# Scandium Containing Aluminum Alloys for Marine Applications

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# Acknowledgements


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# Overview of Presentation

- Development program at ST2
- Aluminum Alloys in Shipbuilding
- Mechanical properties of 7XA
- Corrosion
- Ongoing efforts

# Goals of the ST2 Development Program

*The Need:*

Shipbuilders and Navy warfighters need lighter, cost effective, more lethal platforms.

*National Defense Magazine* May 2003
(Interview with Rear Adm. Dennis M. Dwyer, the Navy's program executive officer for aircraft carriers.)

Redesign is necessary, the admiral explained, for two major reasons. "One of them is sheer weight," he said. "We need to get newer, lighter systems that reduce the weight that's on the ships." A lighter, more powerful ship will save "a tremendous amount of money in total ownership costs over the life of the ship." "You can make up that R&D expense pretty quickly."

# Shipbuilding Requirements for New Aluminum Marine Alloys

- Improved Design Strength
- Better Fatigue Performance
- Increased Stiffness
- Improved Weldability
- Overall Leaner Structures
- Reduced Cost

# Barriers to the Use of Aluminum Alloys in Naval Structures

- Fracture Toughness
- Strength in Fire
- Welding Problems
- Corrosion - SCC, Exfoliation and Pitting
- Fatigue
- Cost

# Mechanical Properties of Marine Aluminum Alloys

| Alloy/Temper | Tensile Strength (ksi) | Yield Strength (ksi) | Elongation (%) | Young's Modulus (msi) |
|---|---|---|---|---|
| 5083-H116 | 44 | 31 | 12 | 10.3 |
| 5086-H116 | 42 | 30 | 12 | 10.3 |
| 6061-T6 | 32 | 28 | 15 | 10.0 |
| 5456-H116* | 51 | 37 | 16 | 10.3 |
| 7XA-T76511** | 72 | 65 | 15 | 10.5 |

* Typical Alloy Currently Used by US Navy
** Al-Sc alloy

# Alloys

**Aluminum-Magnesium 5xxx alloys (Marine alloys, 5456)**

- Strengthened by Mg atoms in Solid Solution and cold work
- Weldable and corrosion resistant
- “Low strength”
- Scandium addition decreases grain size

**Aluminum-Zinc-Magnesium-Copper 7xxx alloys (Aerospace alloys)**

- Strengthened by precipitating Mg,Zn and Cu containing second phases
- Copper increases strength and resistance to SCC but decrease weldability and resistance to pitting corrosion
- High Strength alloys
- Scandium additions increase weldability and refine microstructure

# Systems Identified That Require New High Performance Aluminum Alloys

Lightweight Decks (LCS, CVN21)

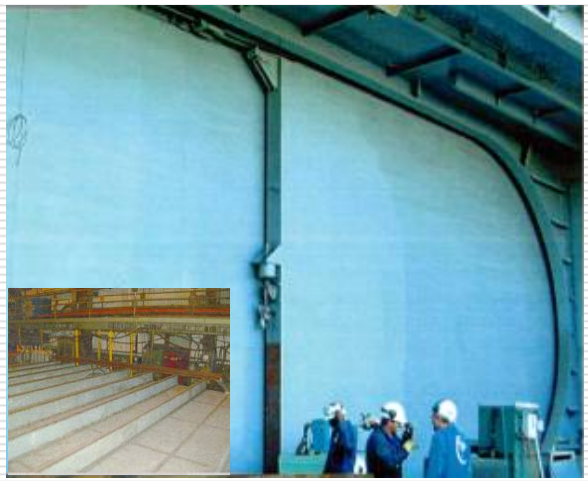
Light weight Doors (CVN21)

- US Navy Carrier Program Office provided a letter of support for this effort

High strength underwater hulls

- ST2 is working with NUWC to evaluate toughness of 7XA forgings

Lightweight structures - high speed ships



# Advantages of the ST2 Al-Sc Alloy

- High Strength (65 ksi)
- Two fold increase in Strength Over Marine Aluminum Alloys (5456)
- ~1/3 the Density of steel
- High Specific Strength (strength/density) Comparable with Titanium
- Refined Microstructure Provides Potential Increases in Fatigue Resistance
- Improved Weldability over Conventional High Strength Aluminum Alloys
- Corrosion Resistant

US Navy Photo by Paul Farley


US Navy Photo by Rebecca J Moat

# Composition of Alloy 7XA

| | |
|---|---|
| Nominal Composition | **Al-Zn-Mg-Sc-Zr-Mn-Ti** |
| Zinc – Magnesium | **Strengthening Precipitates** |
| Zirconium – Scandium | **Recrystallization Inhibitors** |
| Manganese | **Dispersoid Phase** |
| Titanium | **Grain Refiner** |
| Copper | **Removed** |
| Trace addition | **Enhances Nucleation of Strengthening Precipitates** |

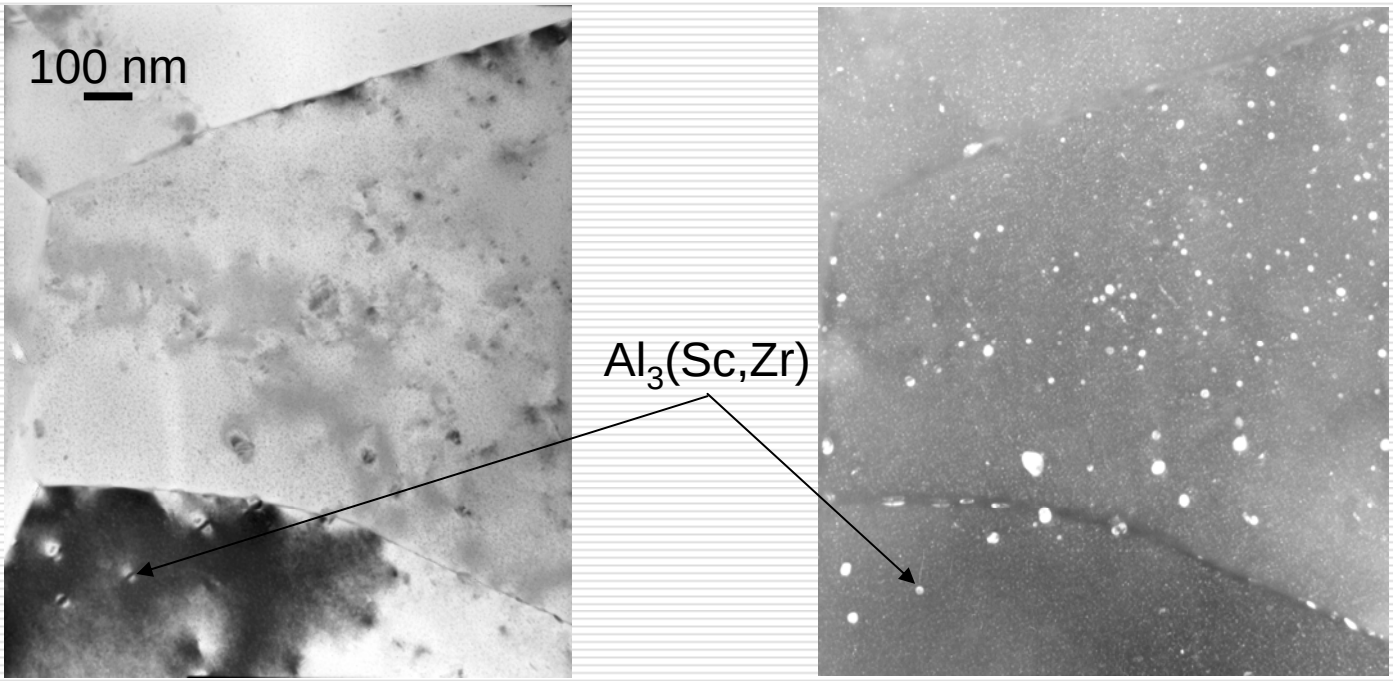
# Benefits of Scandium Additions in Aluminum

- Most potent strengthening element that can be alloyed with Aluminum
- Alloys with poor weldability can be welded crack-free when Sc-modified.
- Scandium additions reduce recrystallization in cold worked aluminum

# $Al_3Sc$ Dispersoid Phase

Bright Field

Dark Field



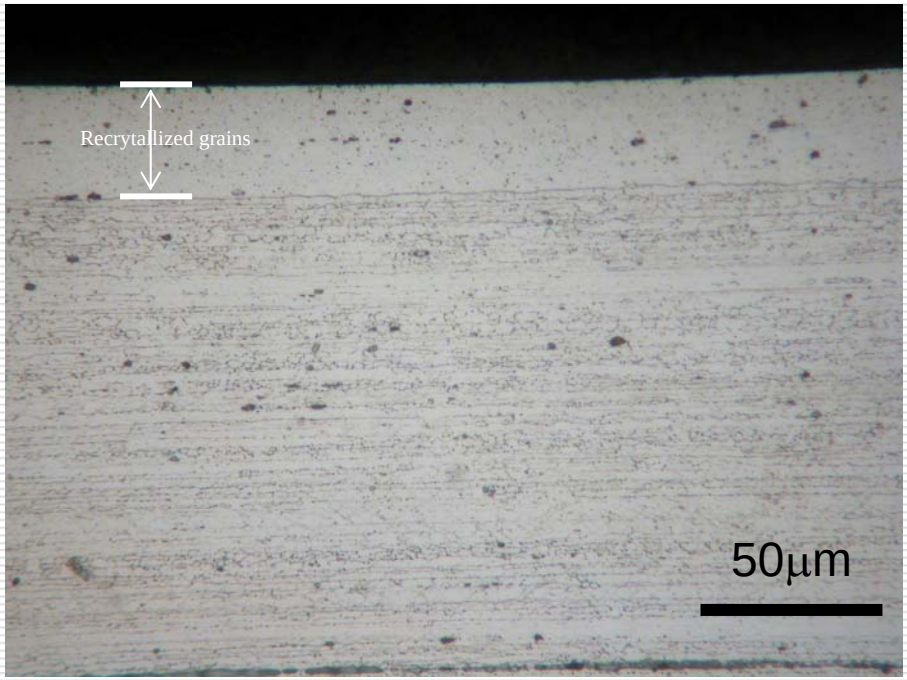

Transmission electron micrographs showing Al-Sc-Zr precipitates in alloy 7XA T6 24hrs at 250°F

# Effect of Recrystallization Inhibitors on Strength

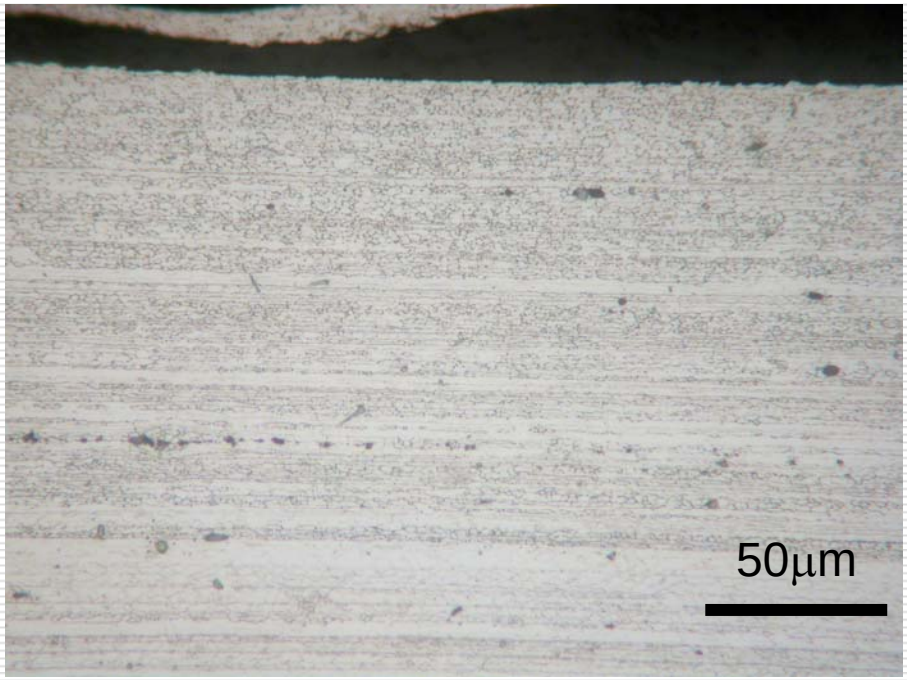
| Alloy | Direction | Yield Strength (psi) | Tensile Strength (psi) | Elongation (%) |
|---|---|---|---|---|
| 7xA | L | 71,027 | 76,797 | 15.0 |
| | LT | 66,030 | 71,475 | 14.4 |
| 7XA No Sc/No Zr | L | 57,895 | 62,606 | 19.3 |
| | LT | 55,223 | 62,373 | 16.6 |

# Effect of Scandium on Surface Recrystallization

Alloy 7XA T7 (No Sc)

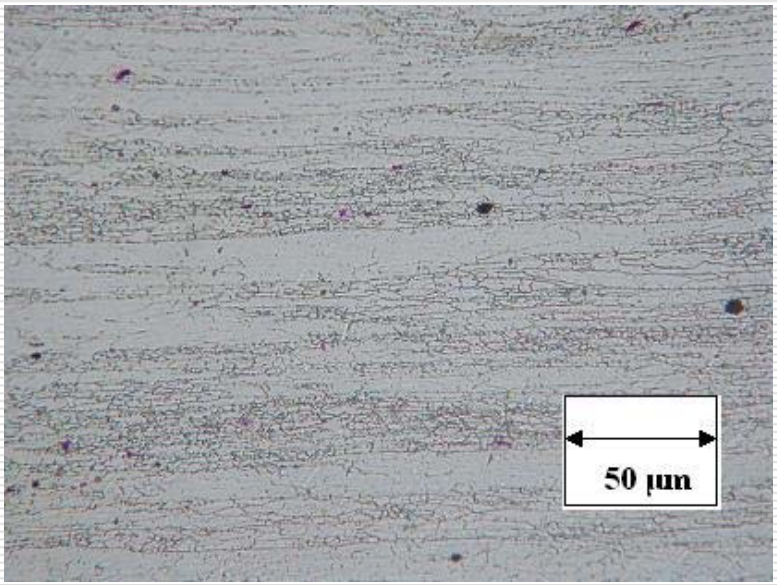



Alloy 7XA T7 (0.12 Sc)

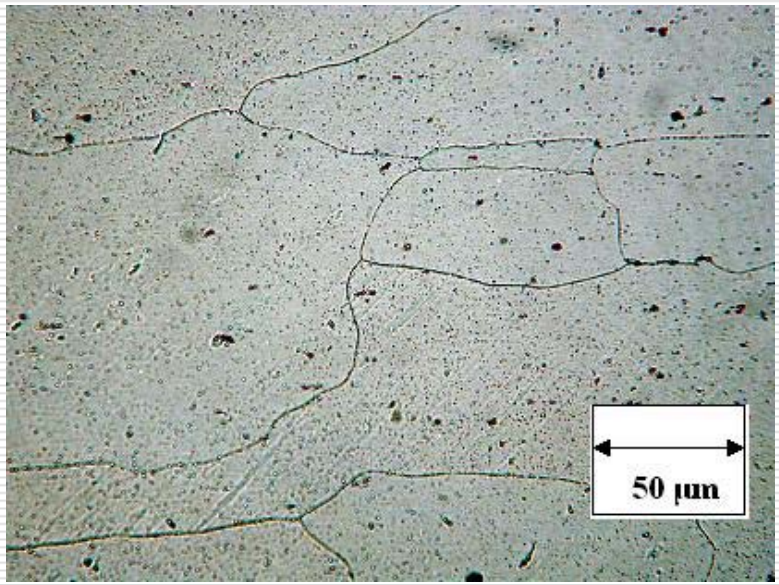


# Recrystallization Inhibition

Alloy 7XA

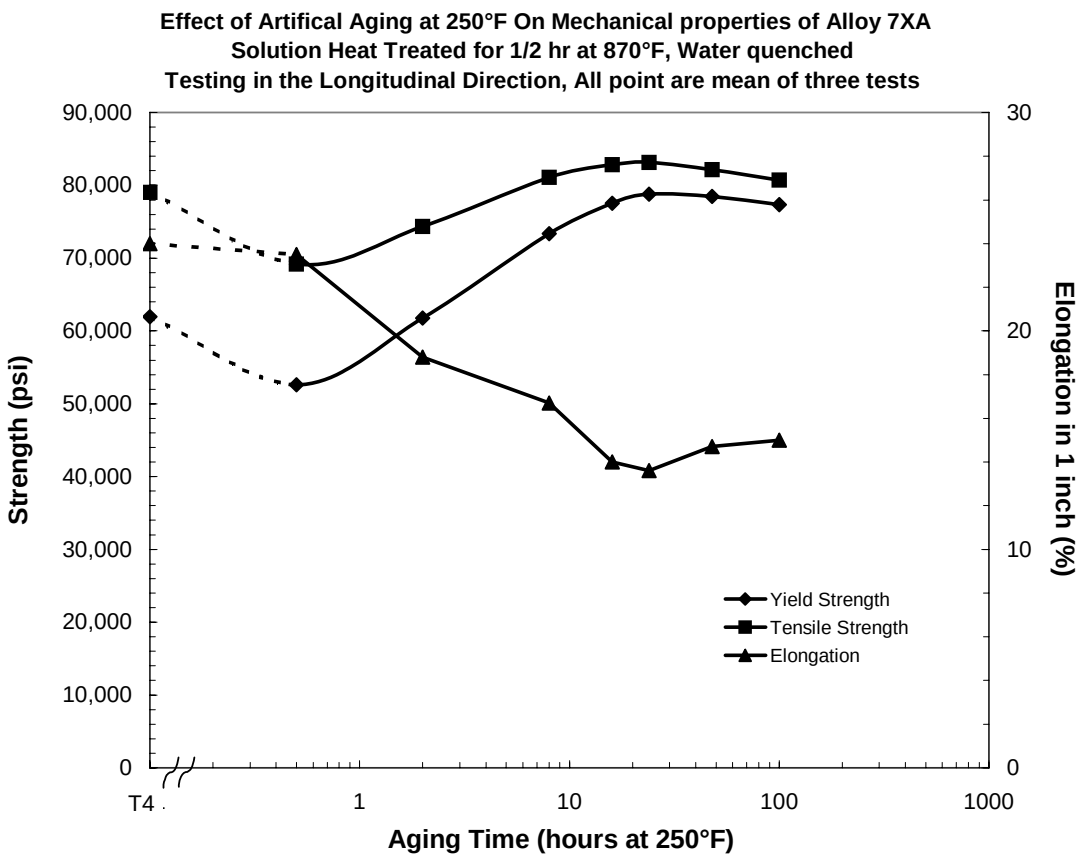



Alloy 7XA (No Sc/No Zr)




- Optical Micrographs showing the synergistic role of Sc and Zr at inhibiting recrystallization
- Center of LT-ST face, 0.5” x 3.5” extruded bar, T6 temper

# Artificial Aging of 7XA



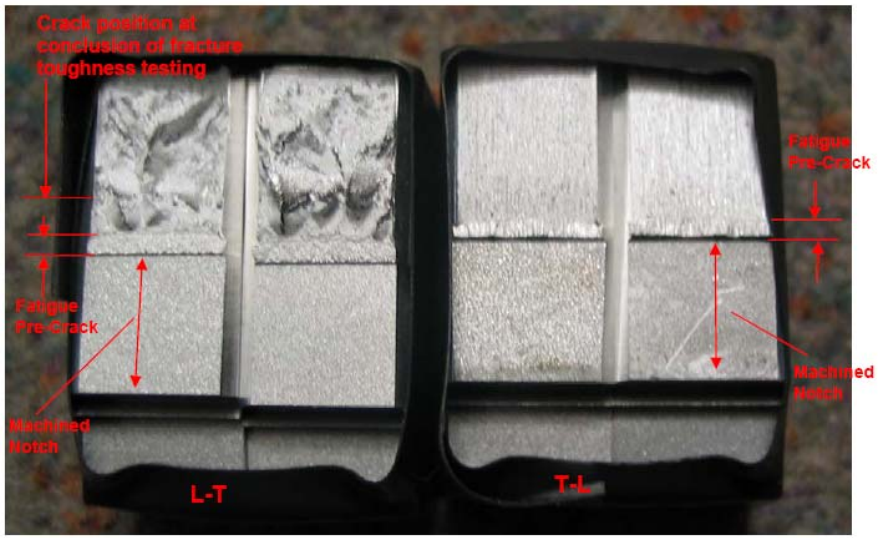
# Mechanical Properties in T7 Temper

| Test Direction | Yield Strength (psi) | Tensile Strength (psi) | Elongation (%) |
|---|---|---|---|
| Longitudinal | 69,879 | 74,745 | 15.3 |
| Long Transverse | 66,216 | 71,290 | 16.7 |
| 45° to Longitudinal | 60,641 | 65,882 | 18.4 |

- Tensile properties measured from 0.5-in x 3.5-in extruded bar.
- Alloy 7XA T7 DC cast in a 1 ton lot.
- Data represents the mean of ten tests using ASTM E8 subsize specimens with a thickness of 0.25 inches.

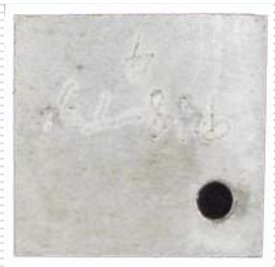
# Toughness of Alloy 7XA T7 Extruded bar

| Orientation | Jq ($kJ/m^2$) | Kjq (MPa√m) | Kjq (ksi√in) | Toughness Ratio |
|---|---|---|---|---|
| L-T | 71.2 | 72.2 | 65.7 | 0.92 |
| T-L | 29.75 | 36.84 | 33.53 | 0.50 |




- Preliminary Toughness values for 7XA T7 extruded bar.
- 0.5 inch thick compact test specimen geometry is based on ASTM-E-1820-01.
- Mean of three tests.
- Courtesy of Robert Doleski at NUWC.

# Corrosion Resistance



7XA T7

5456 H116

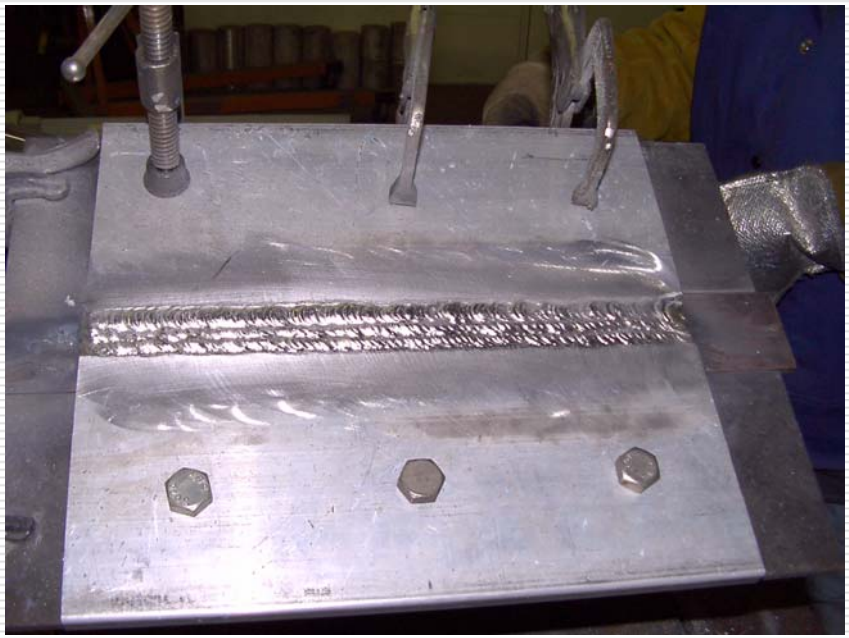
7075 T7

| Alloy/Temper | Casting | EXCO Rating | | | |
|---|---|---|---|---|---|
| | | 5h | 24h | 48h | 96h |
| 7XA T7 | DC cast-UAC *[Heat 104]* | N | N | N | N |
| 7XA [High Fe] T7 | DC cast-UAC *[Heat 102]* | N | N | N | P |
| 7075 T6 | Commercial product | P | EA | EC | ED |
| 7075 T7 | Commercial product | P | EA | EB | EC |

# Stress Corrosion Crack (SCC) Susceptibility Testing

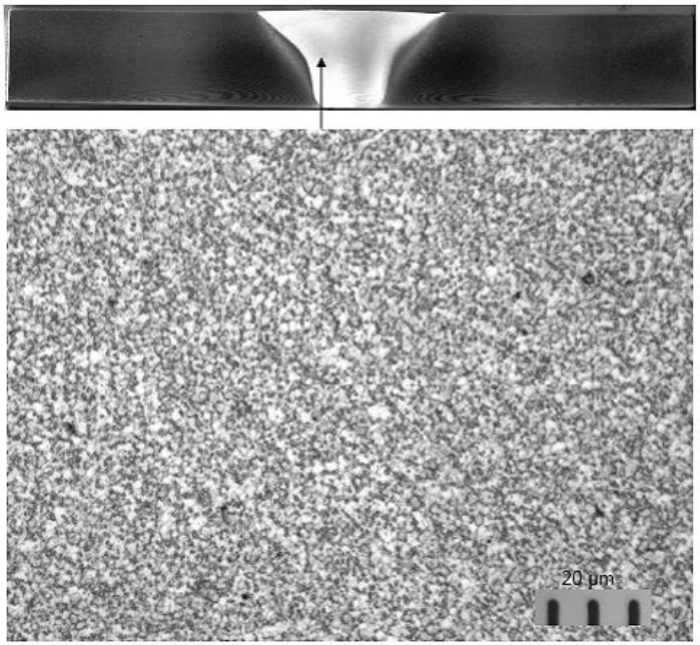
ASTM G 47
0, 25, 50 and 75% of LT yield strength
7XA extrusion #103
No Failures in T7 temper

# “Conventional” Welding Trials



- Multi-pass gas metal arc welding (GMAW)
- 1-inch thick integrally stiffened extruded 7XA panels
- Constrained weld with no cracking observed
- 5456 filler
- 50% joint efficiency measure transverse to the weld
- Transverse tensile strength of 34 ksi

# Friction Stir Welding




- Friction Stir Welding trials performed at The University of South Carolina
- 1-inch thick integrally stiffened extruded 7XA panels
- 93% joint efficiency measured transverse to the weld after PWHT

# Summary

- The Sc + Zr addition is very effective at reducing recrystallization
- Alloy 7XA is resistant to SCC and exfoliation corrosion in the T7 temper
- Alloy 7XA resistant to general corrosion
- ½ -in 7XA T7 has a Toughness/strength ratio of 0.9 in the L-T and 0.5 in the T-L direction
- Friction stir welding
- Fusion Welding

# Ongoing Work

- Qualification of extrusion process
- SCC of thick extrusions and forgings
- Corrosion performance of Weldments
- SCC in weldments