Friction Plug Weld Repair Geometric Innovations

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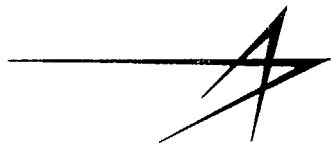
Introduction



- **Fundamentals of Friction Push Plug Welding**
  - **Process Overview**
- **Fundamentals of Friction Pull Plug Welding**
  - **Process Overview**
  - **Defect Characterization**
  - **Geometric and Process Solutions**
- **FSW Keyhole Closeout**

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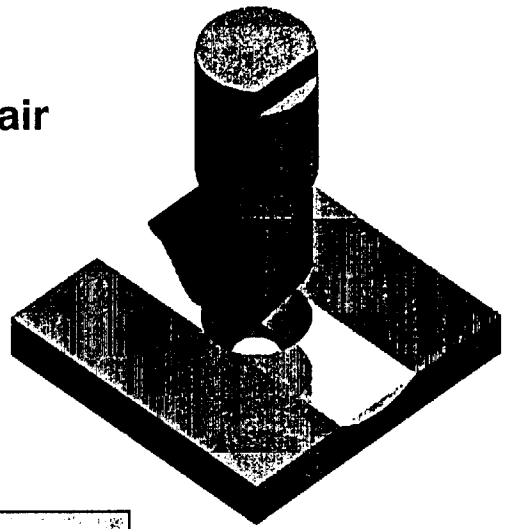
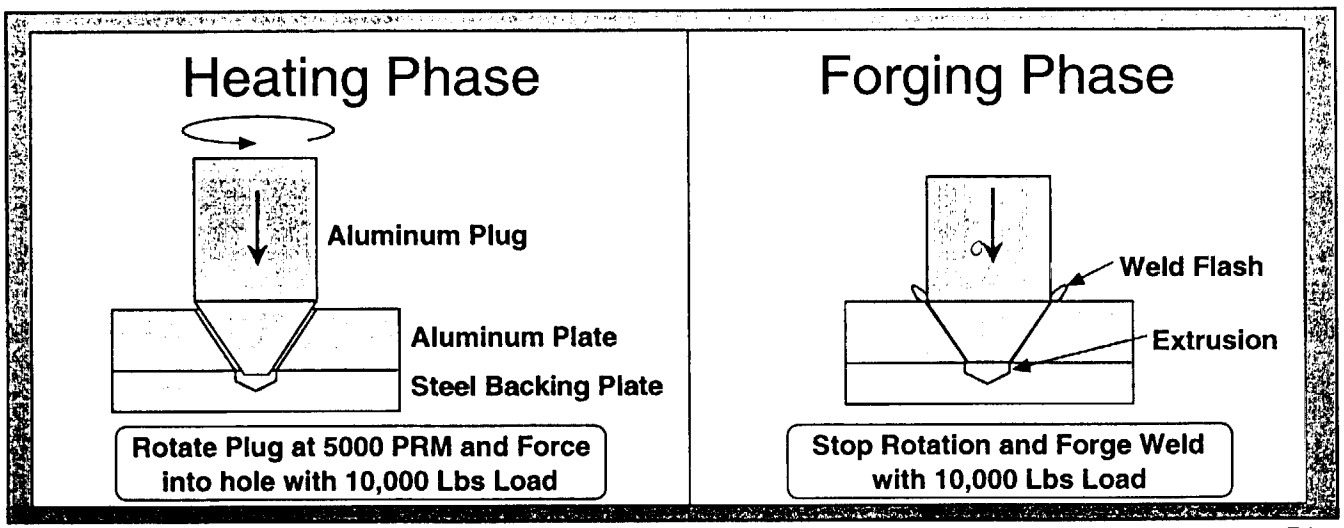
Friction Push Plug Overview

- Friction Plug Welding Is a Solid State Weld Repair Technique Aimed at Replacing Small Volumes of Defective Weldment
- Computer Controlled Direct Drive Weld Equipment
  - High Process Repeatability; Successful First Time Repair
- Thermomechanical, solid state welding process
  - Rotate tapered plug and force into tapered hole.
  - Stop rotation and forge materials together while cooling.
  - Remove excess plug and back side extrusion.





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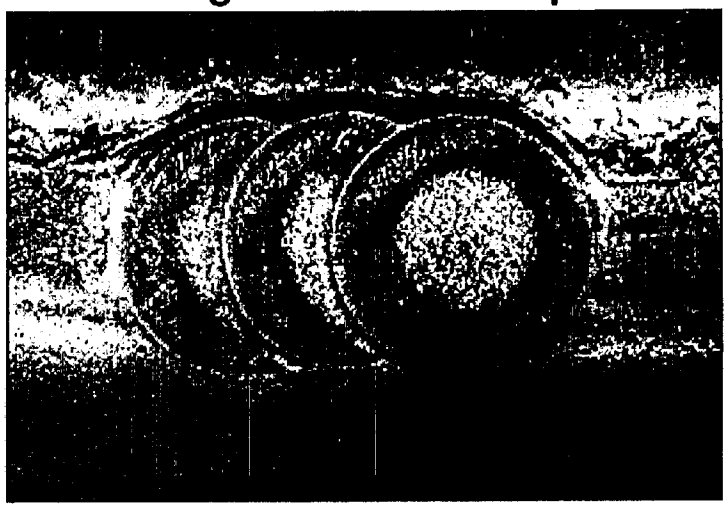
Friction Push Plug Overview

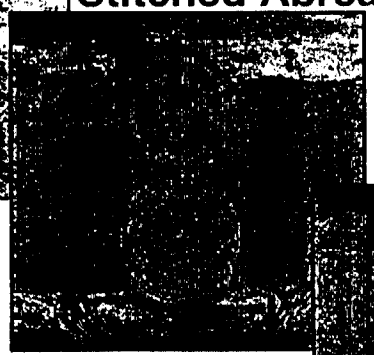
- Extended Process Capabilities
  - Plugs placed off weld centerline
  - Stitch Welding can be utilized to repair defects larger than one plug diameter
  - FSW closeout holes can be repaired

3 Plug Stitch Weld Repair

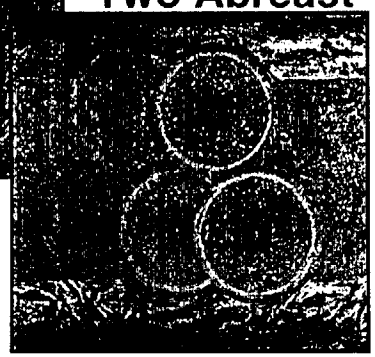


Off-Center Repair

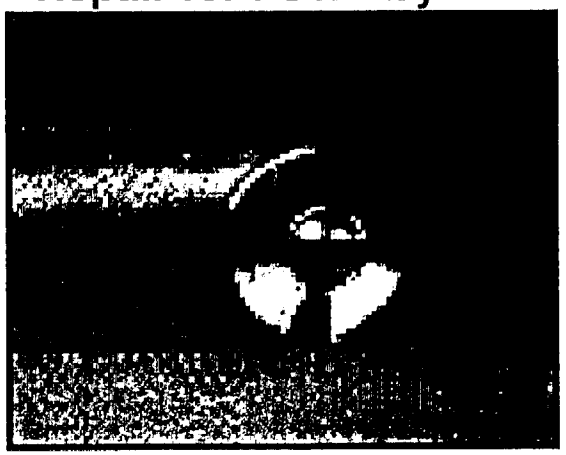
Stitched Abreast



Two Abreast



Repair for FSW Keyhole



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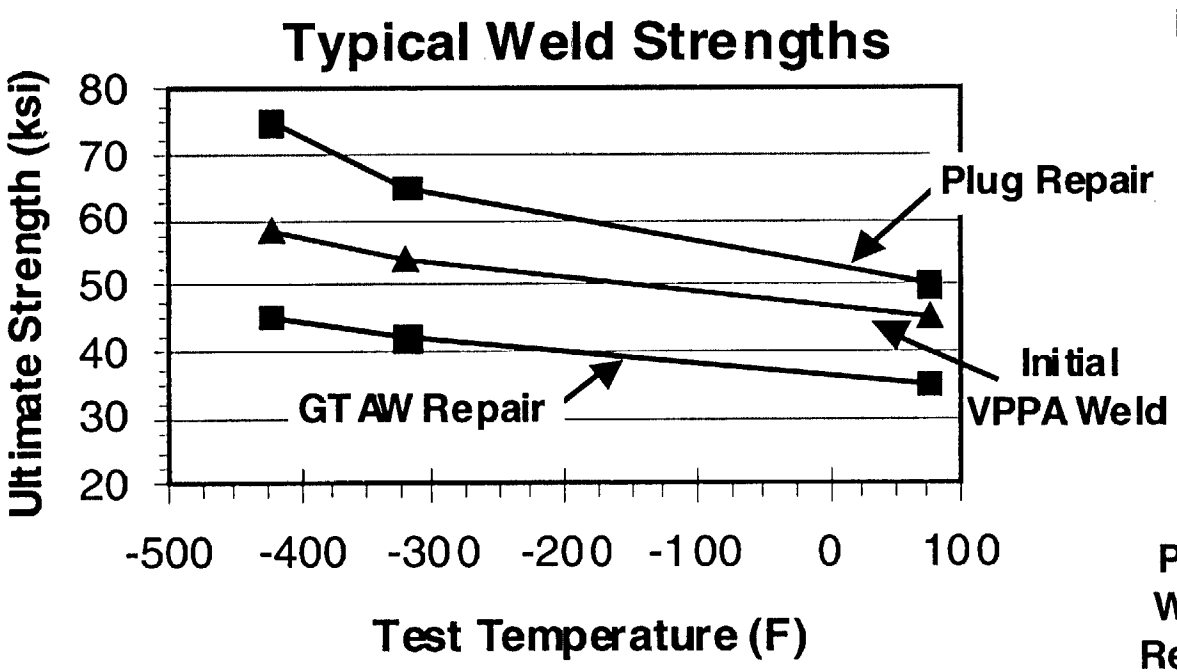
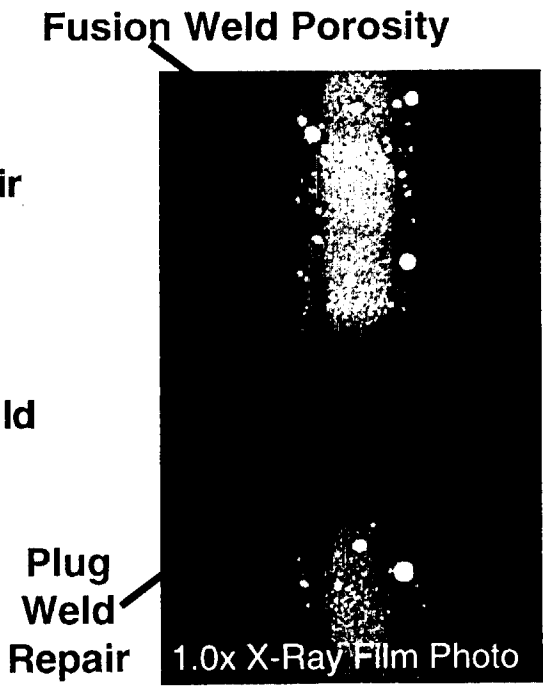
Friction Push Plug Overview

- The effects of all critical parameters have been characterized
- Process capability is above the specification requirements
- Process automation is superior to the required process control
- Mechanical properties are significantly better than current repair allowables





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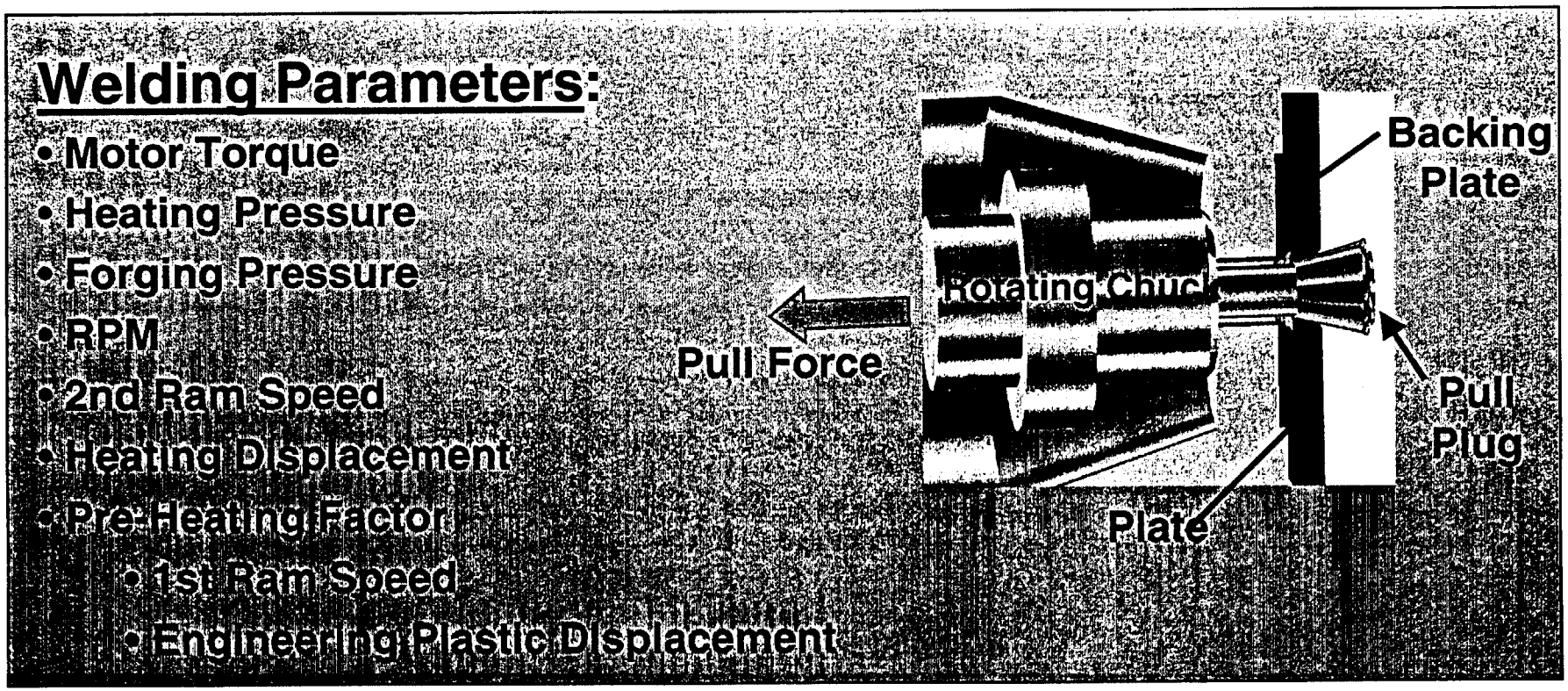
Friction Pull Plug Overview

US Patents Pending: #60/057,111; 153,750; 156,734; 160,131

Friction Pull Plug Welding is a solid state welding variant of the push process which is aimed at eliminating all internal tooling for tank wide plug repairs.



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Friction Pull Plug Overview

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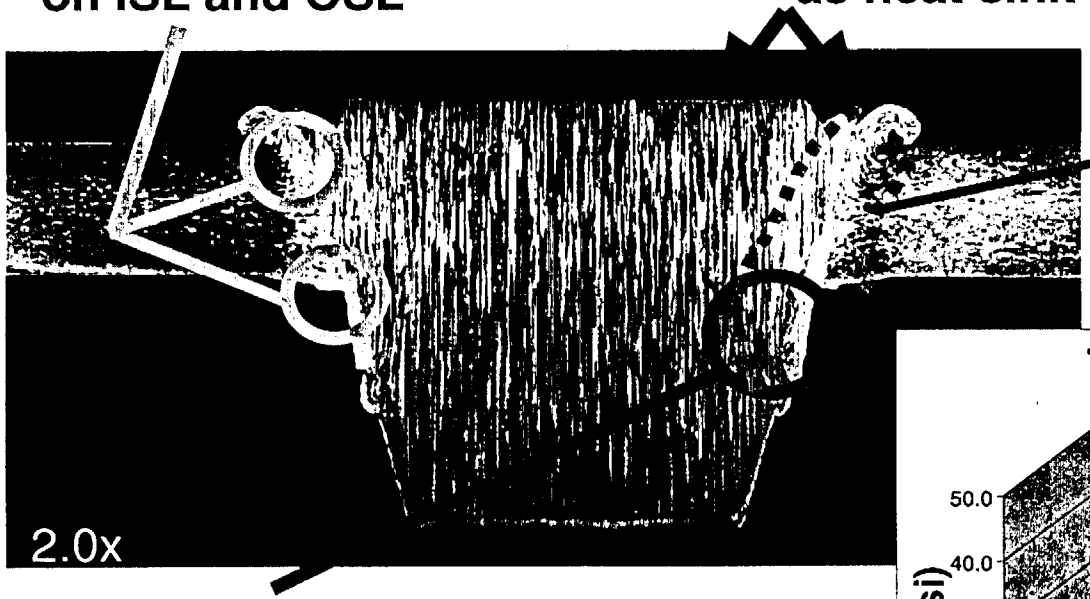
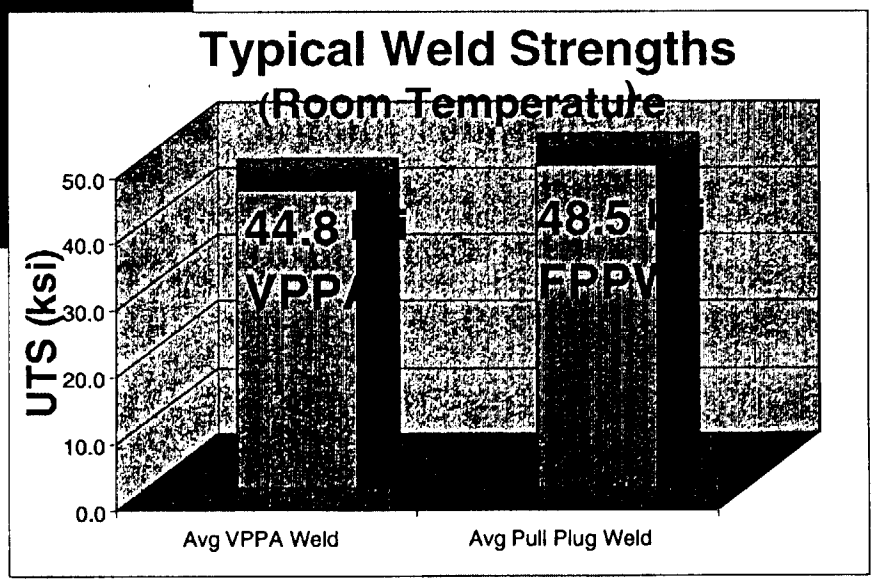
Complete bonding on ISL and OSL

Minimal plug material as heat sink



Heating localized to interface

Plug and plate forging from backing plate



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FPPW: Defect Characterization

Observed Defects

1. Rotational stall during initial plug/plate contact
2. Bottom side lack of bonding (OSL)
3. Rotational stall during welding
4. Top side lack of bonding (ISL)
5. Complete plug pull through
6. Central plug pull through
7. Top Hat separation
8. Weak Interfacial Bonding

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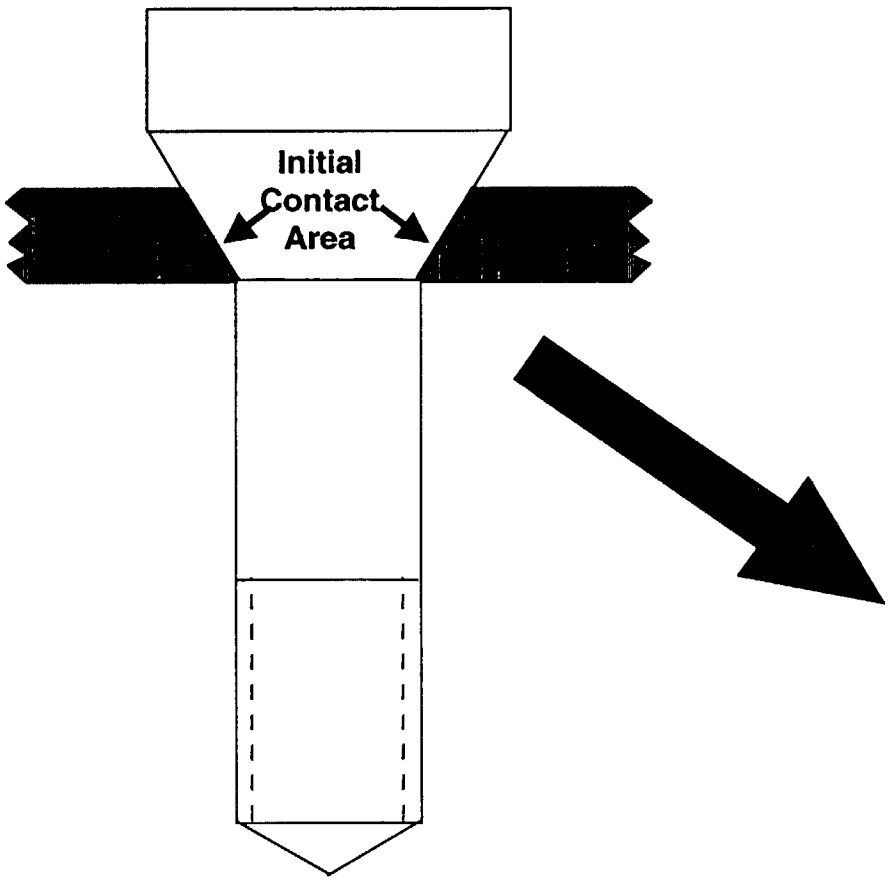
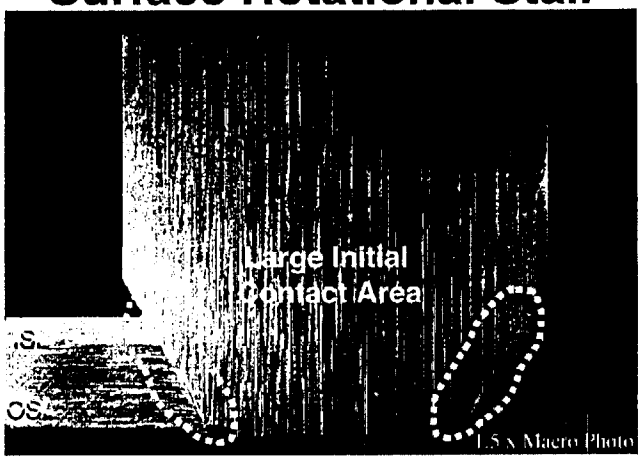
FPPW: Surface Rotational Stall

US Patents Pending: #60/057,111; 153,750; 156,734; 160,131

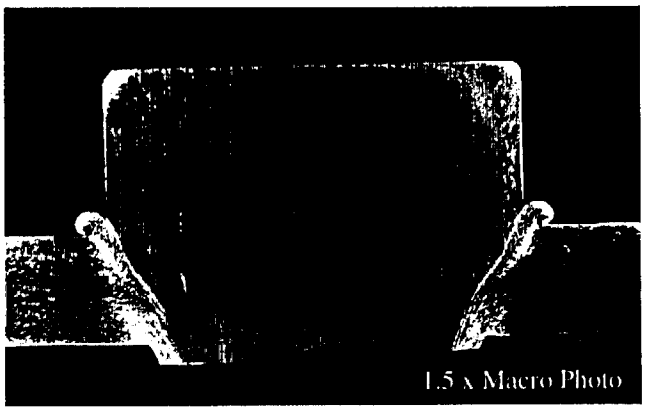
Matching Plug & Plate Hole Chamfer Angle



Surface Rotational Stall



Pull Plug Necking



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FPPW: Surface Rotational Stall

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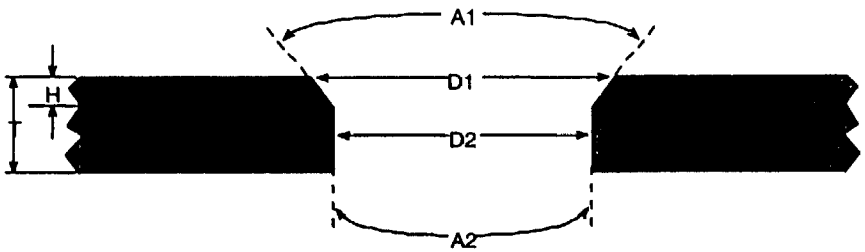
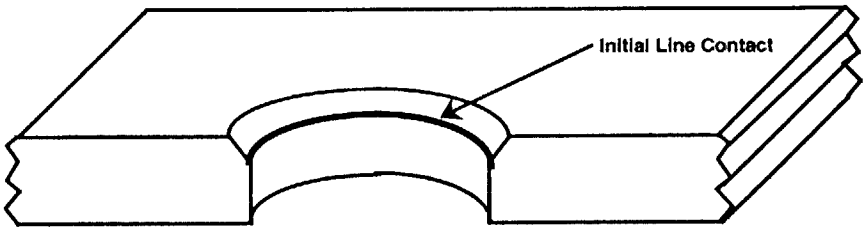
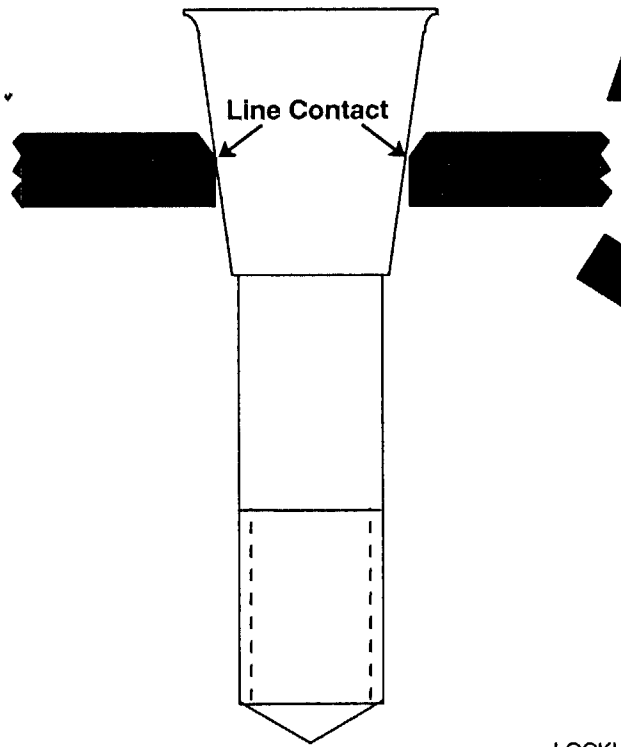
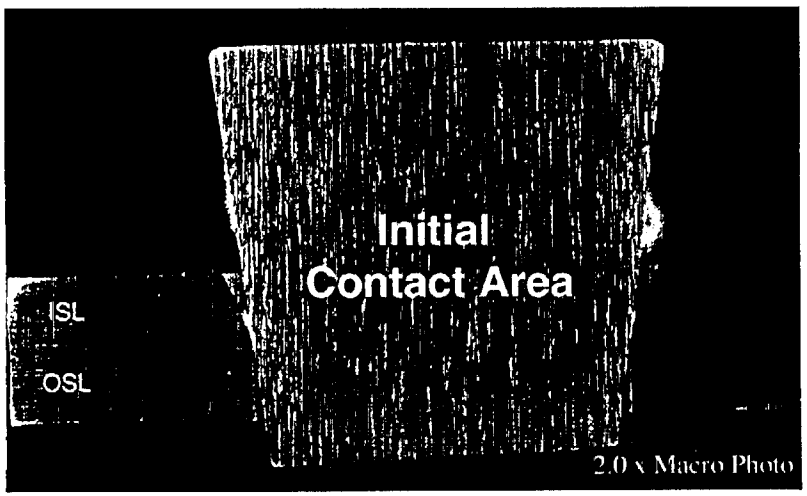
Dual Chamfered Plate Hole







Process stopped after initial contact



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FPPW: OSL Lack of Bonding

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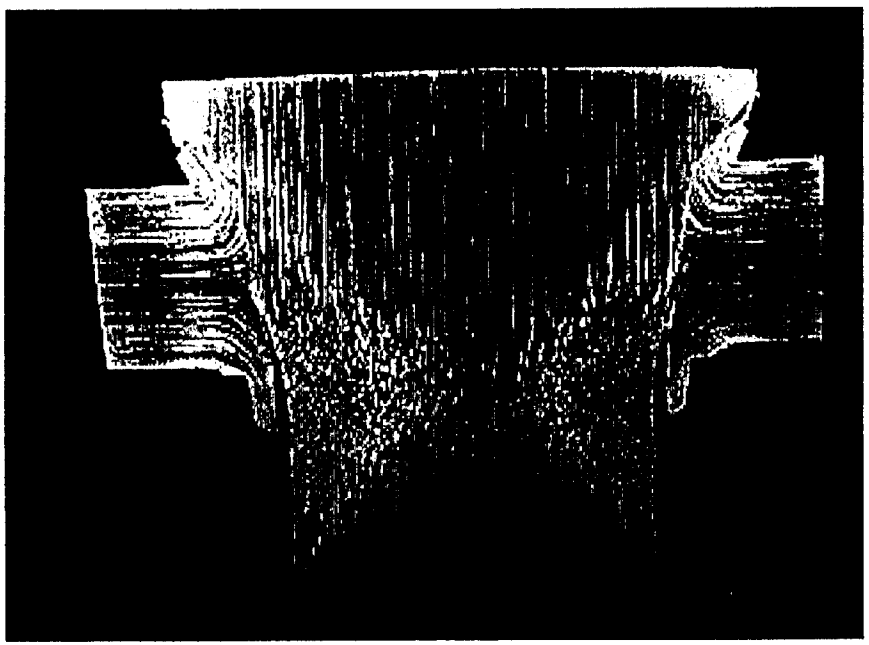
Possible Causes

- Backing plate geometry
- Material geometry
- Weld Parameters
  - High heat input
  - High Forging Pressure

Lack of Bonding Bottom (OSL)



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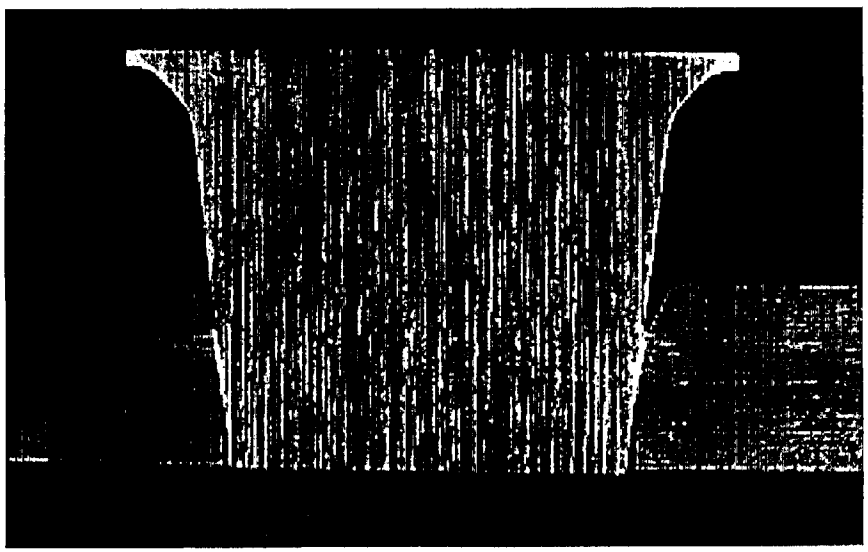
FPPW: Rotational Stall During Welding

US Patents Pending: #60/057,111; 153,750; 156,734; 160,131

Possible Causes

- Weld Parameters
  - Insufficient Pre-Heating
  - 2nd Ram Speed too high
  - RPM too low
- Backing plate geometry
- Material geometry
- Equipment Limitations

Rotational stall during welding



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FPPW: ISL Lack of Bonding

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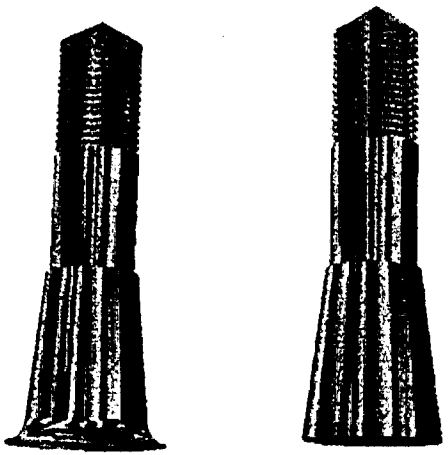
The Pull Plug Top Hat provides both pressure and frictional heating to complete ISL bonding.

Pull Plug Designs

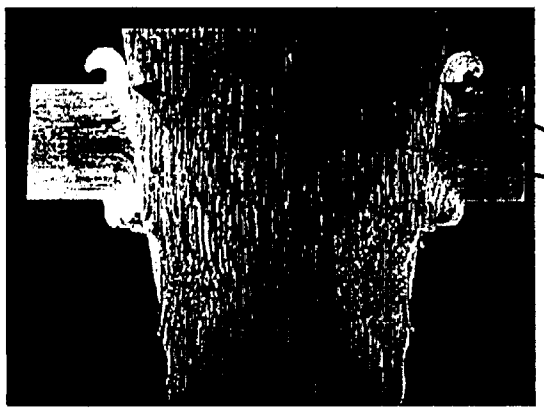


With Top Hat Without

Pull Plug With Top Hat

Bonding

Pull Plug Without Top Hat



Lack of Bonding

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FPPW: Chamfered Heat Sink

US Patents Pending: #60/057,111; 153,750; 156,734; 160,131

Diagram of a Pull Plug with a Large Heat Sink Mass

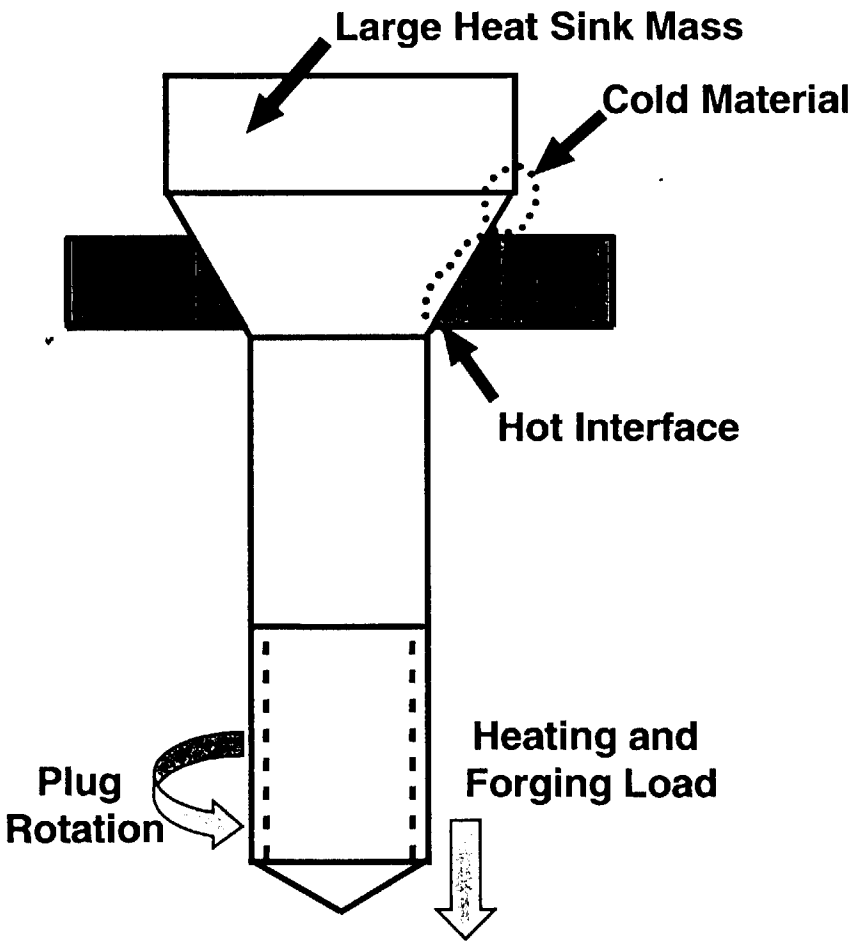
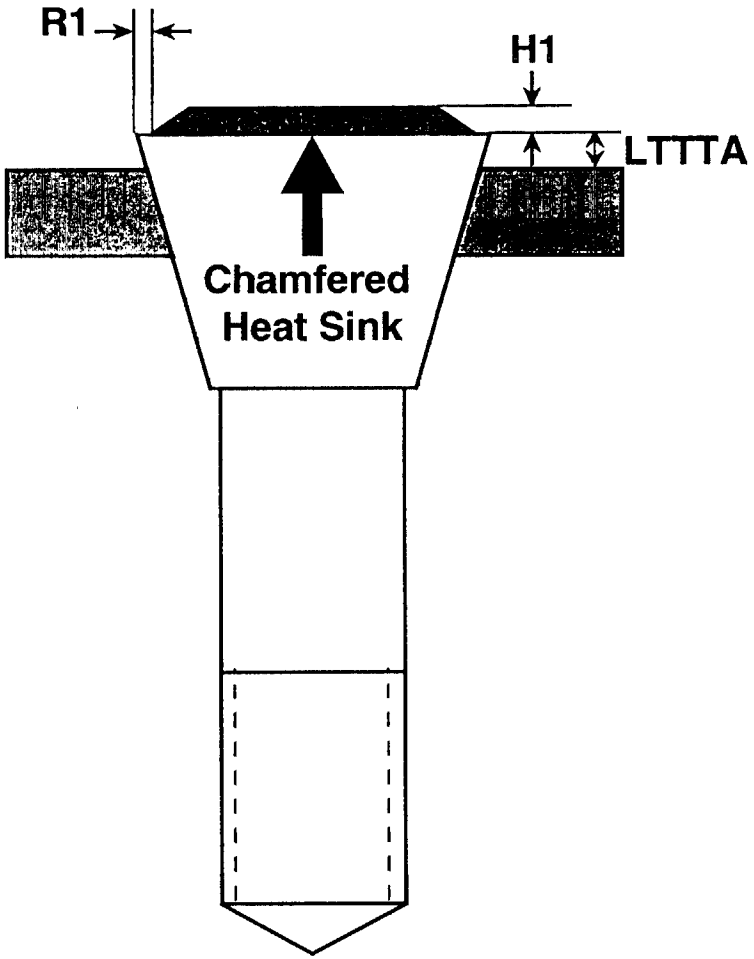


Diagram of a Pull Plug with a Chamfered Heat Sink



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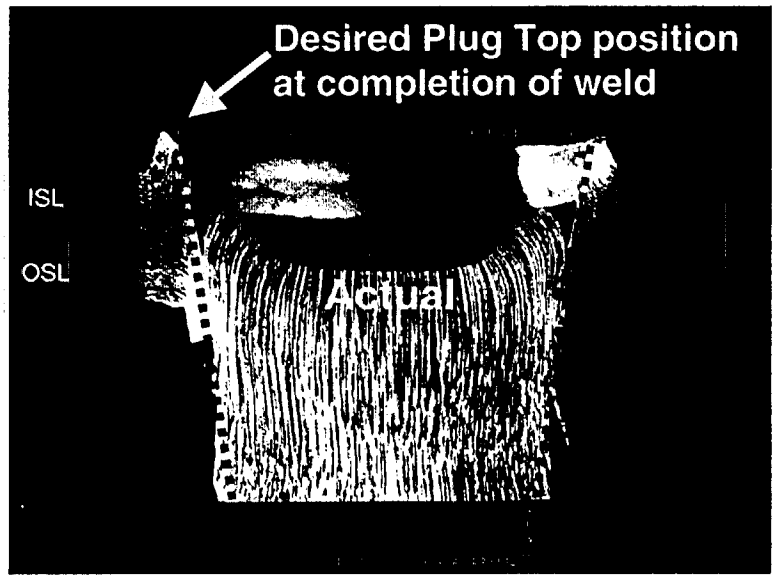
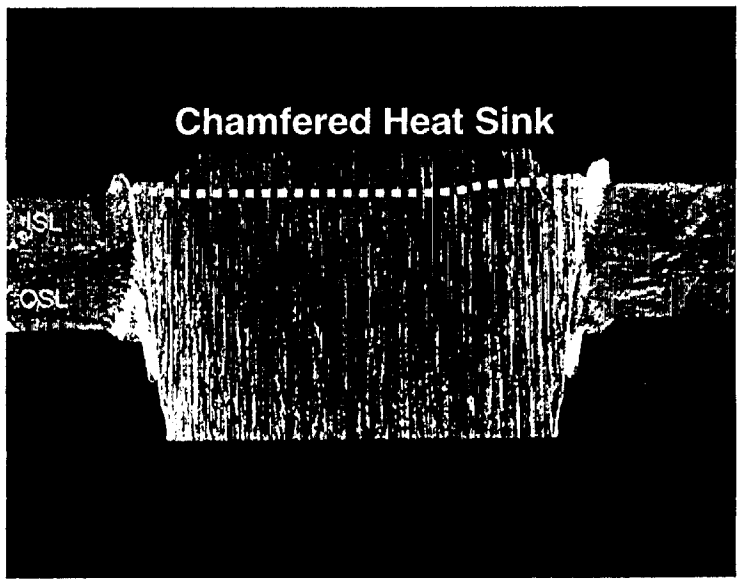
FPPW: Complete Plug Pull Through

US Patents Pending: #60/057,111; 153,750; 156,734; 160,131

Interfacial Plug Pull-through
(Low Angle Pull Plug without a Chamfered Heat Sink)



"Good" Pull Plug Weld
(Low Angle Pull Plug with Chamfered Heat Sink)



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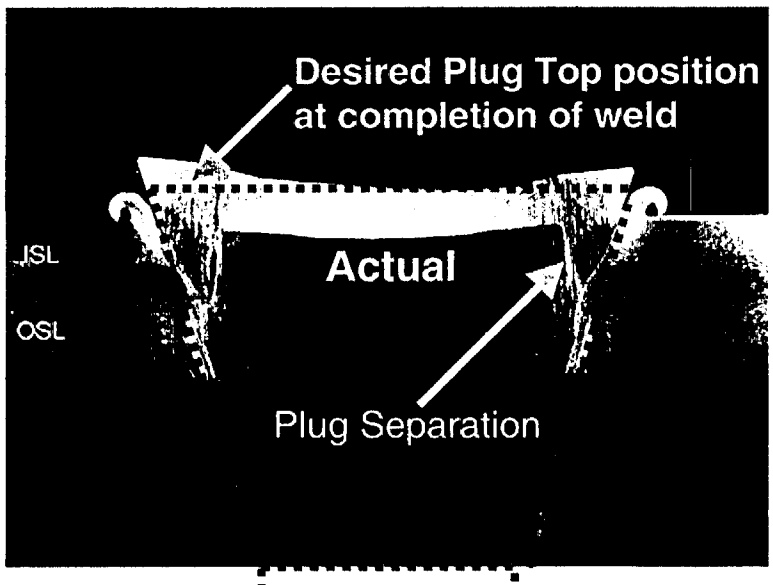
FPPW: Central Plug Pull Through

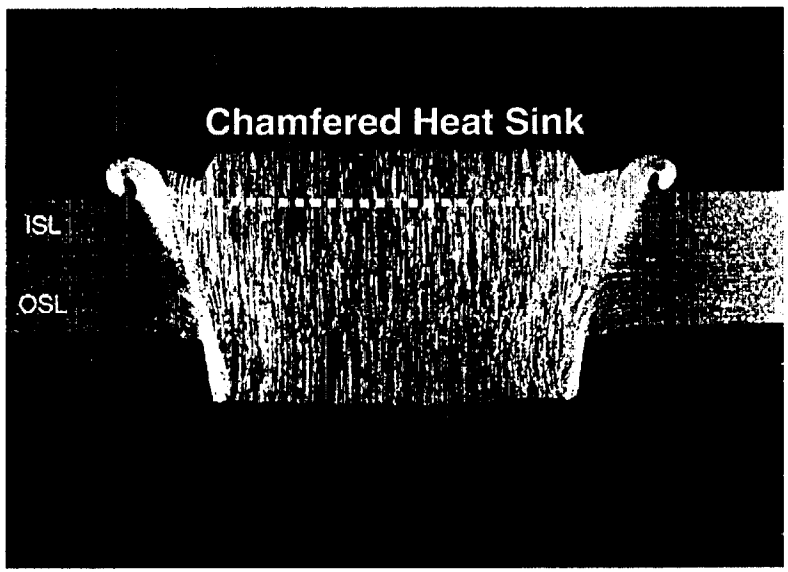
US Patents Pending: #60/057,111; 153,750; 156,734; 160,131

Central Plug Pull-through
(High Angle Pull Plug without a Chamfered Heat Sink)



30 Degree Pull Plug

"Good" Pull Plug Weld
(High Angle Pull Plug with Chamfered Heat Sink)



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FPPW: Top Hat Separation

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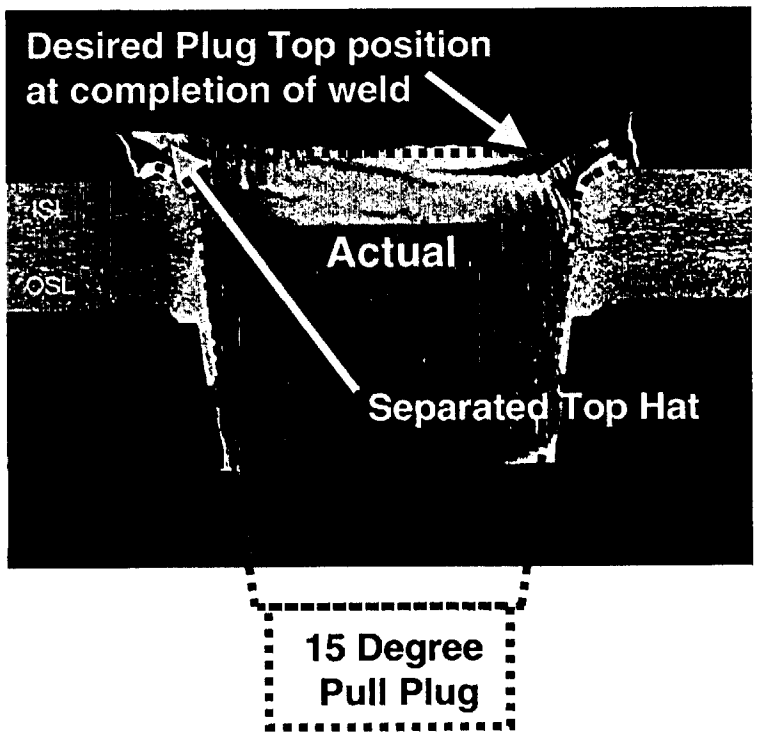
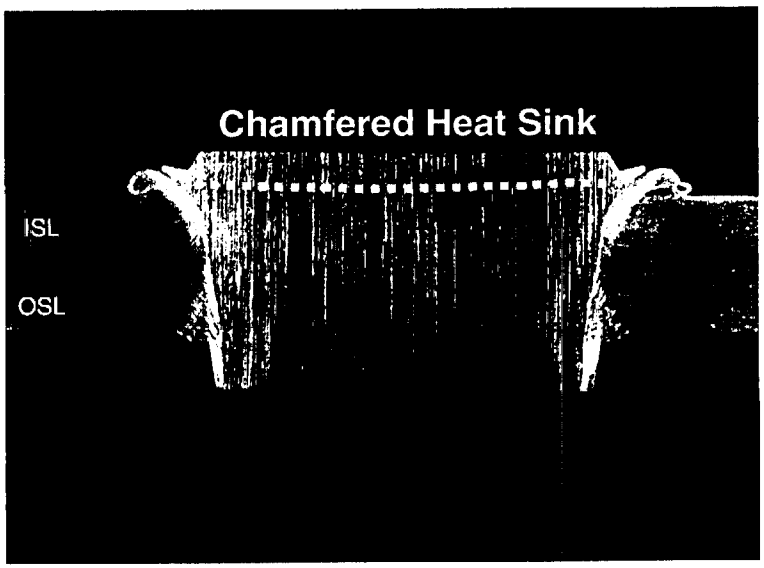
Top Hat Separation
(Low Angle Top Hat Pull Plug without a Chamfered Heat Sink)



"Good" Pull Plug Weld
(High Angle Pull Plug with Chamfered Heat Sink)



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FPPW: Typical Fractures

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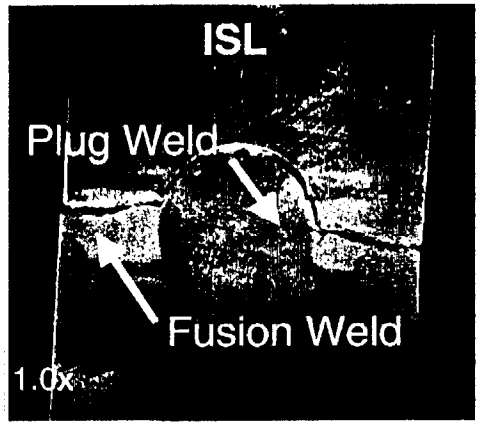
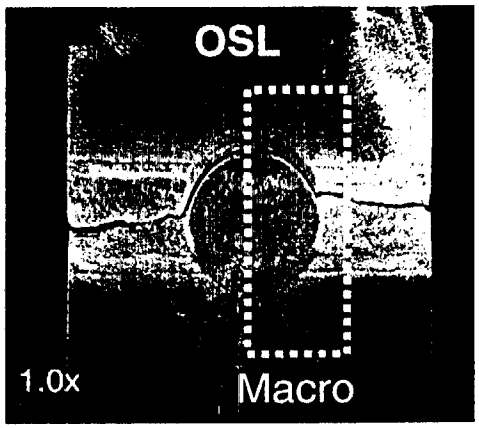
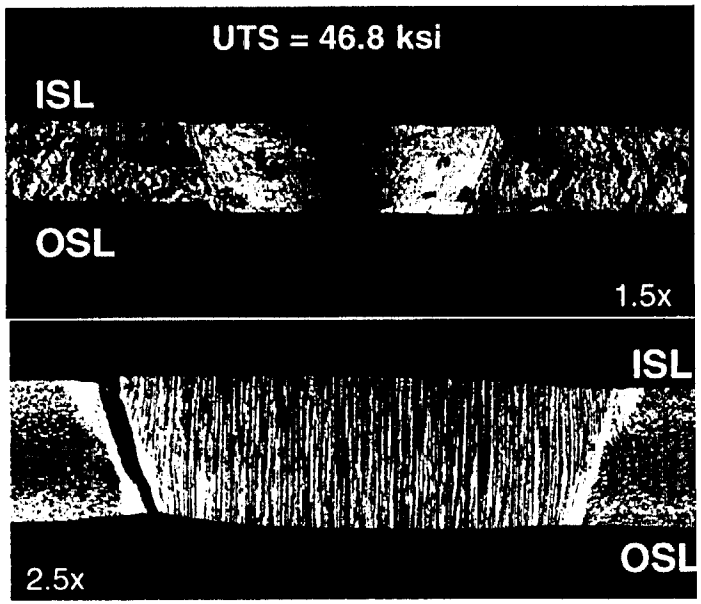
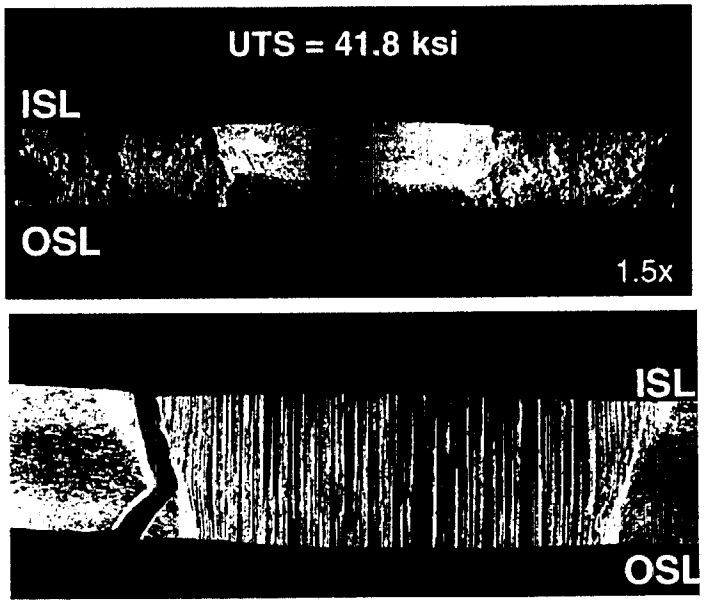




Interfacial Fracture Path



Interfacial / HAZ Fracture Path



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FPPW: Weak Bonding

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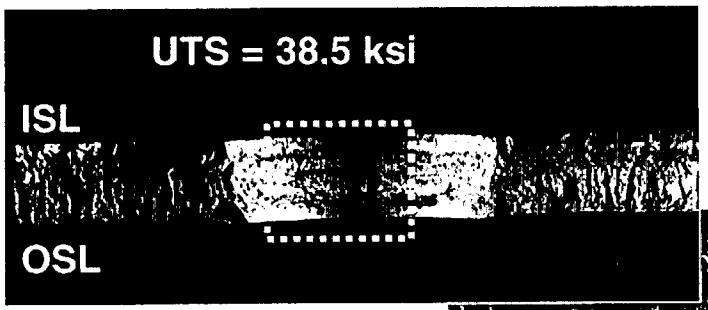
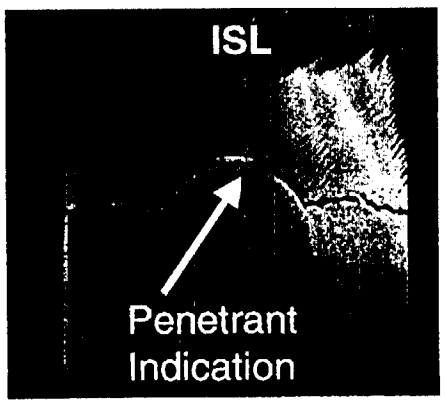
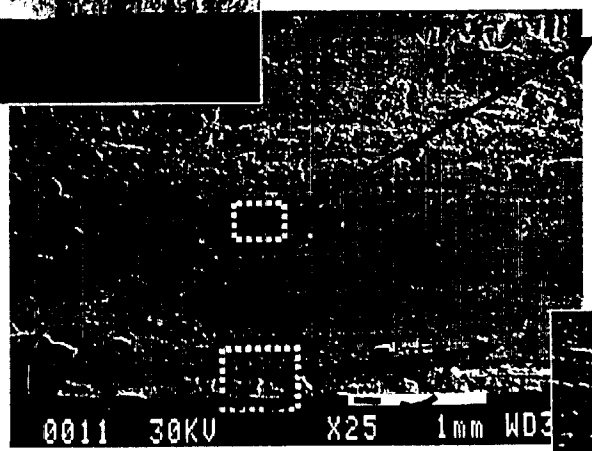
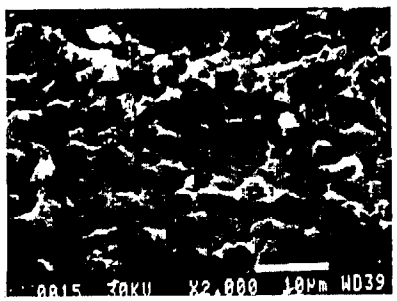
Bonding observed in all SEM examined locations



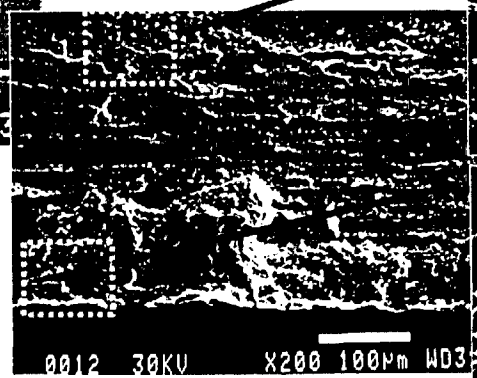


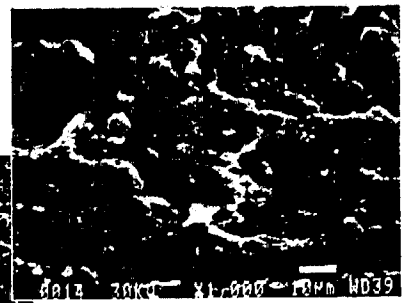


Peak



Valley





Pentrant Indication Reference on Fracture Surface

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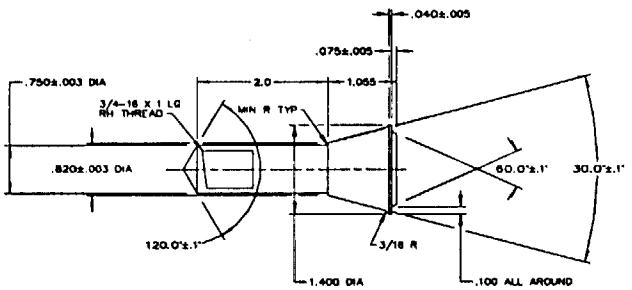
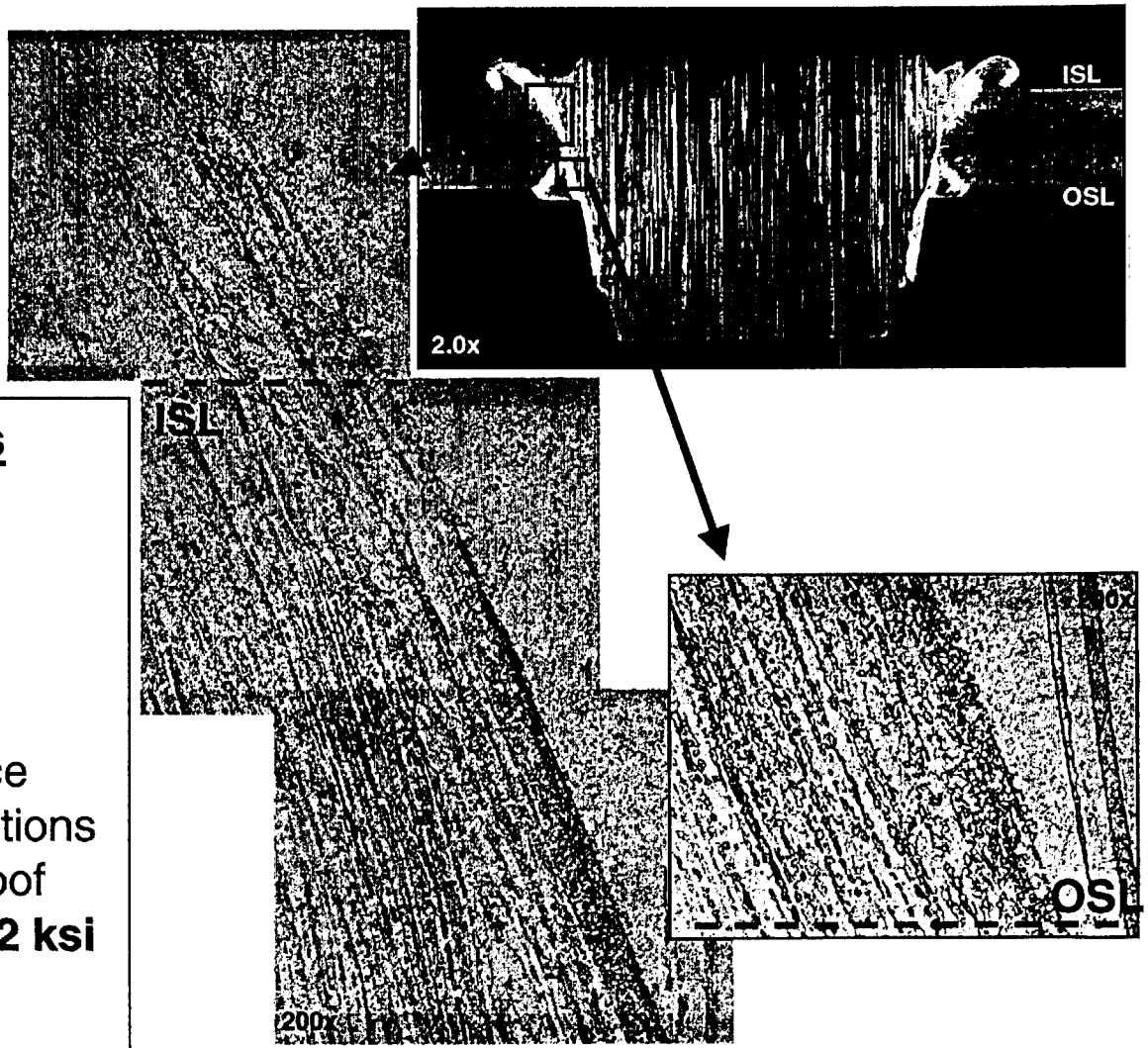
FPPW: 0.040" Thick Top Hat

US Patents Pending: #60/057,111; 153,750; 156,734; 160,131





Expected Benefits

- Reduced Edge Heating
- Increased Axial/Radial Pressure

Results

- Lamellar Tearing @ hat
- Shear zones along interface
- Pre/Post Proof NDE Indications
- 3 samples failed during proof
- **Int. Weld Avg. UTS = 41. 2 ksi**
- **Avg. UTS = 30.7 ksi**
- **Min. UTS = 23.2 ksi**

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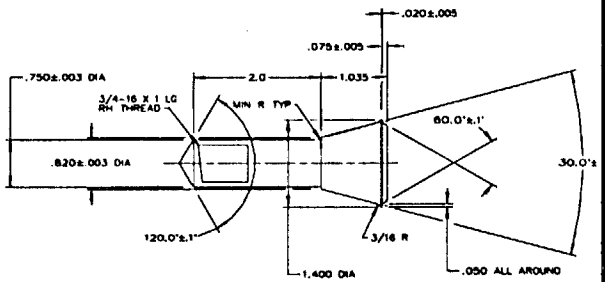
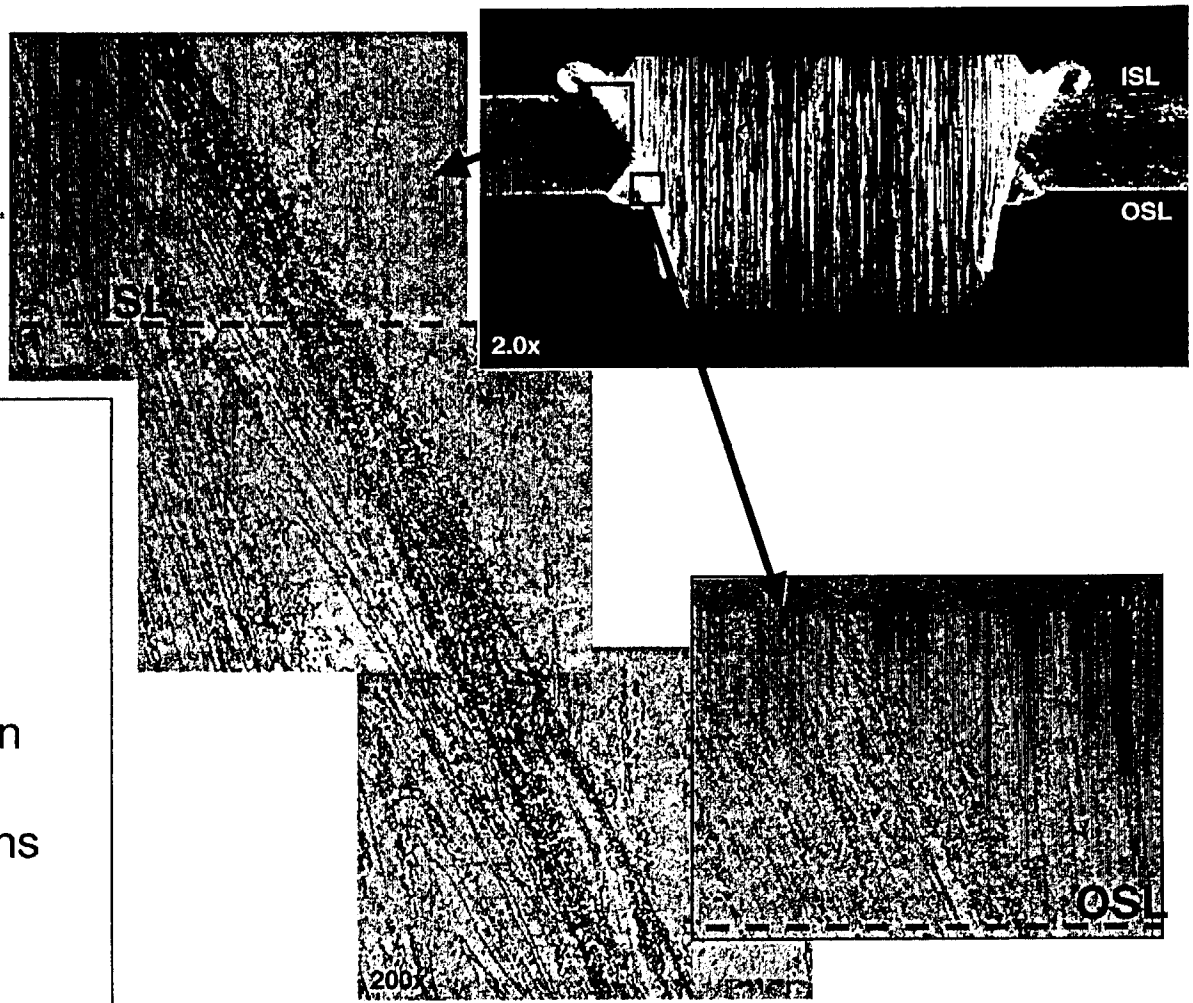
FPPW: 0.050" All Around Top Hat

US Patents Pending: #60/057,111; 153,750; 156,734; 160,131





Expected Benefits

- Reduced Edge Heating
- Increased Axial/Radial Pressure

Results

- Minimal top hat deflection
- Tight recrystallized zone
- Pre-Proof NDE Indications
- 6 samples failed during proof - **Test Stopped**
- **Min. UTS = 24.4 ksi**

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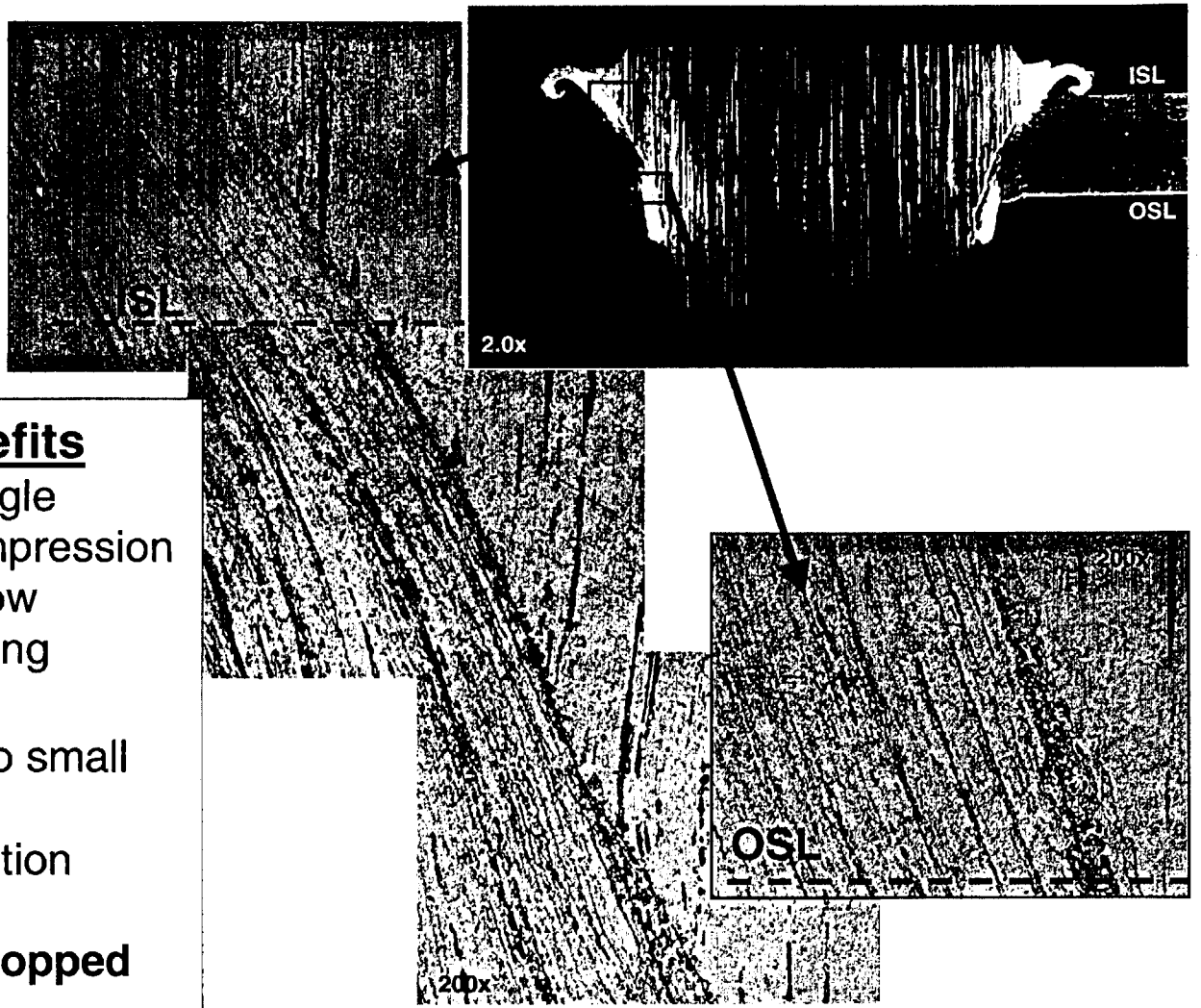
FPPW: Transition Plug (Style #1)

US Patents Pending: #60/057,111; 153,750; 156,734; 160,131



Expected Benefits

- Variable interfacial angle
  - Increased axial compression
  - Increased plastic flow
  - More frictional heating

Results

- Plug min. diameter too small
  - Plug pull through
  - Central plug separation
  - Minimal OSL flash
- Only macros - **Test Stopped**

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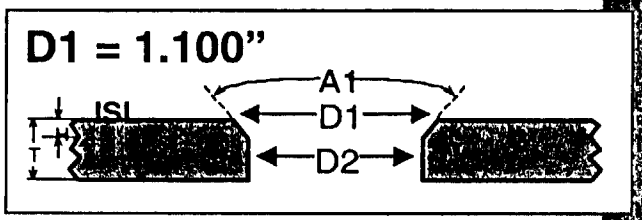
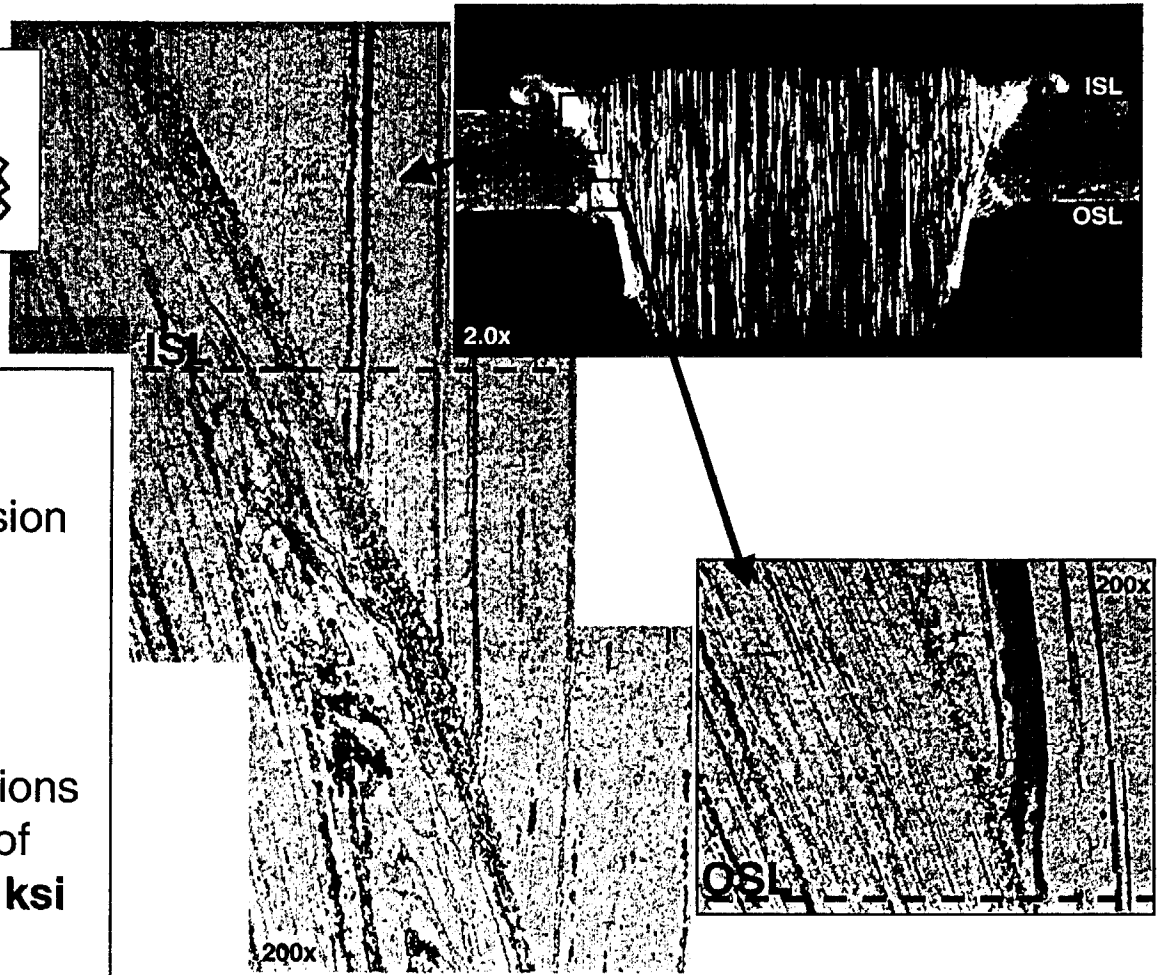
FPPW: 1.100" Diameter Top Chamfer Hole

US Patents Pending: #60/057,111; 153,750; 156,734; 160,131





Expected Benefits

- Line contact closer to ISL
  - Increased axial compression
  - Increased plastic flow
  - More frictional heating

Results

- Tight recrystallized zone
- Pre/Post Proof NDE Indications
- 7 samples failed during proof
- **Int. Weld Avg. UTS = 37.0 ksi**
- **Avg. UTS = 32.3 ksi**
- **Min. UTS = 22.1 ksi**

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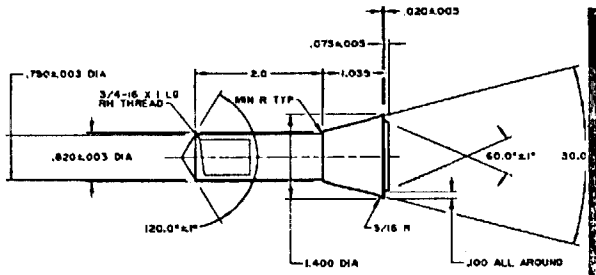
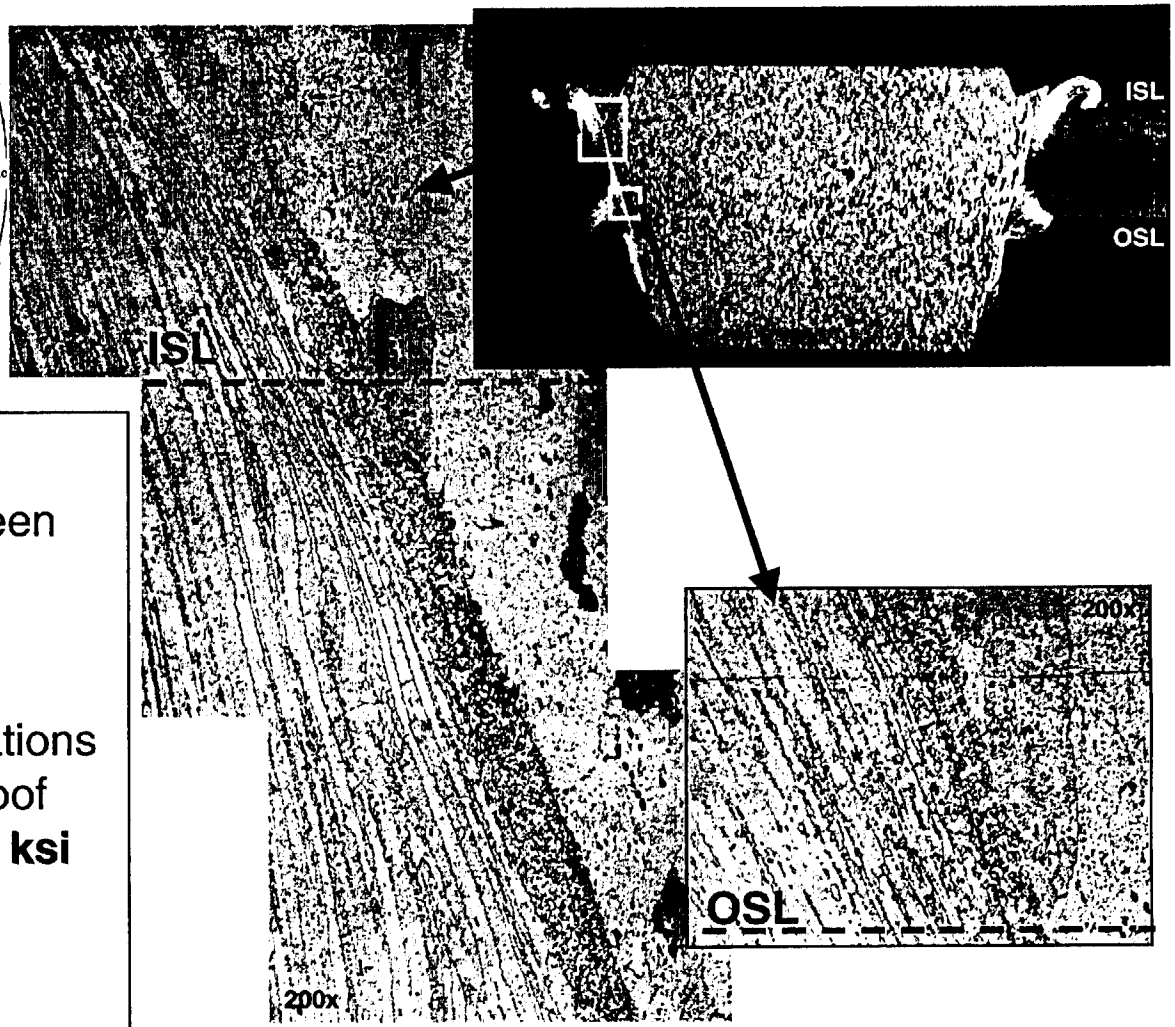
FPPW: Standard plug from 2219-T8

US Patents Pending: #60/057,111; 153,750; 156,734; 160,131





Expected Benefits

- Modified heat profile between plug and plate

Results

- Tight recrystallized zone
- Pre/Post Proof NDE Indications
- 3 samples failed during proof
- **Int. Weld Avg. UTS =40.5 ksi**
- **Avg. UTS = 33.9 ksi**
- **Min. UTS = 22.7 ksi**

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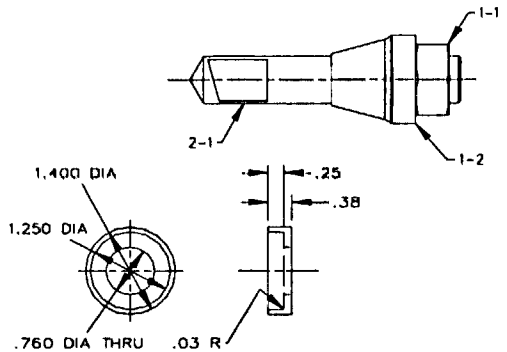
FPPW: ISL Compressive Restraint Plug

US Patents Pending: #60/057,111; 153,750; 156,734; 160,131

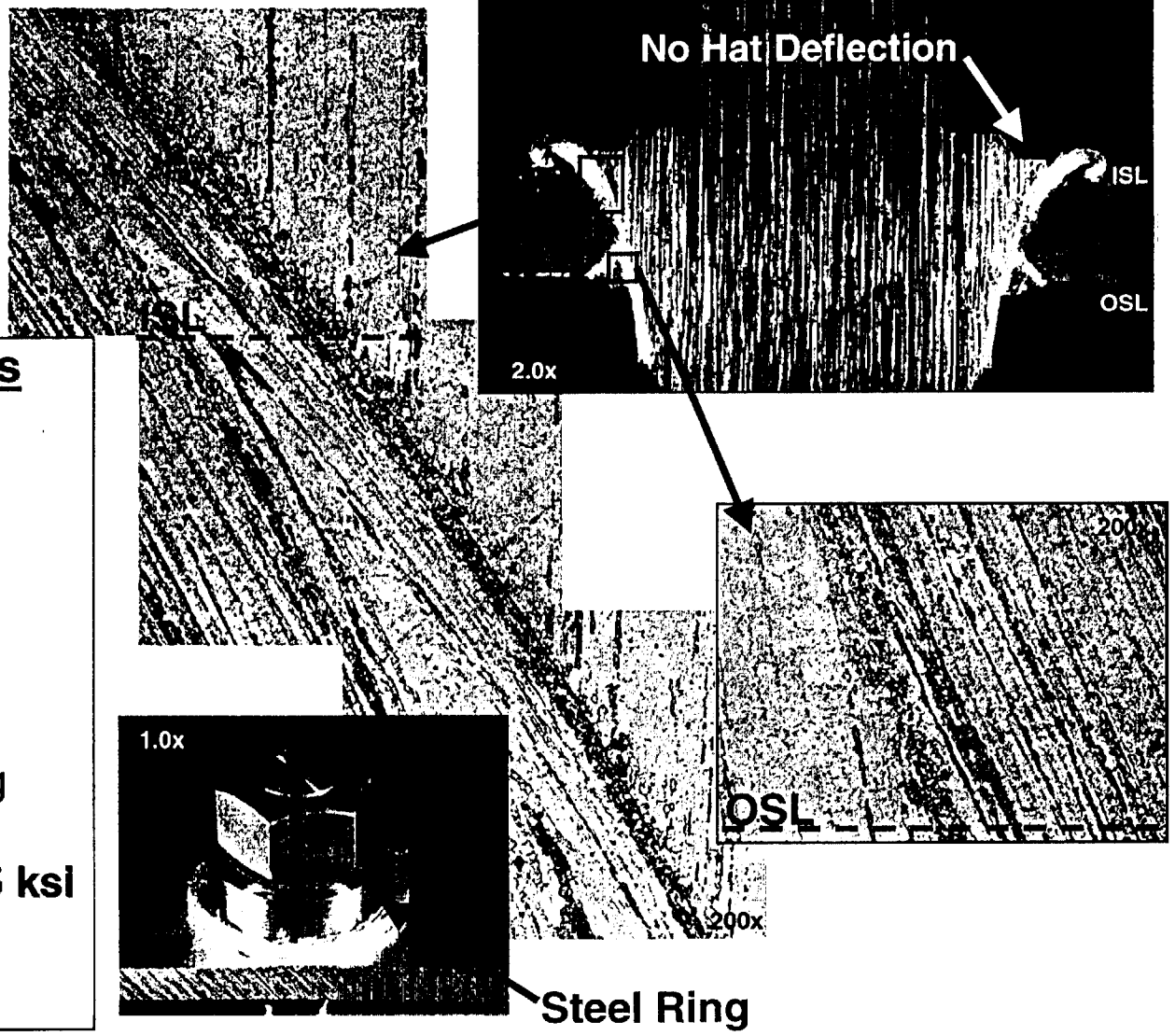


Expected Benefits

- Restrained top hat movement - increased axial/radial pressure
- Heat profile modified

Results

- No Top hat bending
- Tight/linear interface
- 7 samples failed during proof -**Test Stopped**
- **Weld Avg. UTS = 43.5 ksi**
- **Avg. UTS = 28.3 ksi**
- **Min. UTS = 22.6 ksi**



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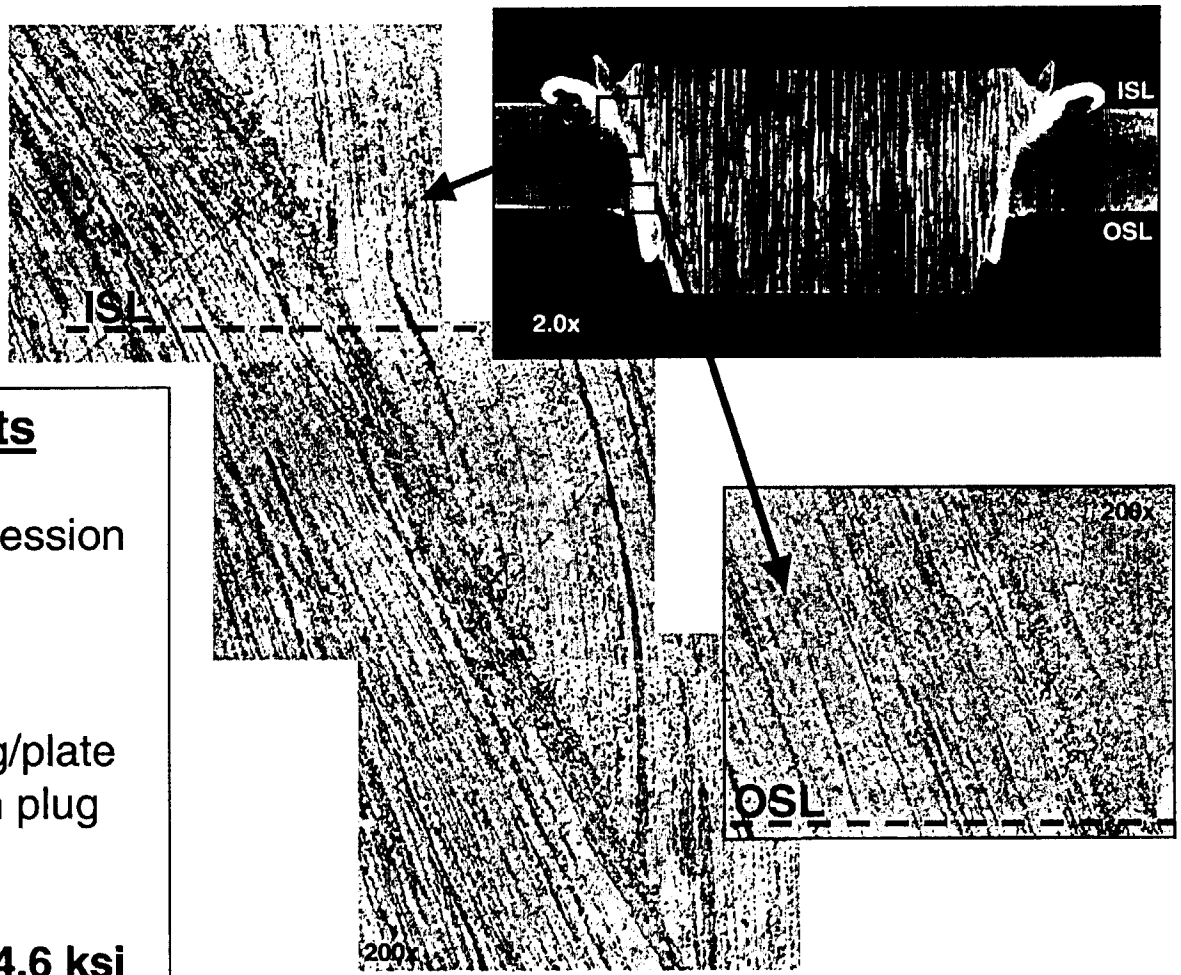
FPPW: Transition Plug (Style #2)

US Patents Pending: #60/057,111; 153,750; 156,734; 160,131



Expected Benefits

- Variable Interface Angle
  - Increased axial compression
  - Increased plastic flow
  - More frictional heating

Results

- Clean interface btw. plug/plate
- Deformation observed in plug
- **No** Pre/Post Proof NDE Indications
- **Int. Weld Avg. UTS = 44.6 ksi**
- **Avg. UTS = 49.4 ksi**

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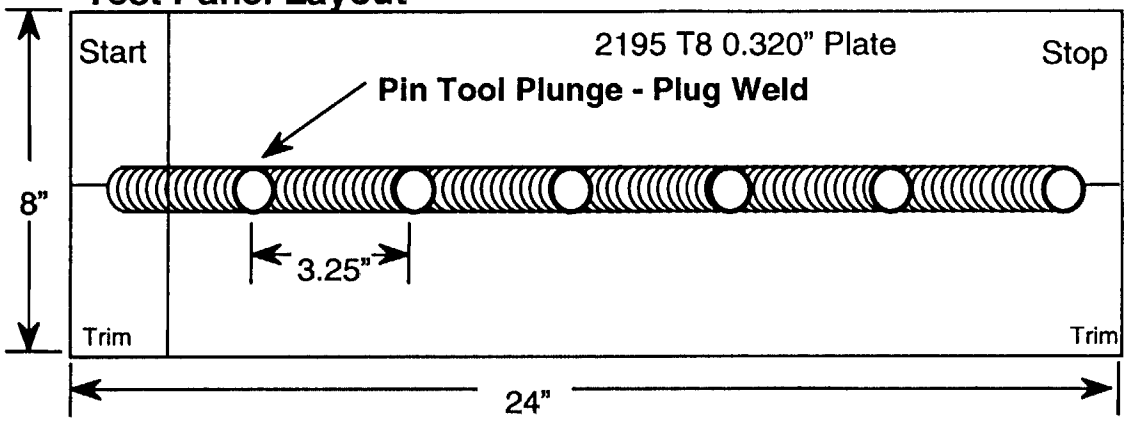
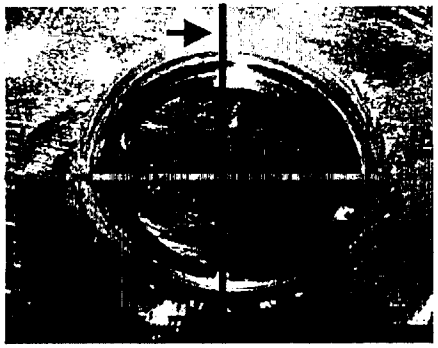
FPPW of FSW Keyhole

US Patents Pending: #60/057,111; 153,750; 156,734; 160,131

Test Panel Layout



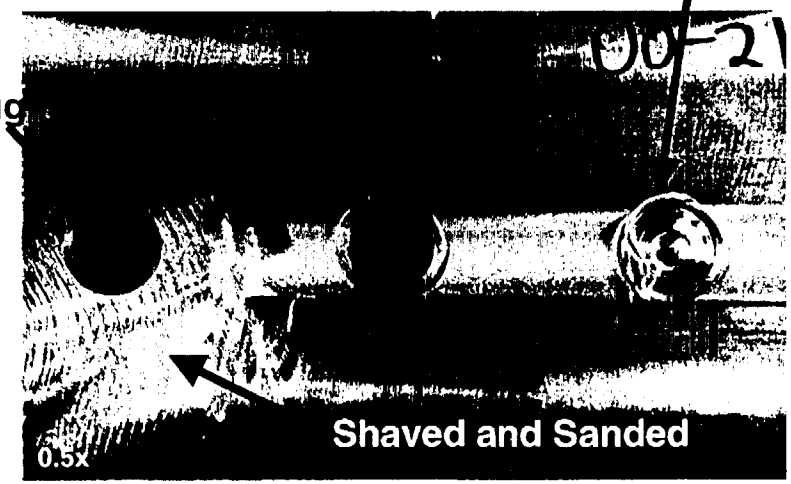
Transverse and Longitudinal Macro Locations



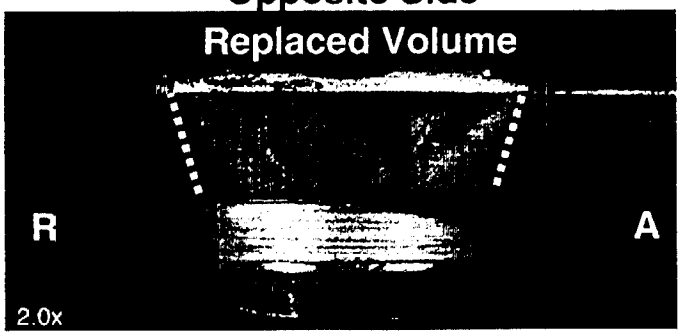
Pull Plug Repair of Keyhole

FSW Keyhole

Pull Plug



Opposite Side Replaced Volume



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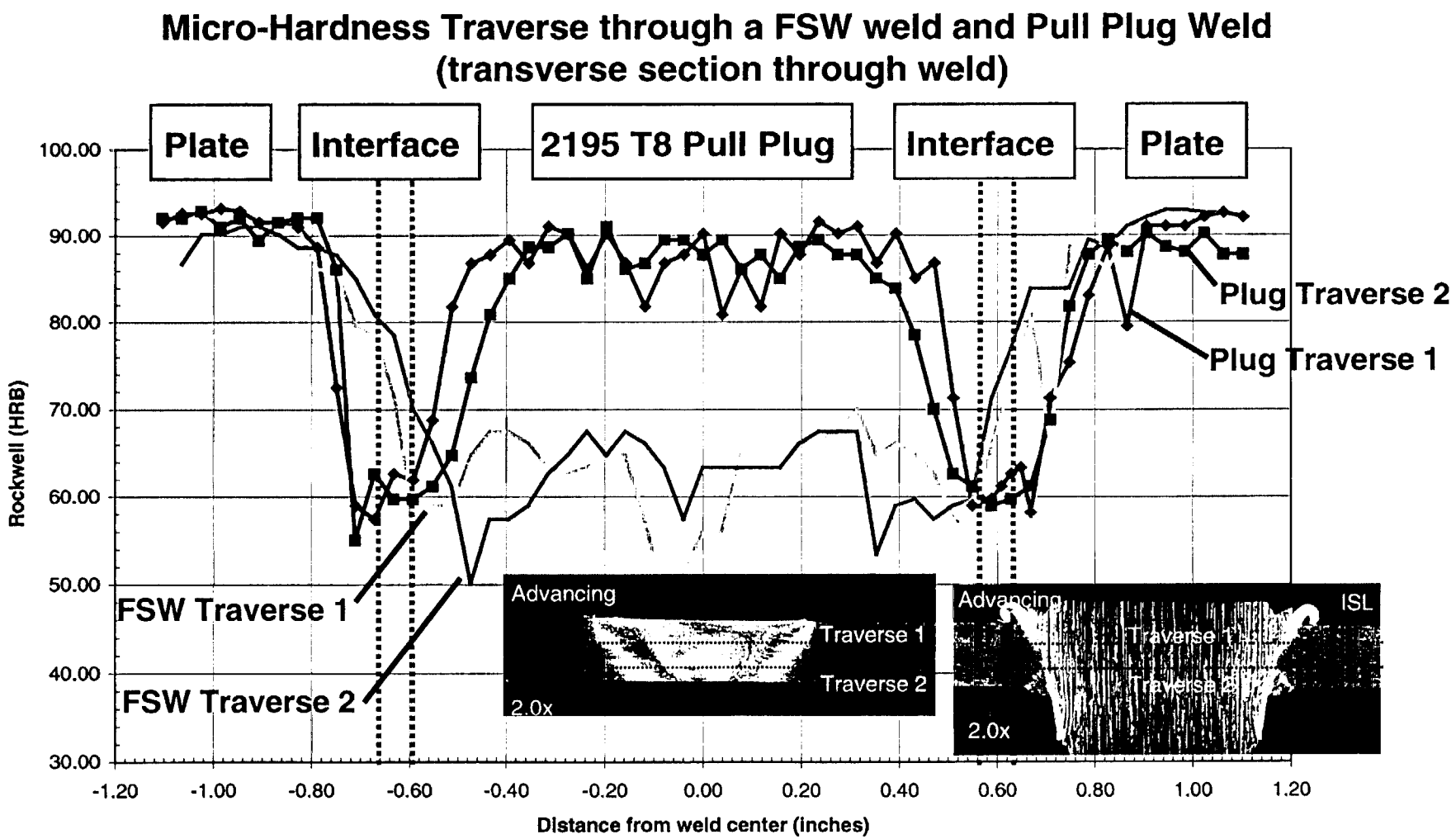
FPPW of FSW Keyhole

US Patents Pending: #60/057,111; 153,750; 156,734; 160,131



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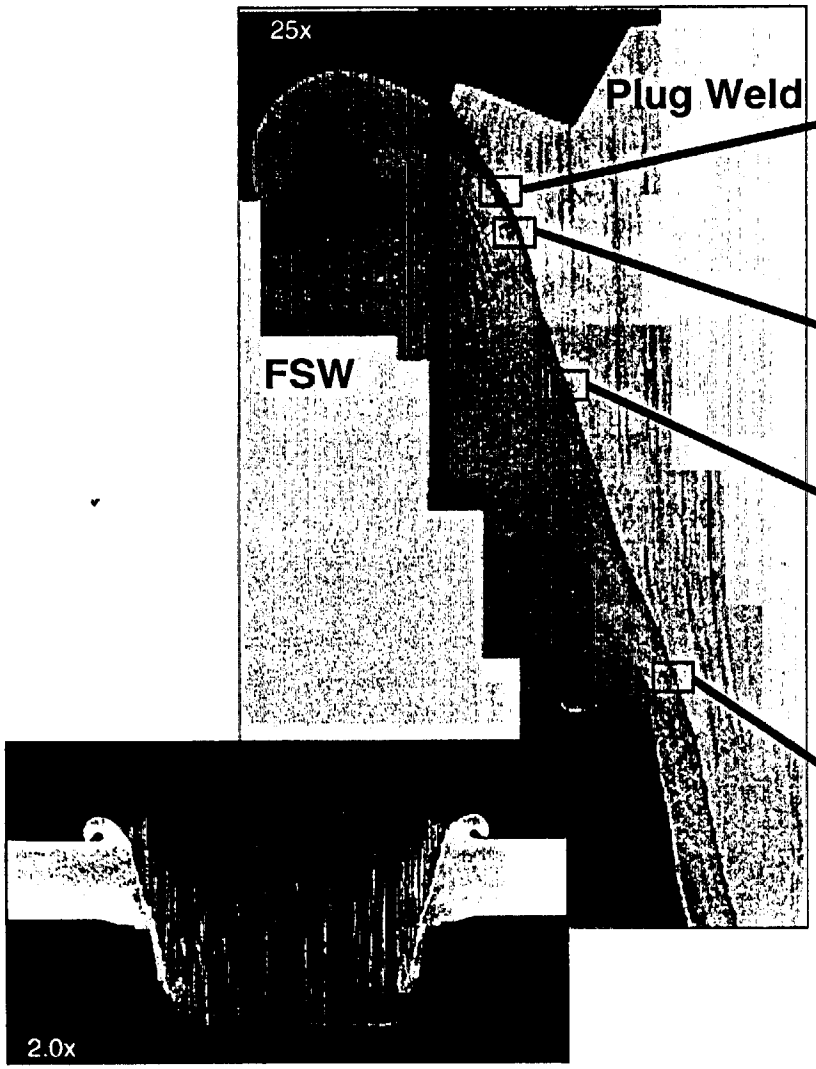
Pull Plug and FSW Interface

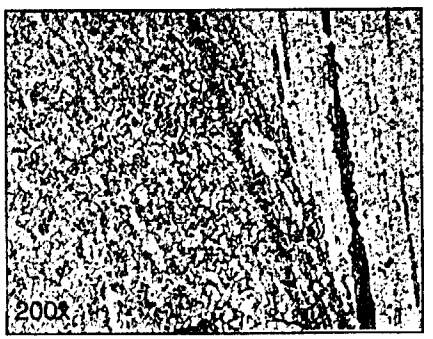
US Patents Pending: #60/057,111; 153,750; 156,734; 160,131

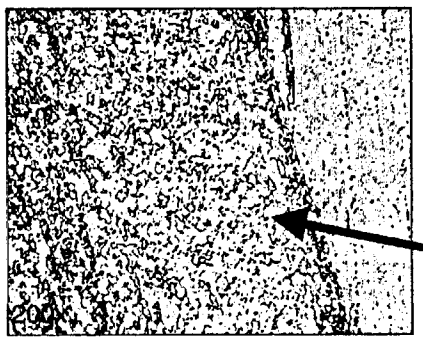


Discontinuous Bonding

Plug Interface - Recrystalized Grain Zone

Plate Surface





Complete Bonding

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Conclusions

- **Friction Push Welding**
  - **Proven as a reliable and cost effective method for repairing fusion weld defects**

- **Friction Pull Plug Welding**
  - **Laboratory development proceeding quite well in both 2195 and 2219 plate from 0.200" thick up to 0.385" thick**
  - **An in-depth defect characterization and analysis has led to a robust weld schedule, hole configuration, and pull plug design for repeatable defect free solid state welding**
  - **Solid state repair welding can be accomplished in a variety of applications through the portability of the technology**
  - **Repair of Friction Stir Weld Keyhole defects have been successfully completed in the laboratory**

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