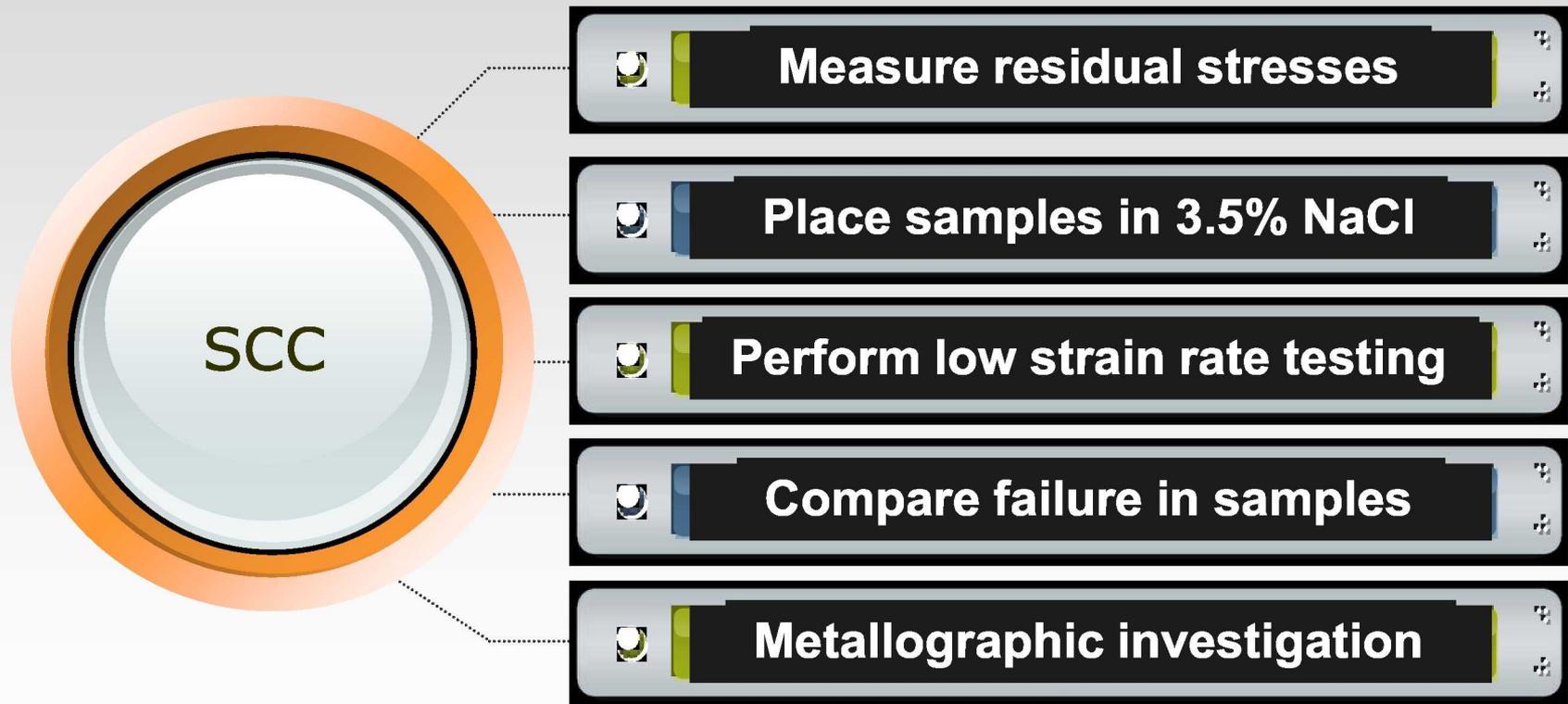


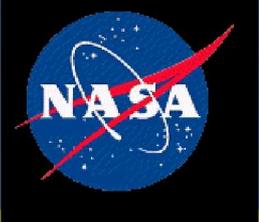
Shot peening



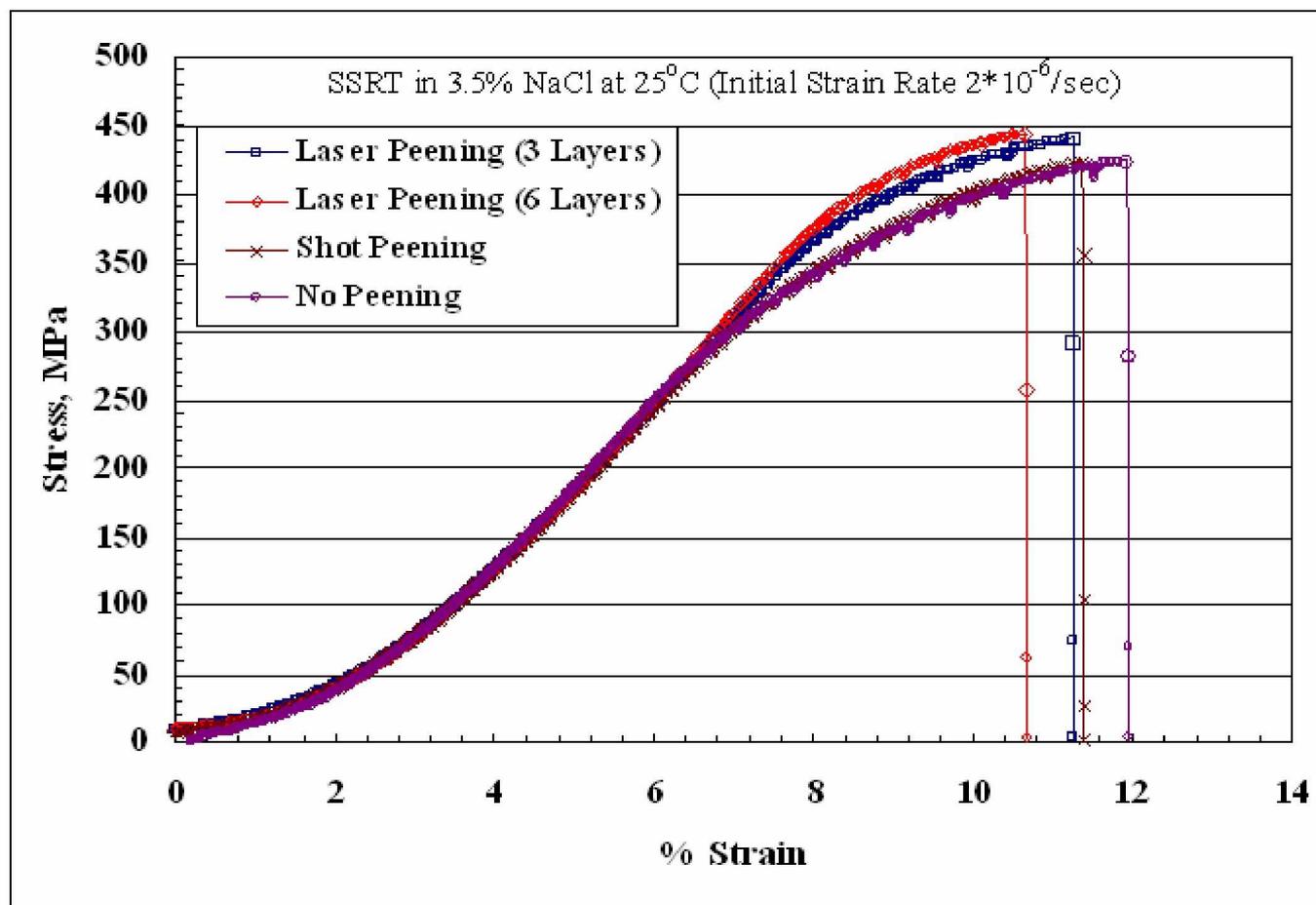


# Stress Corrosion Cracking (SCC)





# Stress Corrosion Cracking (SCC)



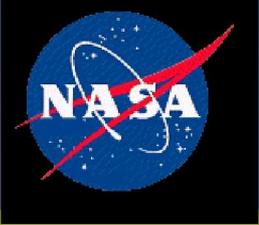


# Stress Corrosion Cracking (SCC)

Materials	Strain Rate (sec <sup>-1</sup> )	Ultimate Strength (MPa)	% Elongation	SCC Susceptibility
Laser Peening (6 Layers)	2*10 <sup>-6</sup>	444.2	3.01	No SCC Susceptibility
Shot Peening	2*10 <sup>-6</sup>	423.0	4.27	
No Peening	2*10 <sup>-6</sup>	423.5	5.27	
█				



# Fatigue Crack Growth



# Fatigue Crack Growth Rates

**FCGR**

Room Temperature

**FCGR**

Elevated Temperatures (360 F)

**FCGR**

Cryogenic Temperatures (-150F)

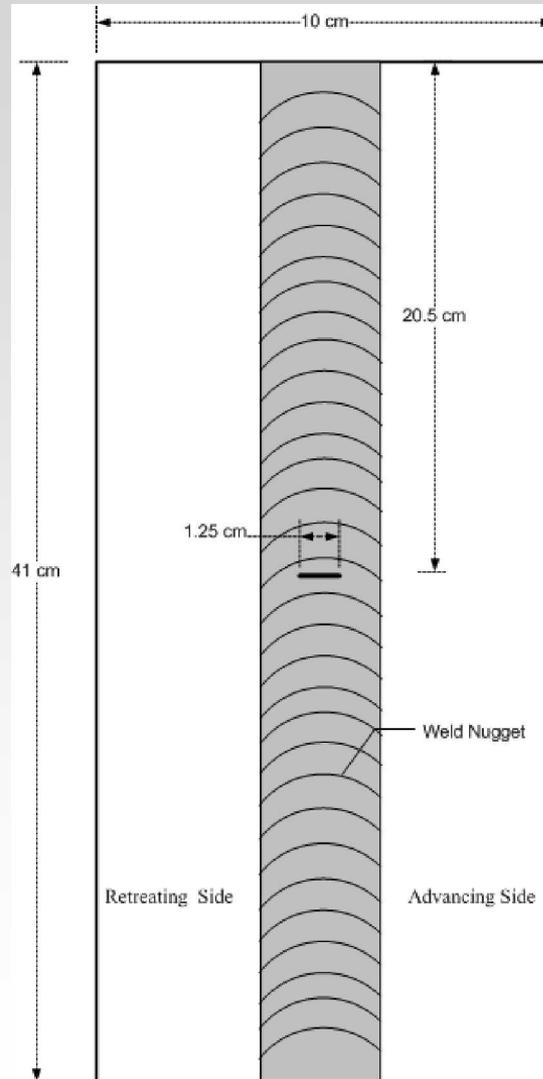
**No Peening**

**Shot Peening**

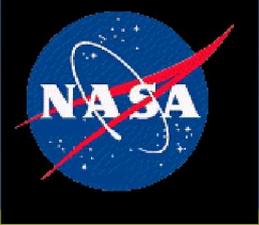
**Laser Peening**



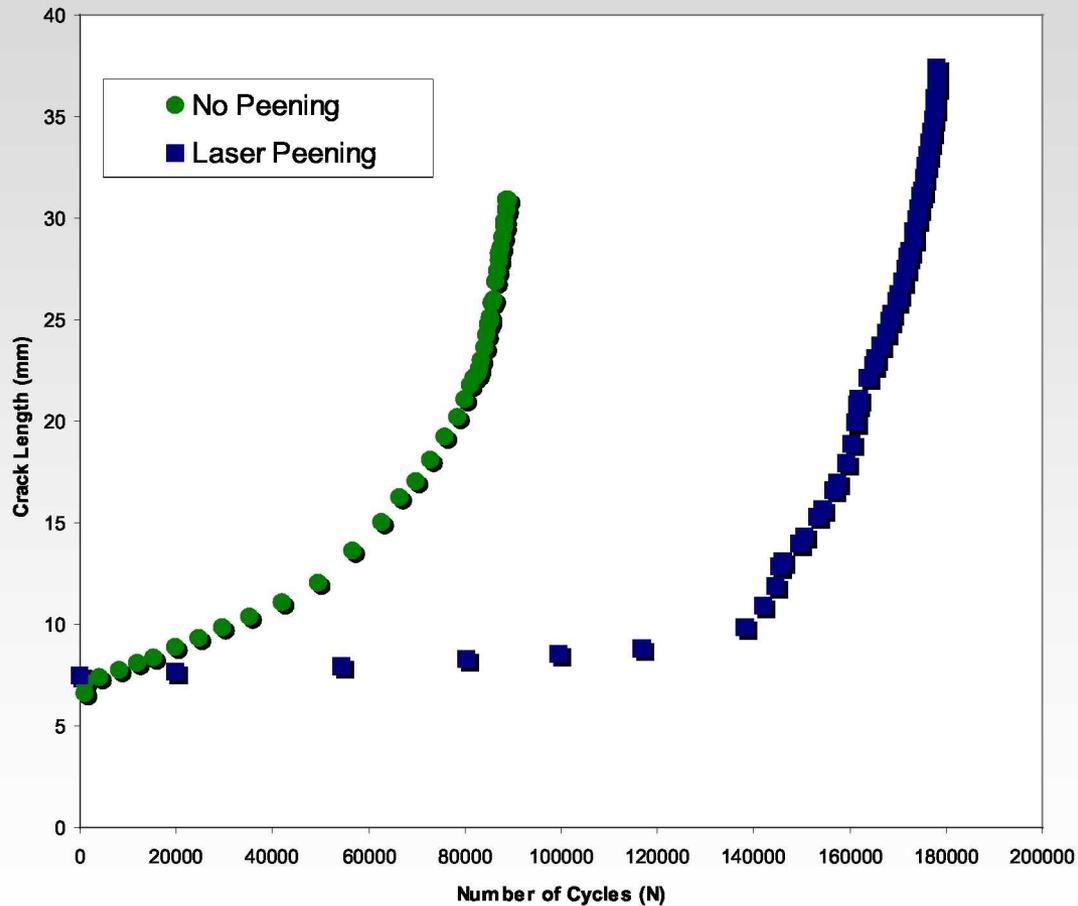
# Fatigue Samples

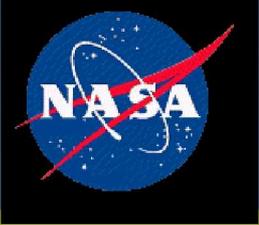


**Through Thickness  
Cracks**

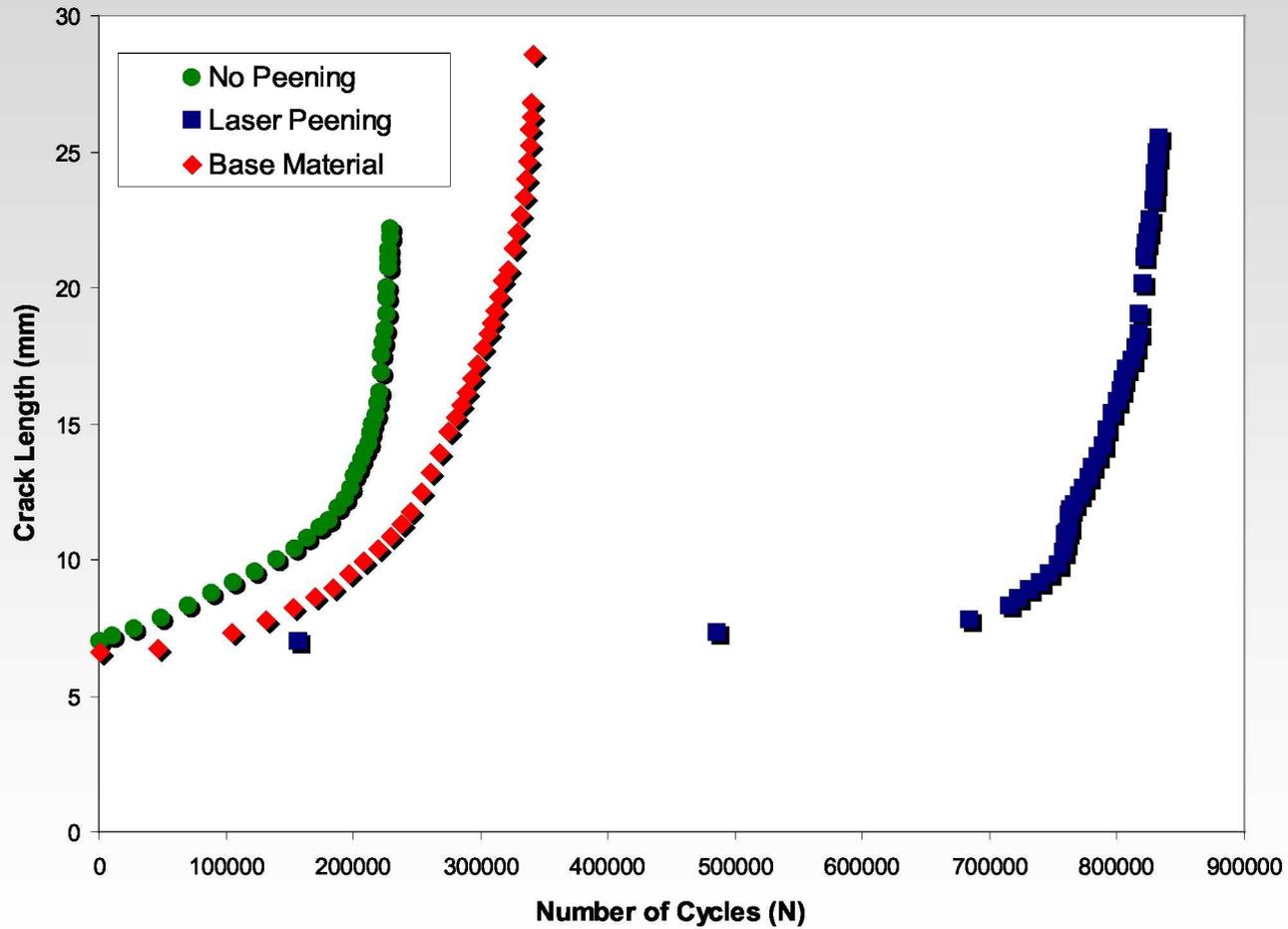


# *a vs. N for $R=0.1$ (RT)*



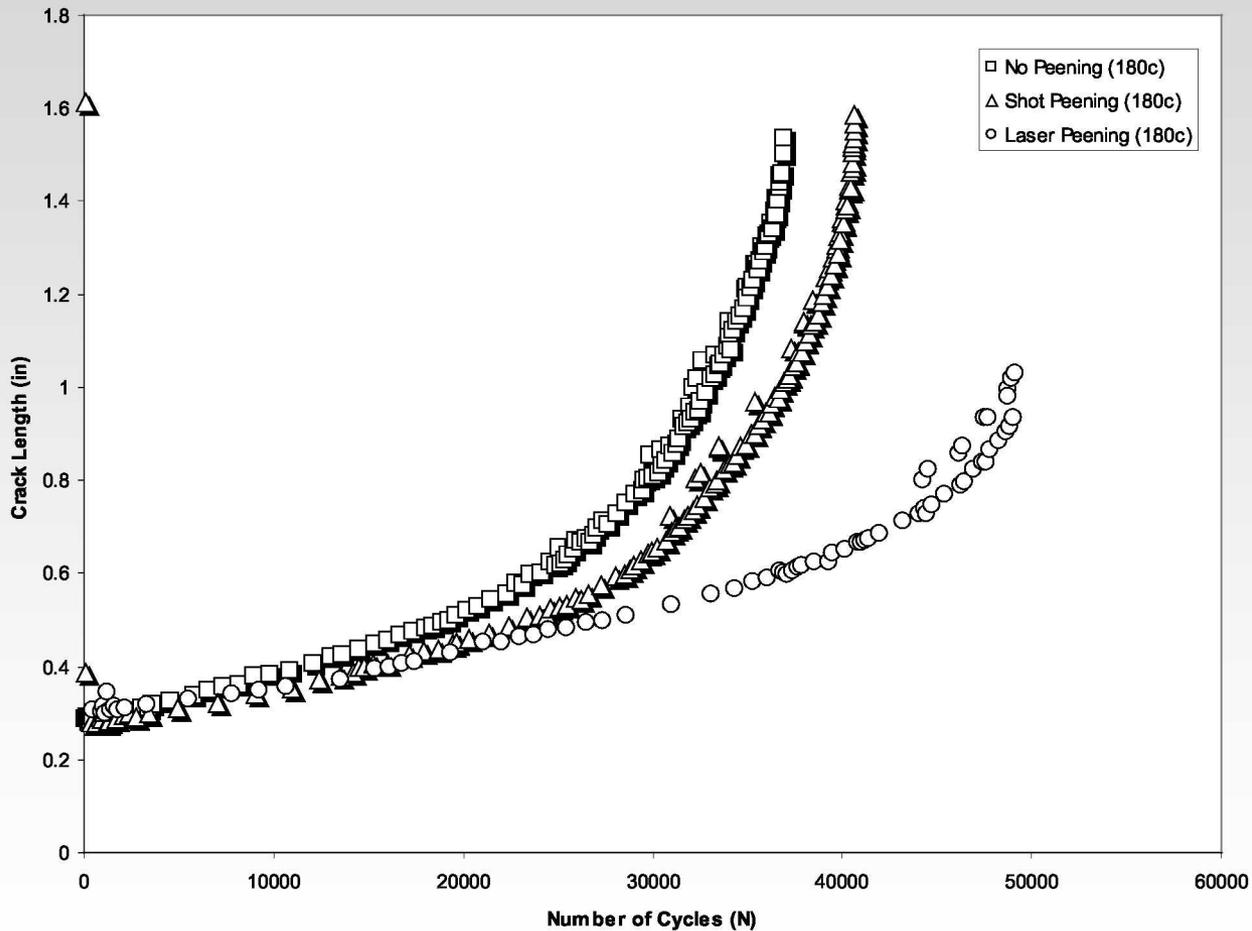


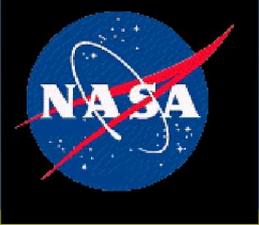
# *a vs. N for R=0.7 (RT)*



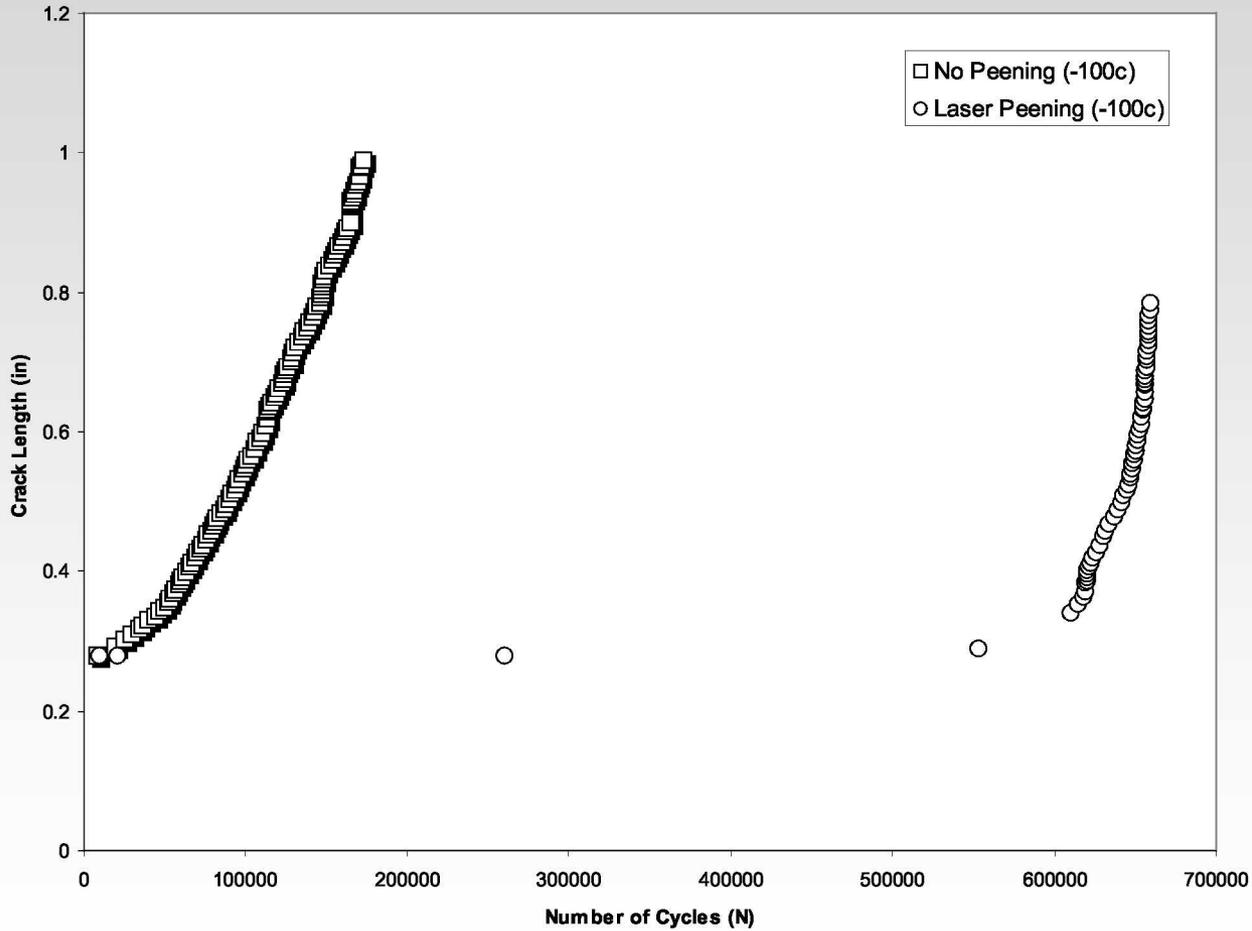


# *A vs. N for $R=0.1$ (180c)*



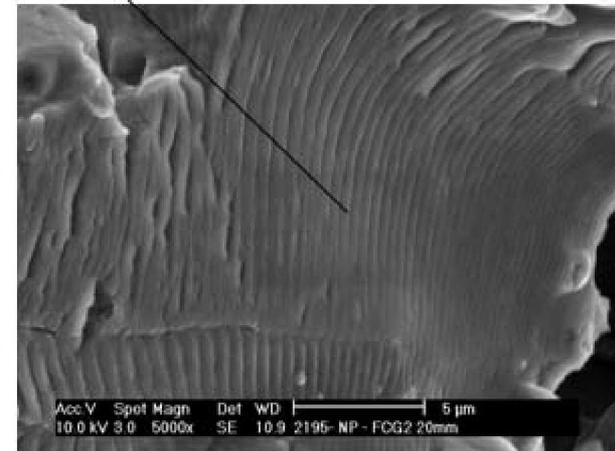
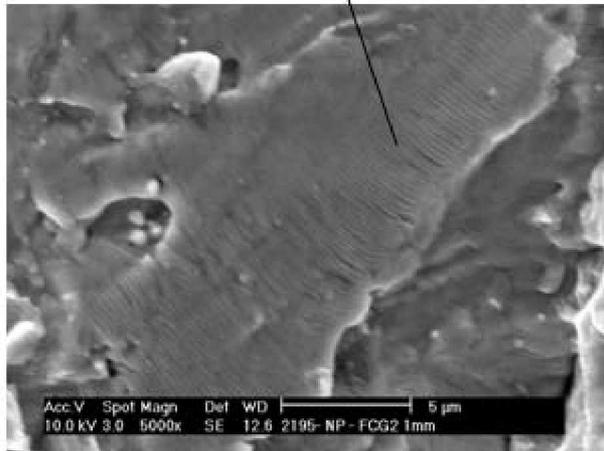
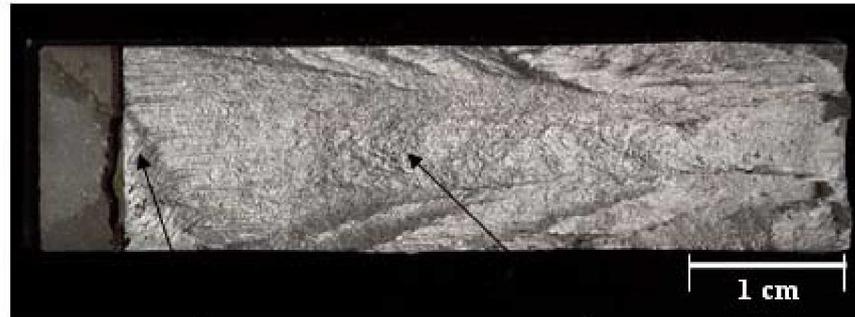


# *A vs. N for $R=0.1$ (-100c)*





# Fractured Surfaces



Fractured surface and fatigue striations of an unpeened sample at  $R=0.1$

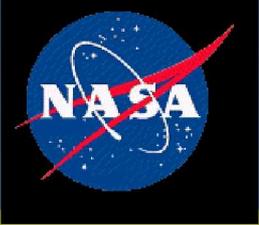


Conclusions



# Research Program





# Conclusions

- The laser peening process can result in considerable improvement to crack initiation, propagation, and mechanical properties in FSW
  - *Longer hardware service life*
- Improve processed 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***



**Thank You !**