Colorado School of Mines - CSM
Center for Welding, Joining and Coatings Research - CWJCR

Significant Highlights in Underwater Wet Welding Research & Applications

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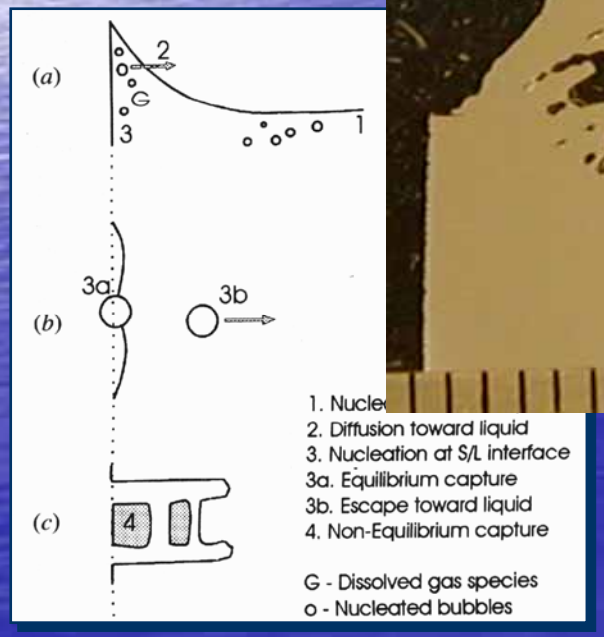
Example of Underwater Wet Welding Repair

(Global Divers & Contractors)

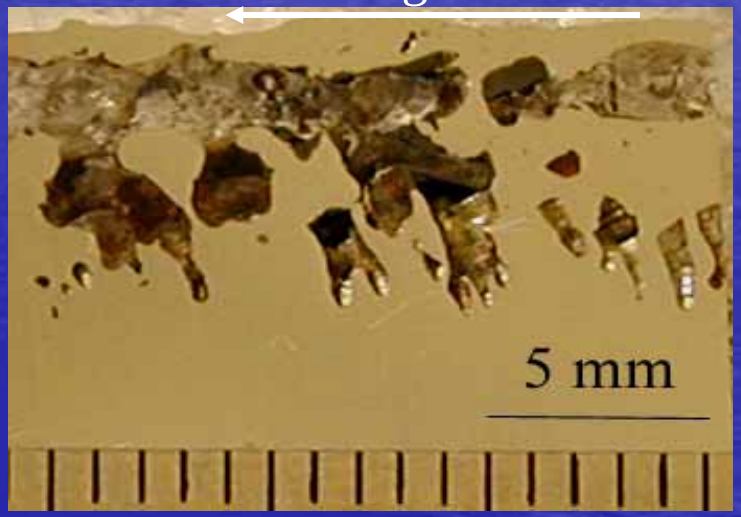
UWW - Porosity Mitigation

Extreme Case: Large longitudinal pore

E7018 at 100 m depth.

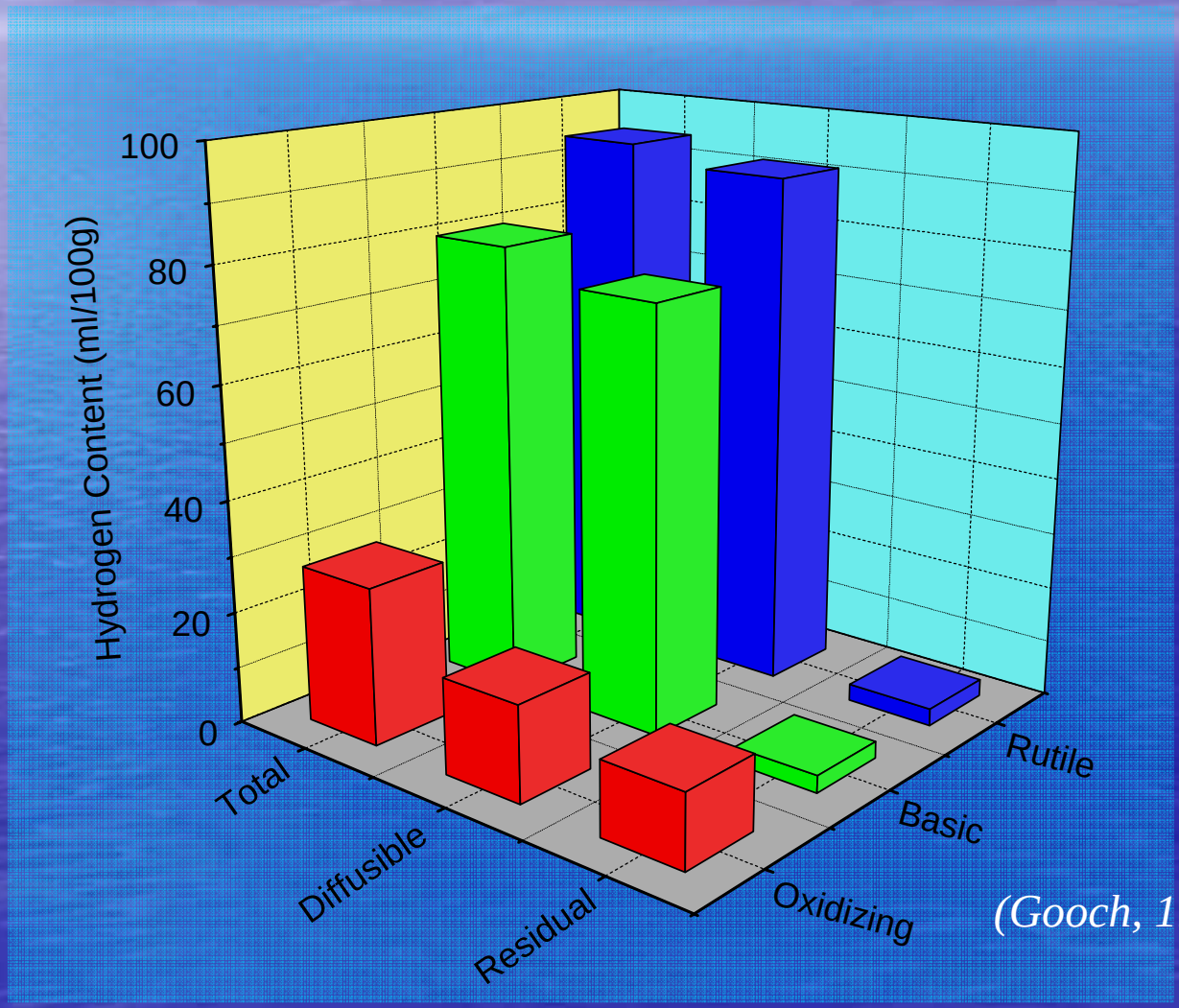


Welding Direction



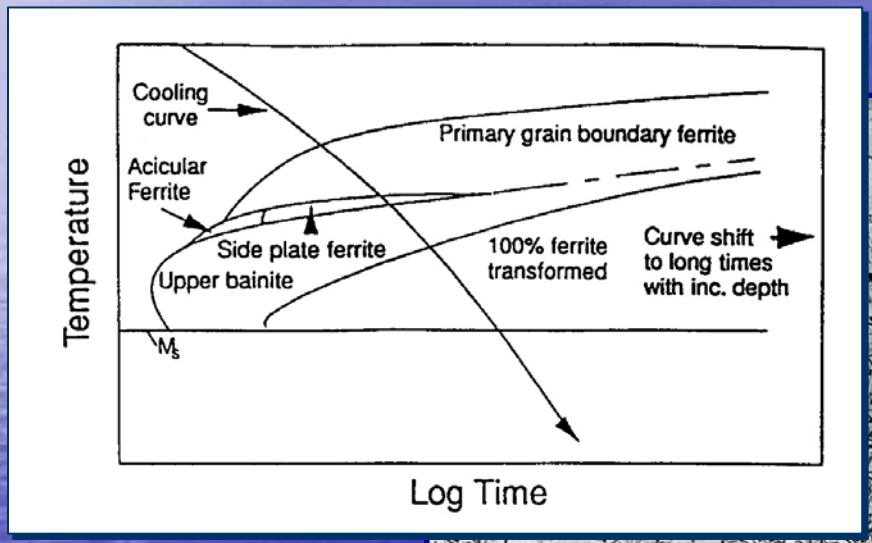
(Pessoa, Bracarense, Perez and Liu, 2003)

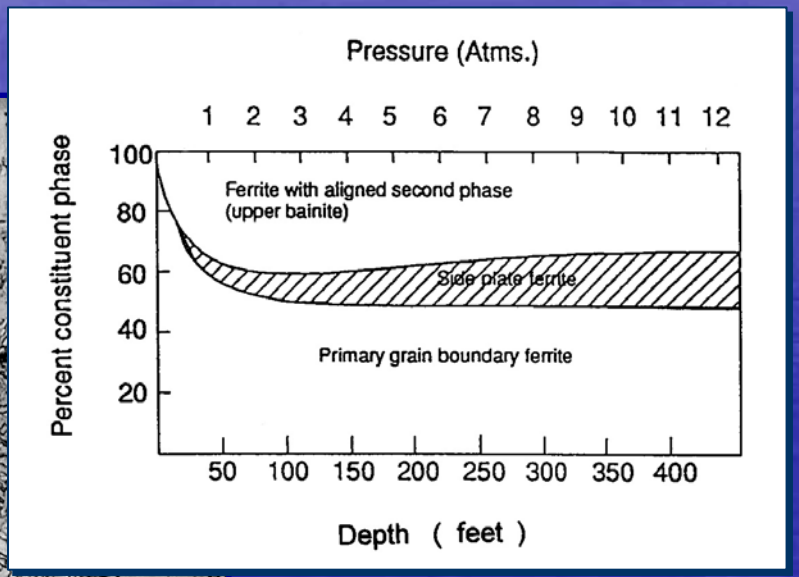
UWW - Hydrogen Contents

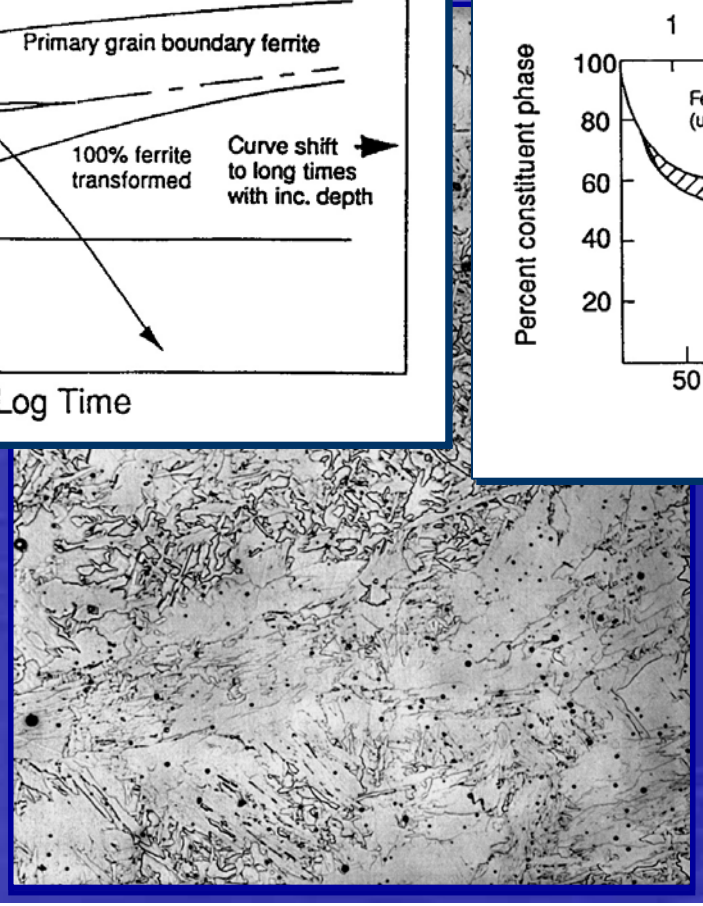


(Gooch, 1983)

UWW - Microstructural Distribution

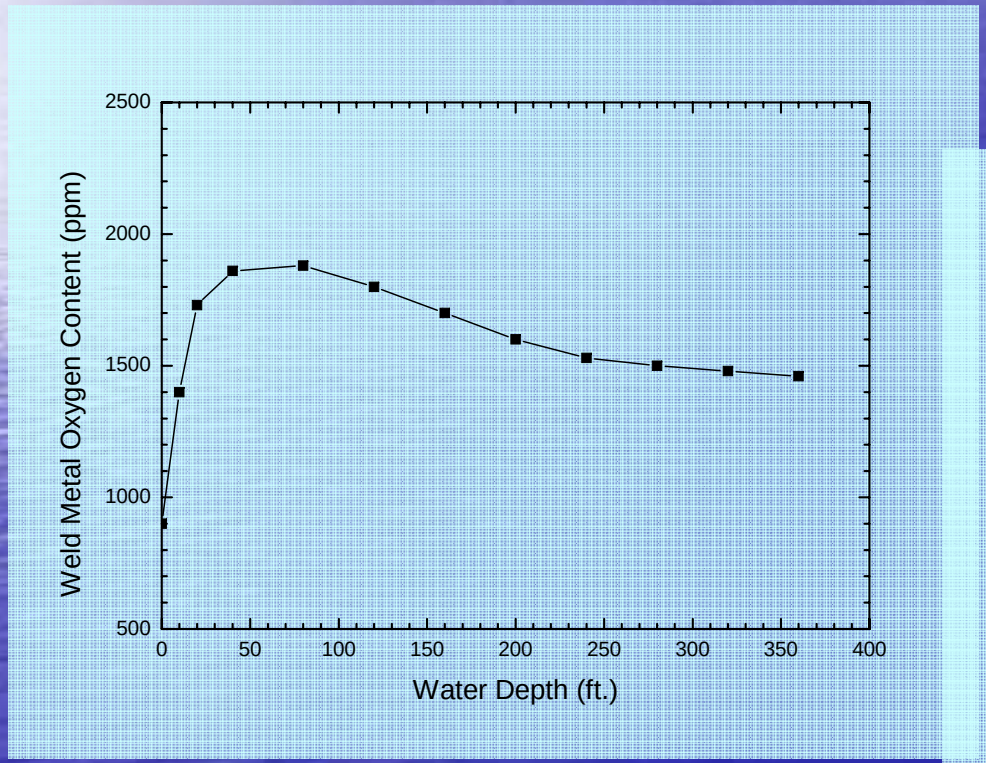


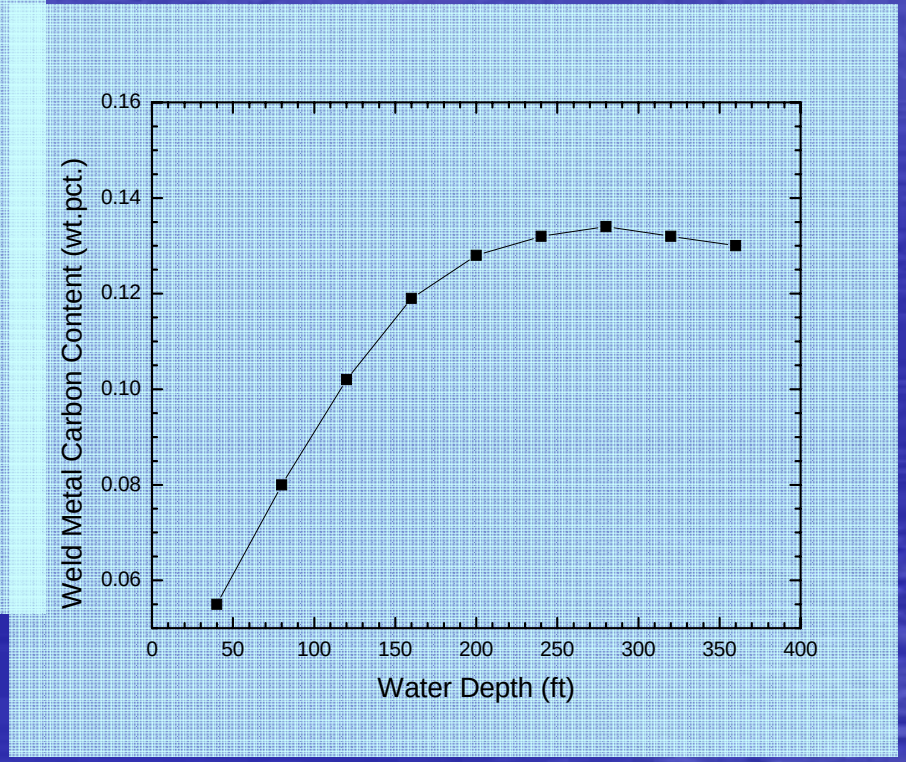




(Ibarra, Olson, and Liu, 1994)

UWW – Oxygen Pickup and Carbon Loss





(Ibarra and Olson, 1984)

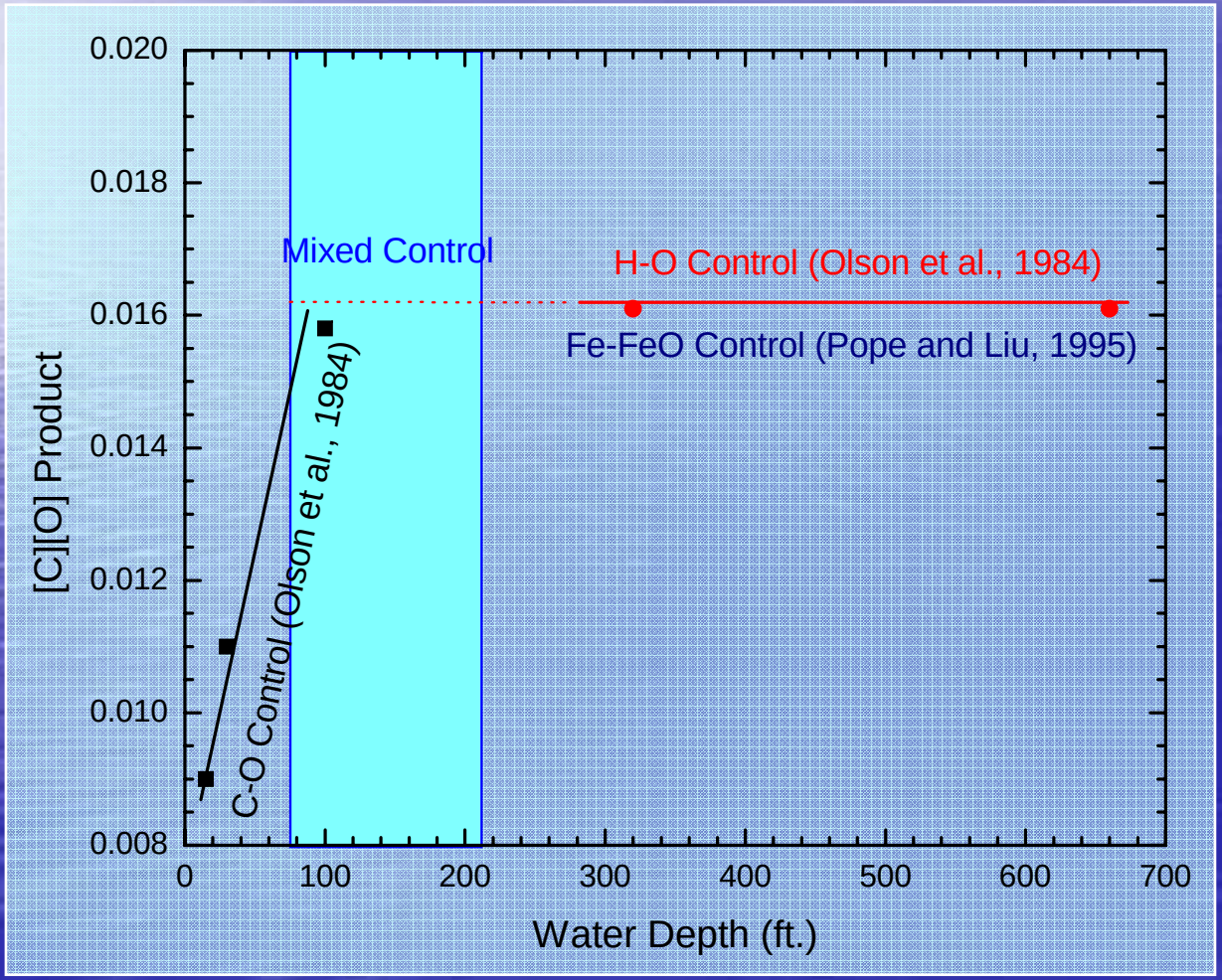
CSM Approach & Contribution

- Multi-Equilibria in Weld Pool
  - Weld Pool Chemistry & Chemical Composition
- Microstructural Transformations in Weld Metal
  - Solidification Sub-Structure Refinement
  - As-Welded Microstructure Refinement
- Fatigue Properties Clarification
- Impact Toughness Enhancement
- Porosity Mitigation in Weld Metal
- Diffusible Hydrogen Minimization

- Applications in Tubular Structures
- Comfortable Depth Range – 325 ft

- ***Potential Application in Pipelines in "Shallow" Water***

UWW - Controlling Mechanism for Carbon and Oxygen Pickup



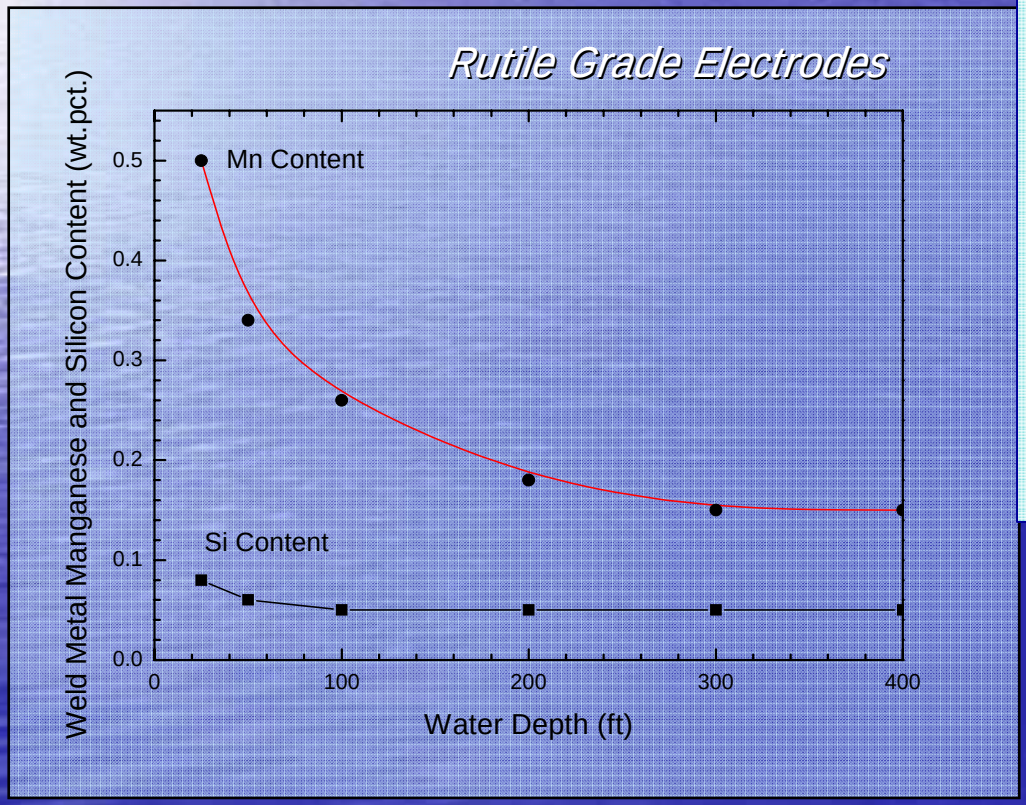
- Shallow Water: Carbon-Oxygen Reaction Control
- Deeper Water: Hydrogen-Oxygen Reaction or Iron-Oxygen (FeO) Reaction Control

UWW - Alloying Element Loss

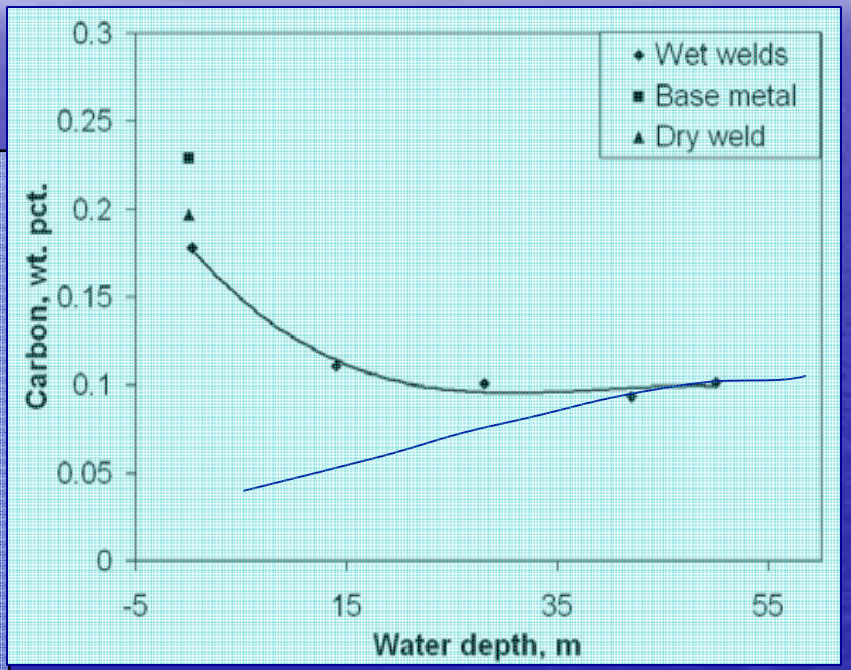
(Perez and Liu, 2005)

$$CE_{simplified} \approx C + \frac{Mn}{6}$$

Rutile Grade Electrodes



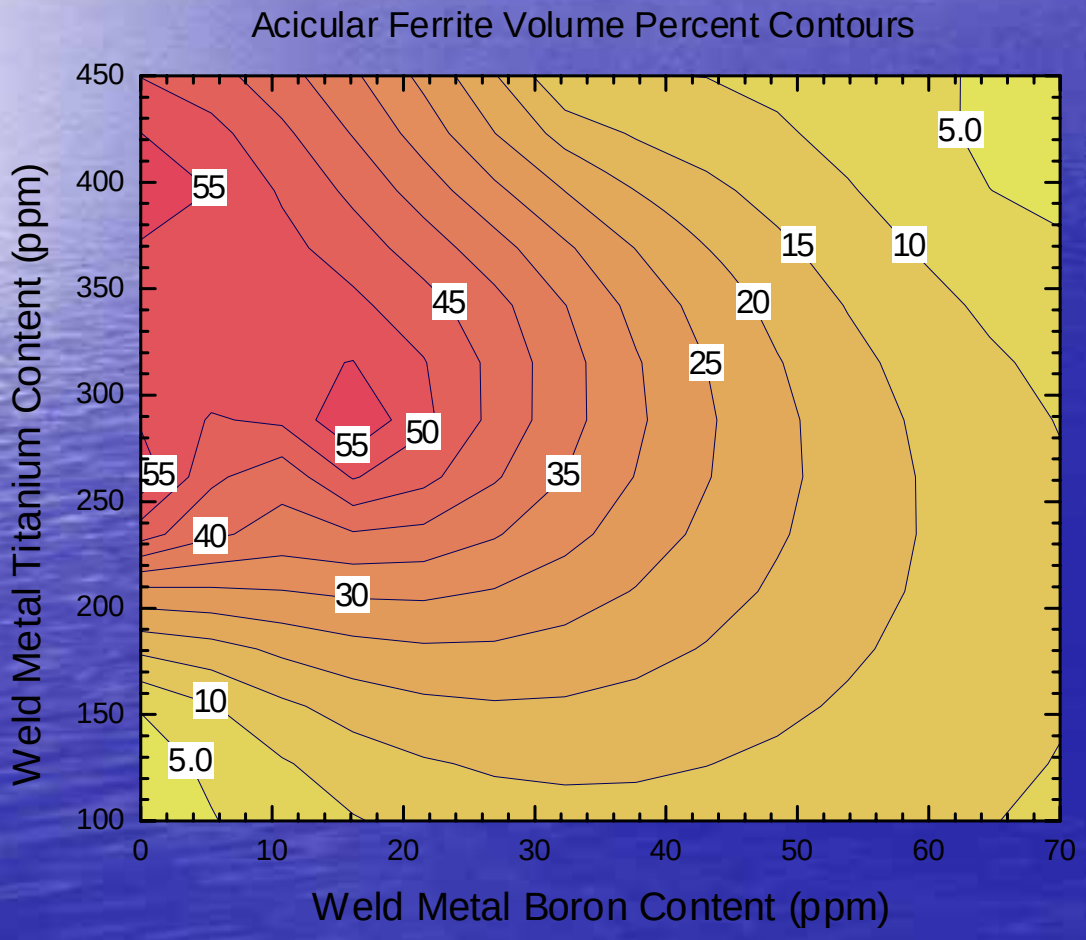
(Rowe and Liu, 1999)



Cellulosic Grade Electrodes

- Alloying Elements must be Replenished with increasing Welding Depth: Electrode Reformulation

UWW - Microstructural Enhancement via Alloying



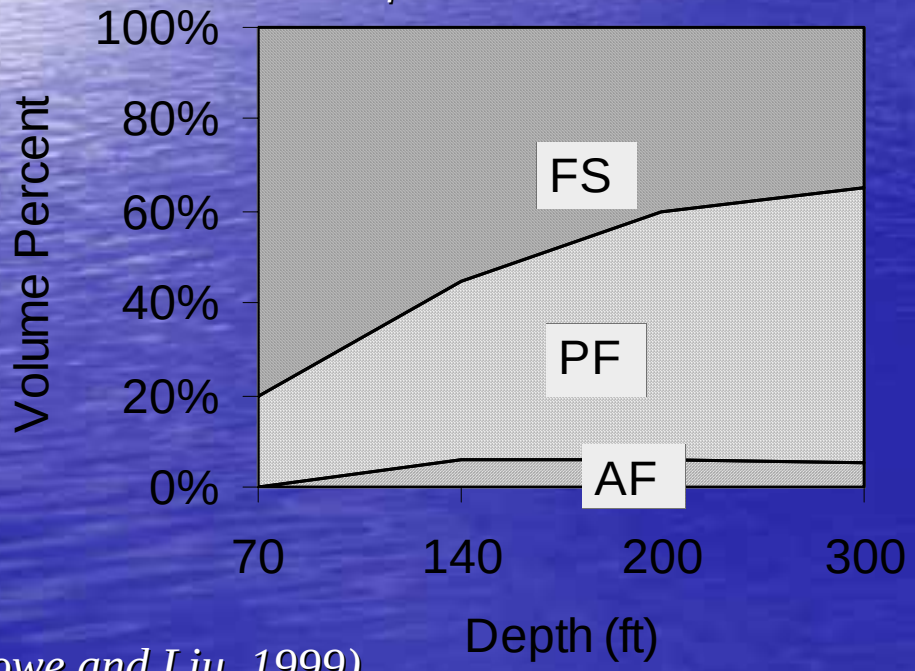
- Optimal Ti-B Alloying Maximizes Weld Metal Acicular Ferrite @ 33ft H_2O

(Sanchez and Liu, 1994)

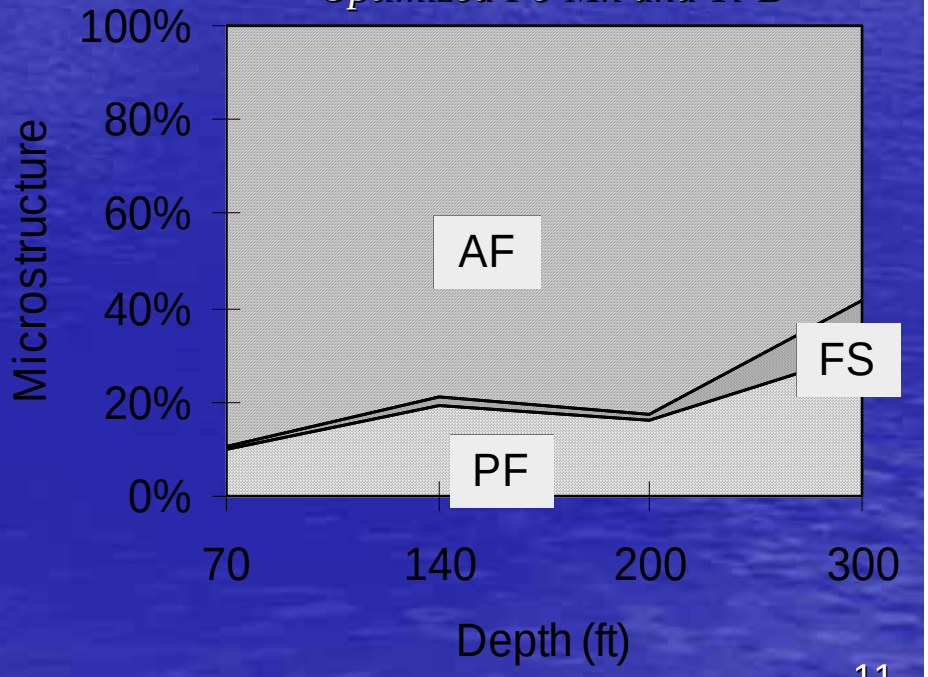
UWW - Microstructural Enhancement via Alloying

Substantial Acicular Ferrite Increase in the Weld Metal Microstructure

Reference Microstructure

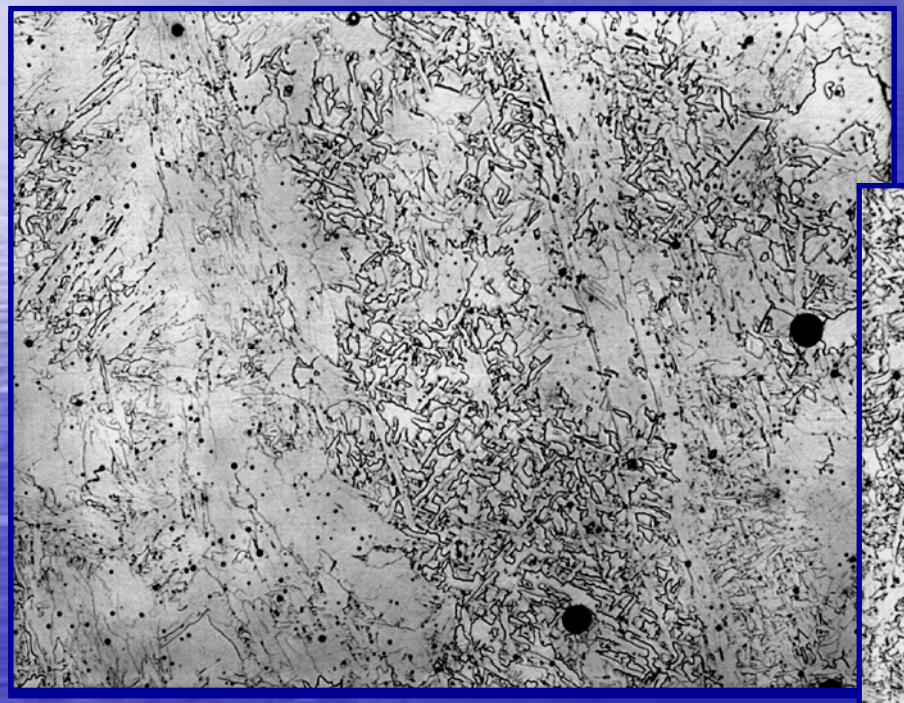


Microstructure with Optimized Fe-Mn and Ti-B



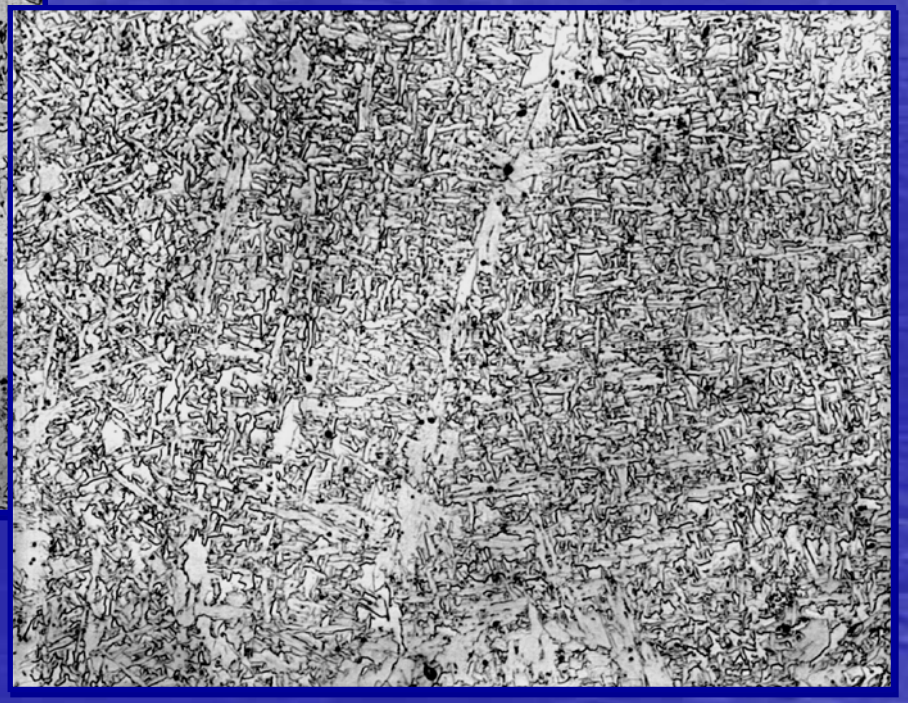
(Rowe and Liu, 1999)

UWW Microstructure - Blocky Ferrite, FS vs. Acicular Ferrite



Reference Microstructure

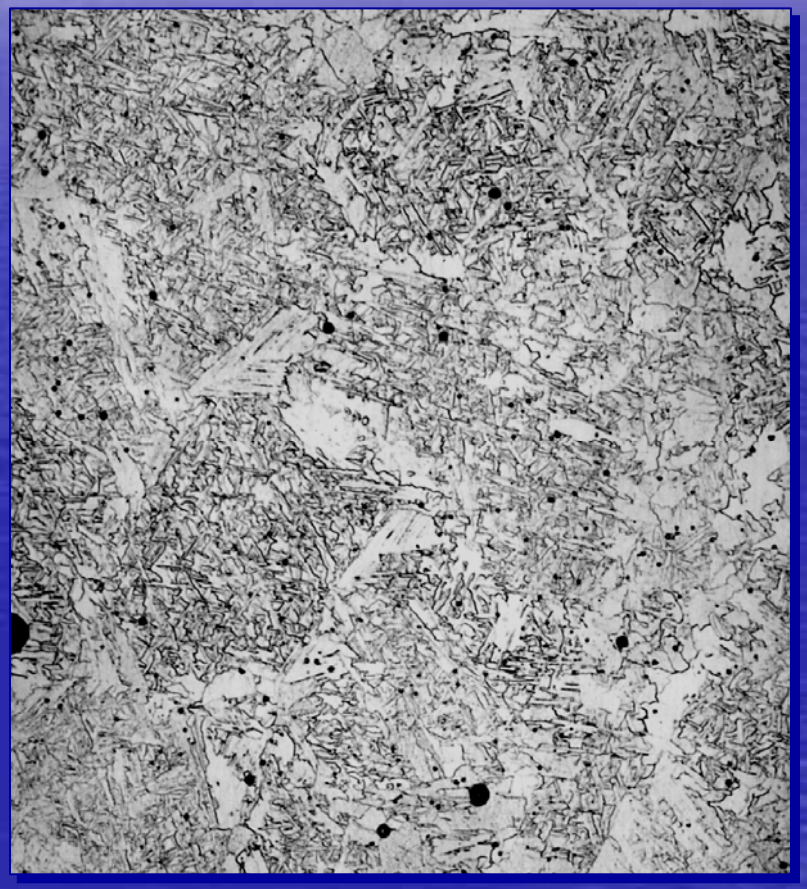
Microstructure with Optimized Fe-Mn and Ti-B



(Rowe and Liu, 1999)

UWW - CGRHZ Microstructure

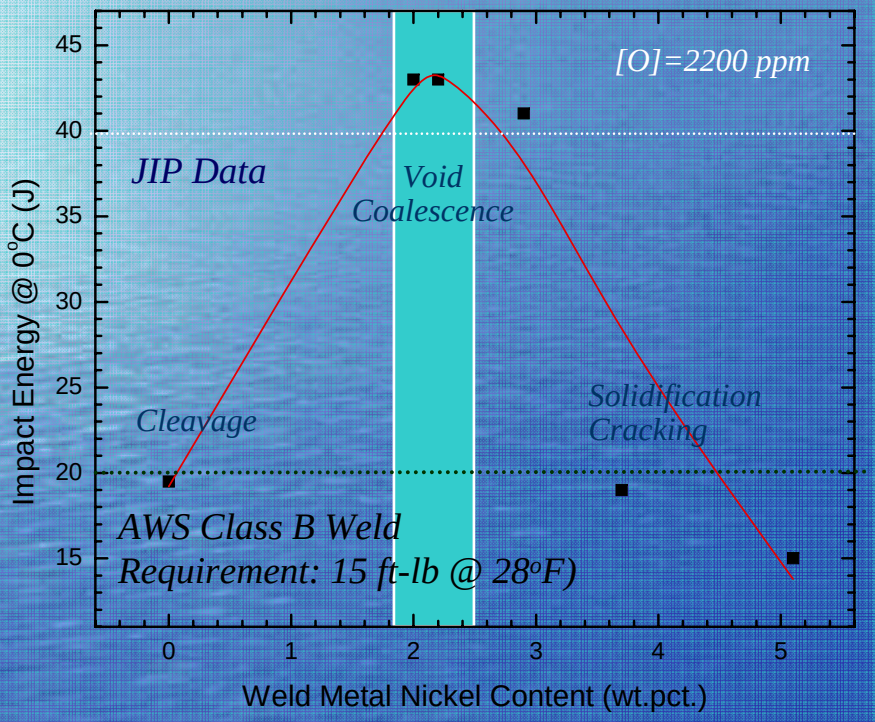
Ferro-manganese



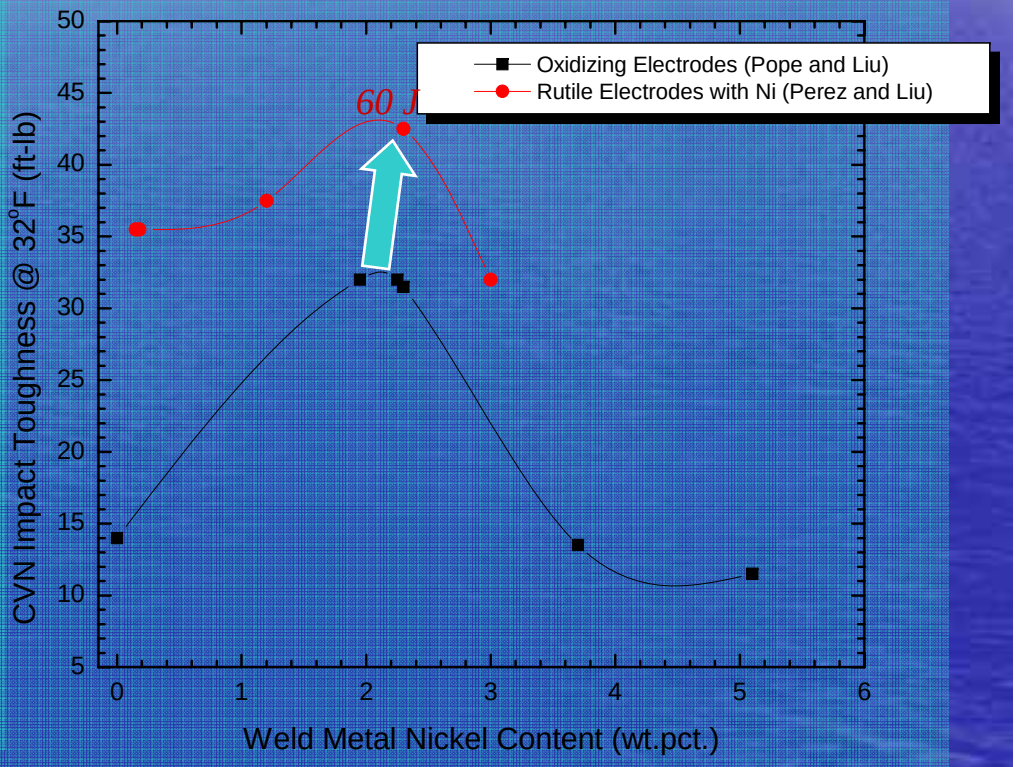
Titanium -Boron

(Rowe and Liu, 1999)

Consumable Optimization Mechanical Properties – Ni Effect



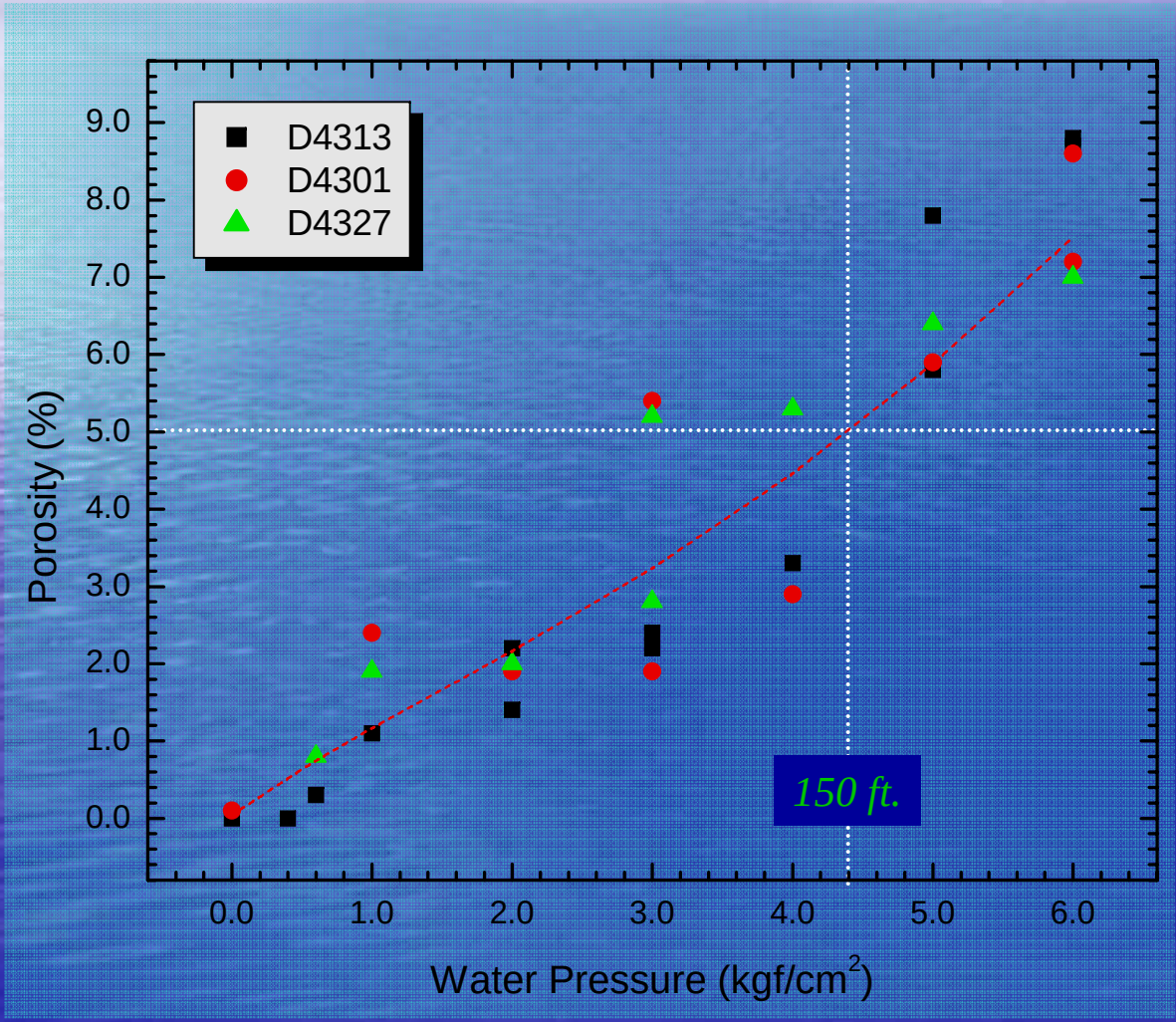
(Pope and Liu, 1995)

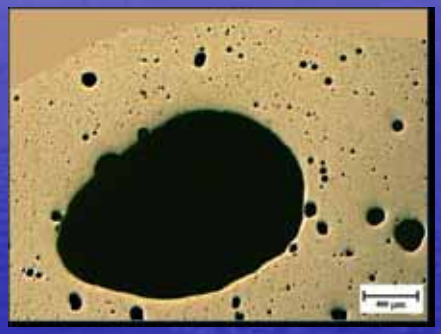


(Perez and Liu, 2003)

- 1 ft-lb = 1.356 J, i.e. 20 J = 15 ft-lb & 43 J = 32 ft-lb
- At 2.2 wt. pct. Ni, Grain Refinement occurred and Stacking Fault Energy decreases to facilitate Cross-Slip

UWW - Porosity Question



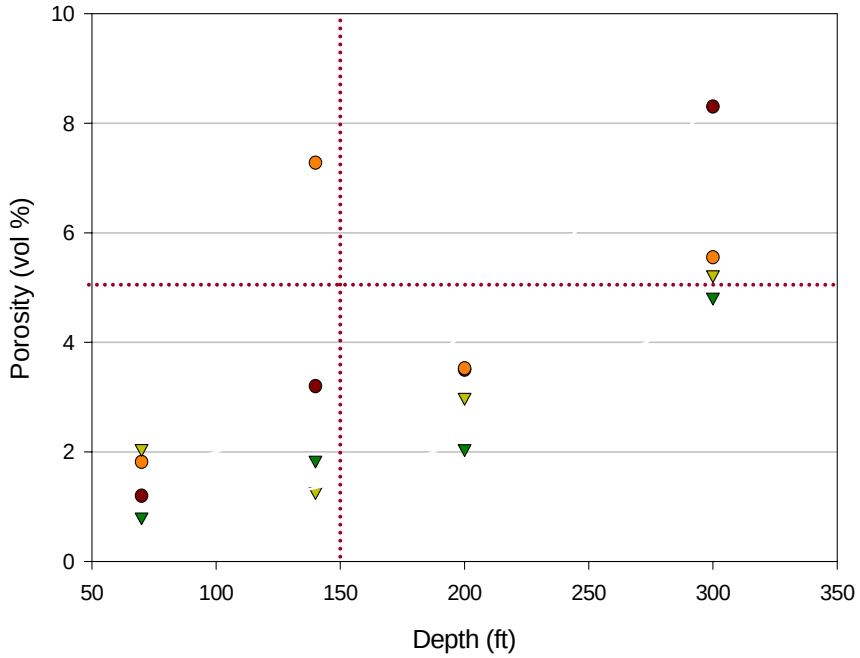


- Pressure
  - 1 kgf/cm^2 = 1 atm
- Water Depth
  - 1 atm = 10 m

(Suga and Hasui, 1986)

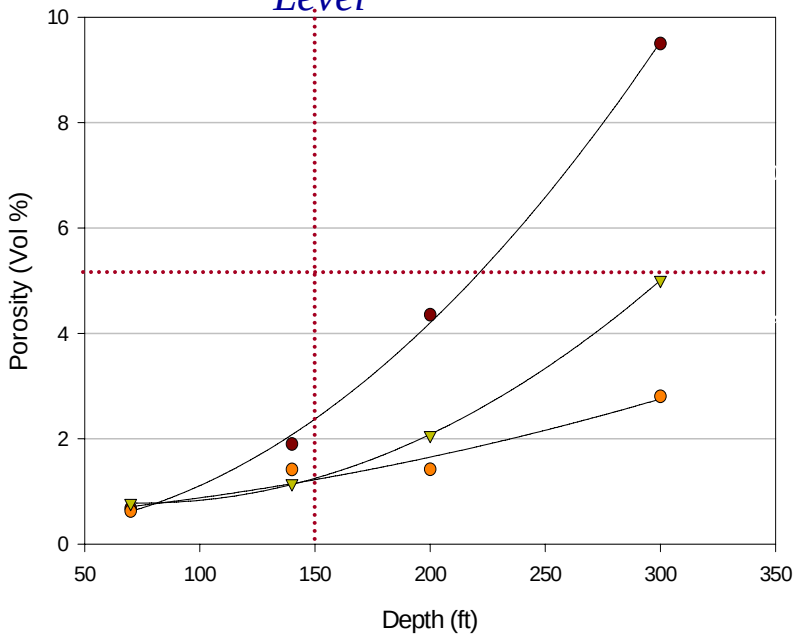
UWW - Porosity Mitigation

Reference Porosity Level



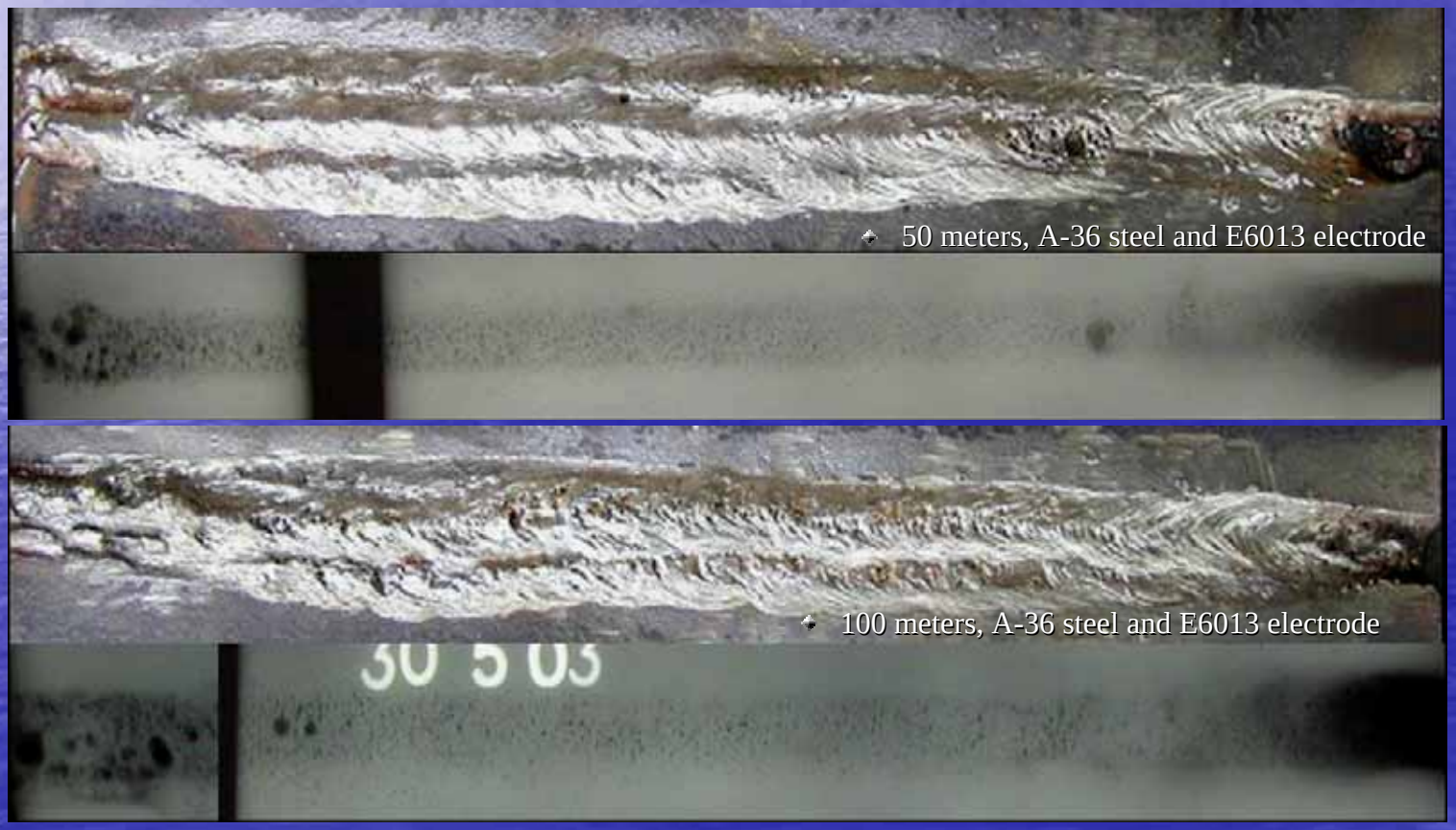
(Rowe and Liu, 1999)

Reference Porosity Level



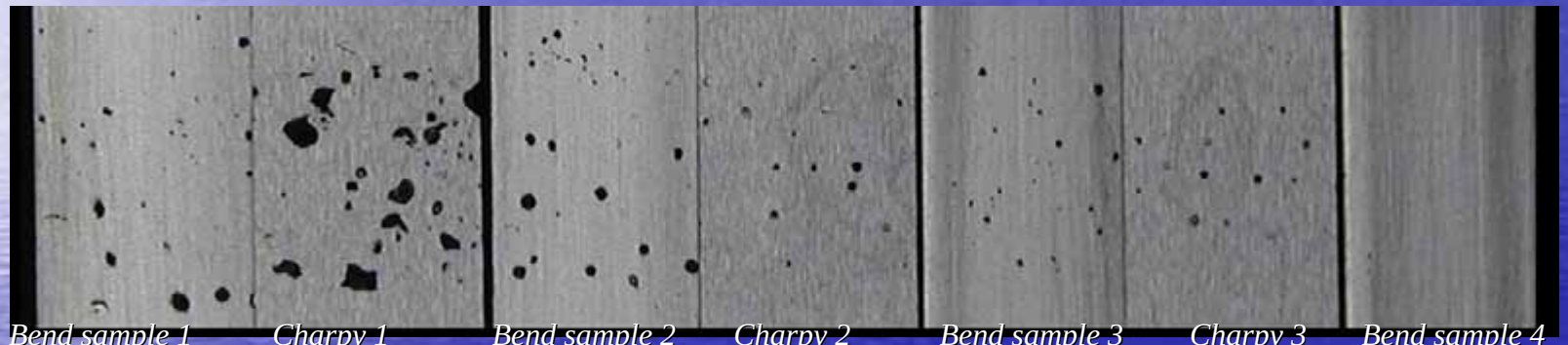
With Proper Alloying, Porosity Level decreased to Around 1%

UWW - Porosity Mitigation – Pore Location - Longitudinal



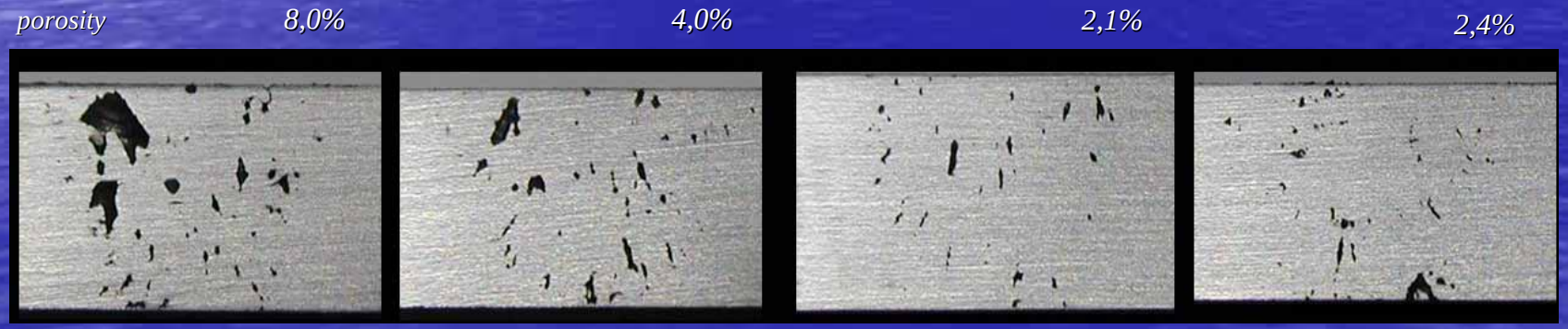
(Pessoa, Bracarense, Perez and Liu, 2005)

UWW - Porosity Mitigation – Pore Location – Longitudinal & Transverse



Welding direction →

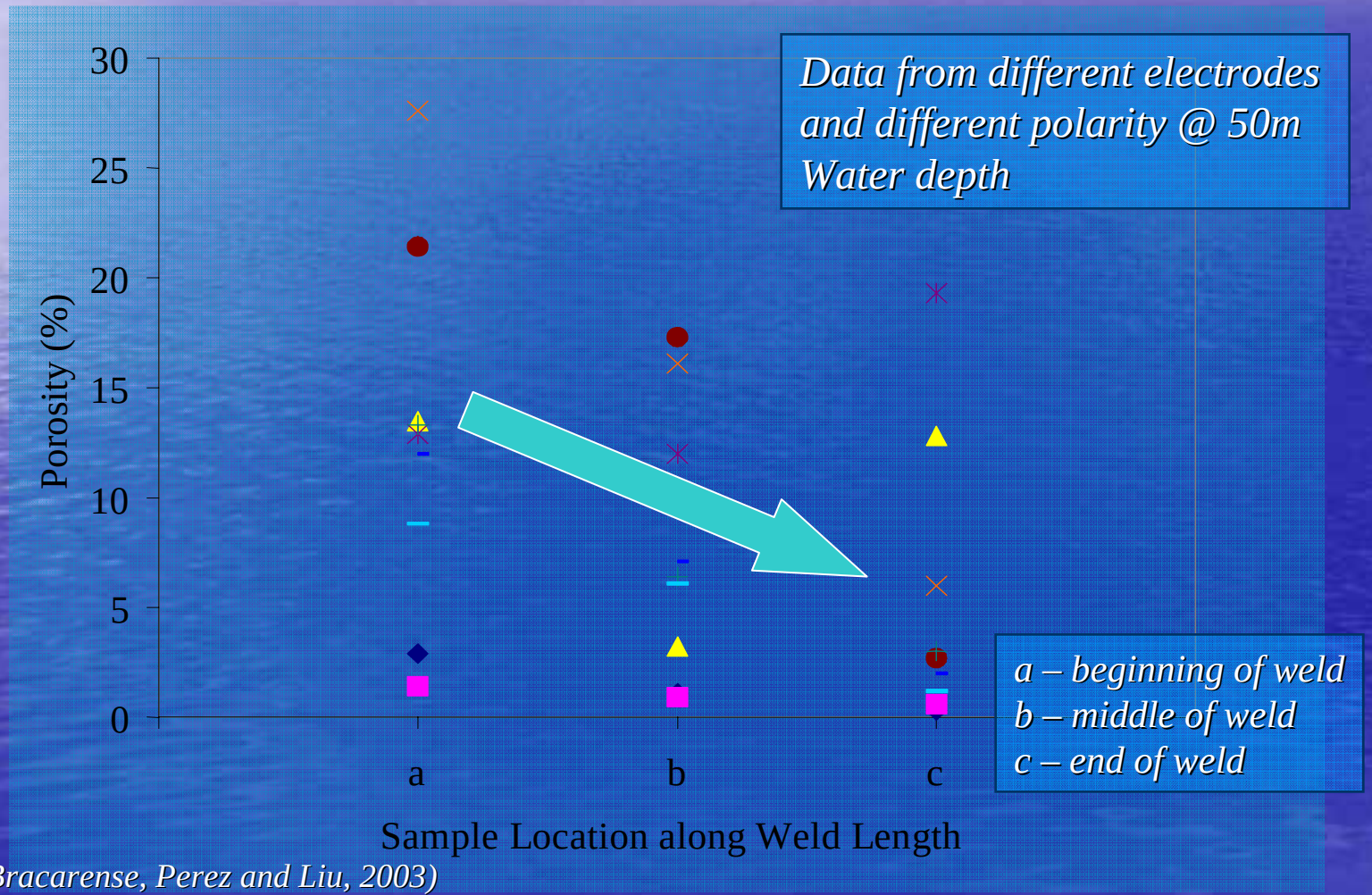
- 50 m, E7024 electrode and A-572 steel



(Pessoa, Bracarense, Perez and Liu, 2005)

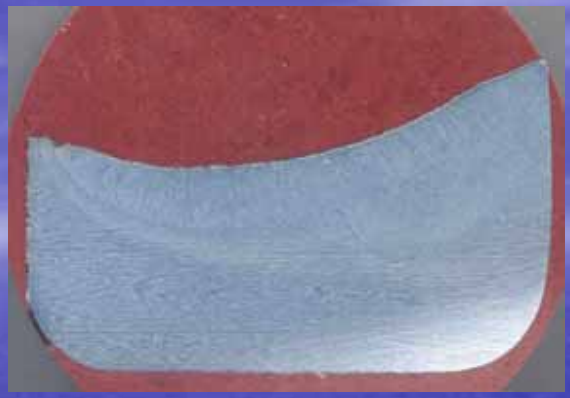
- 100 meters, E6013 electrode and A-36 steel

UWW - Porosity Mitigation – Pore Location - Longitudinal

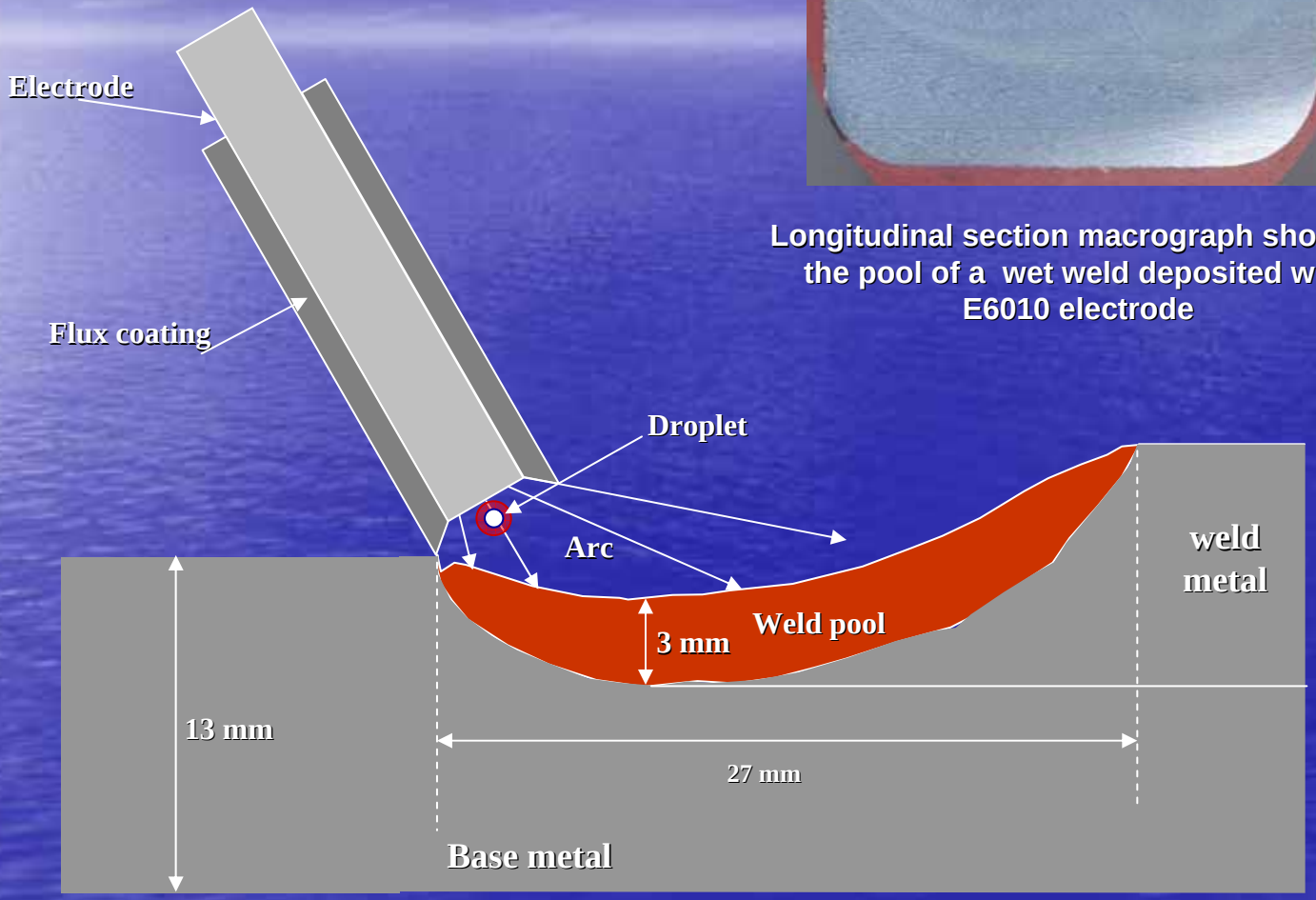


(Pessoa, Bracarense, Perez and Liu, 2003)

Weld pool

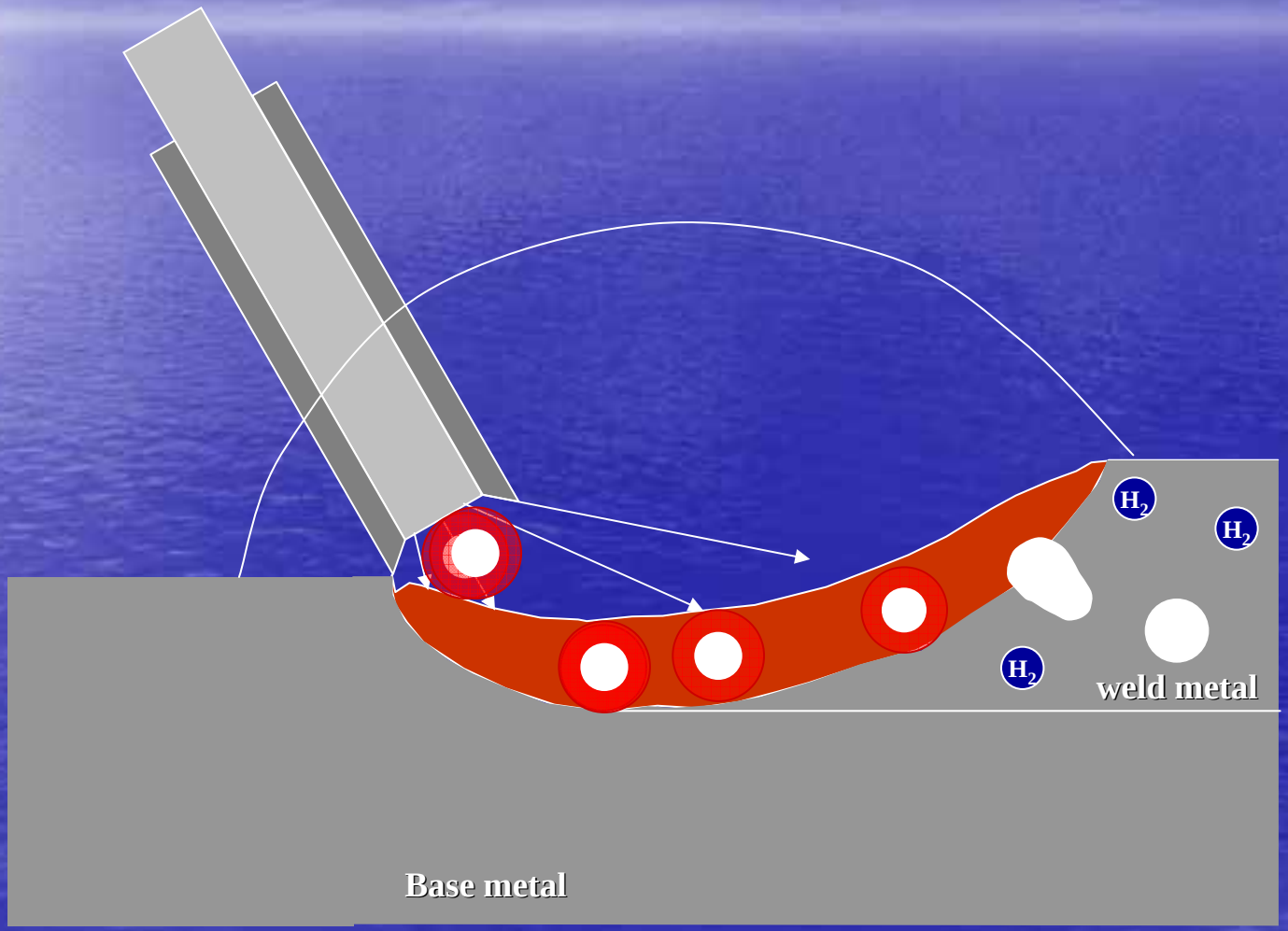


Longitudinal section macrograph showing the pool of a wet weld deposited with E6010 electrode

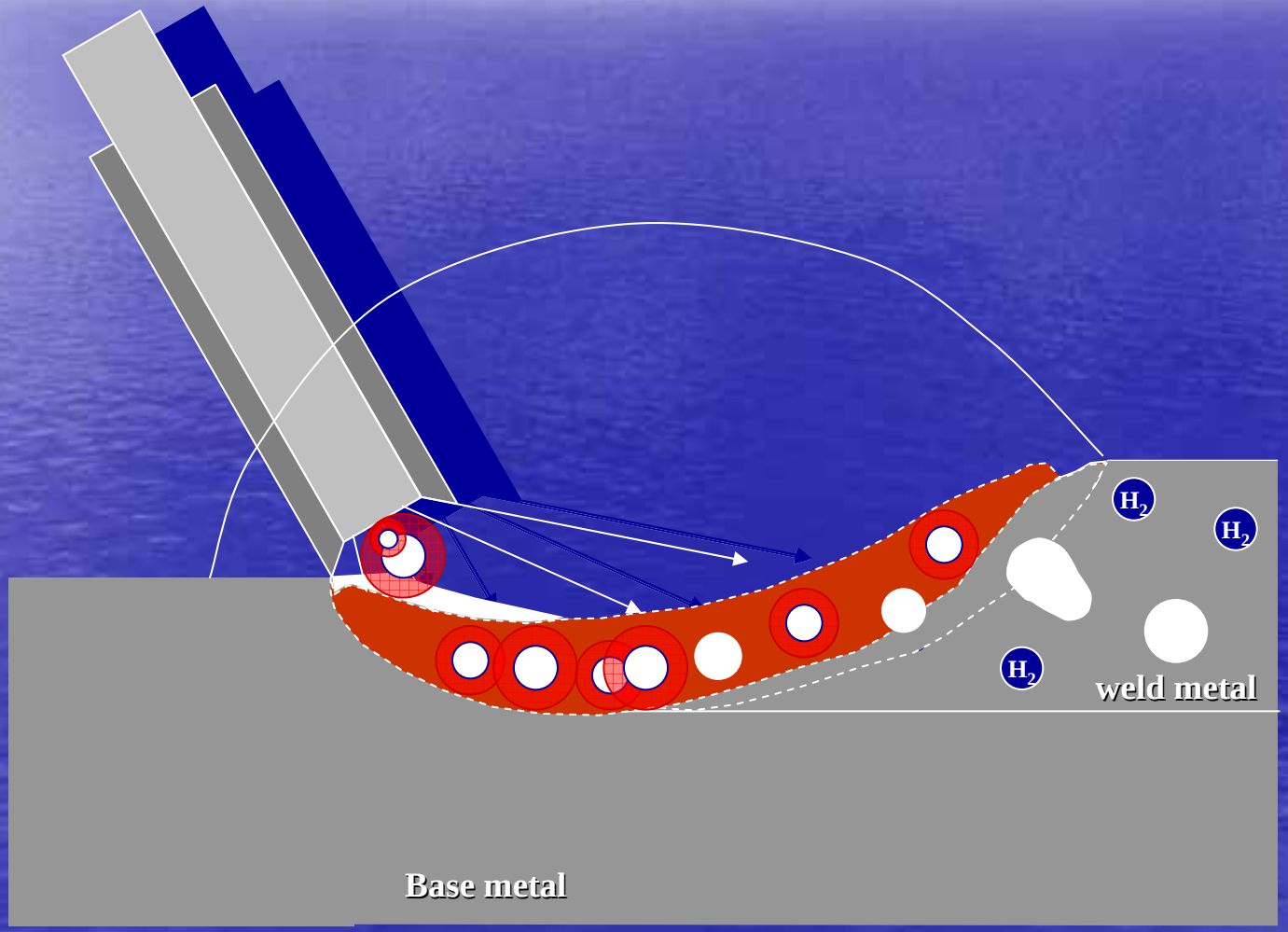


Schematic illustration of the longitudinal section macrograph above shown

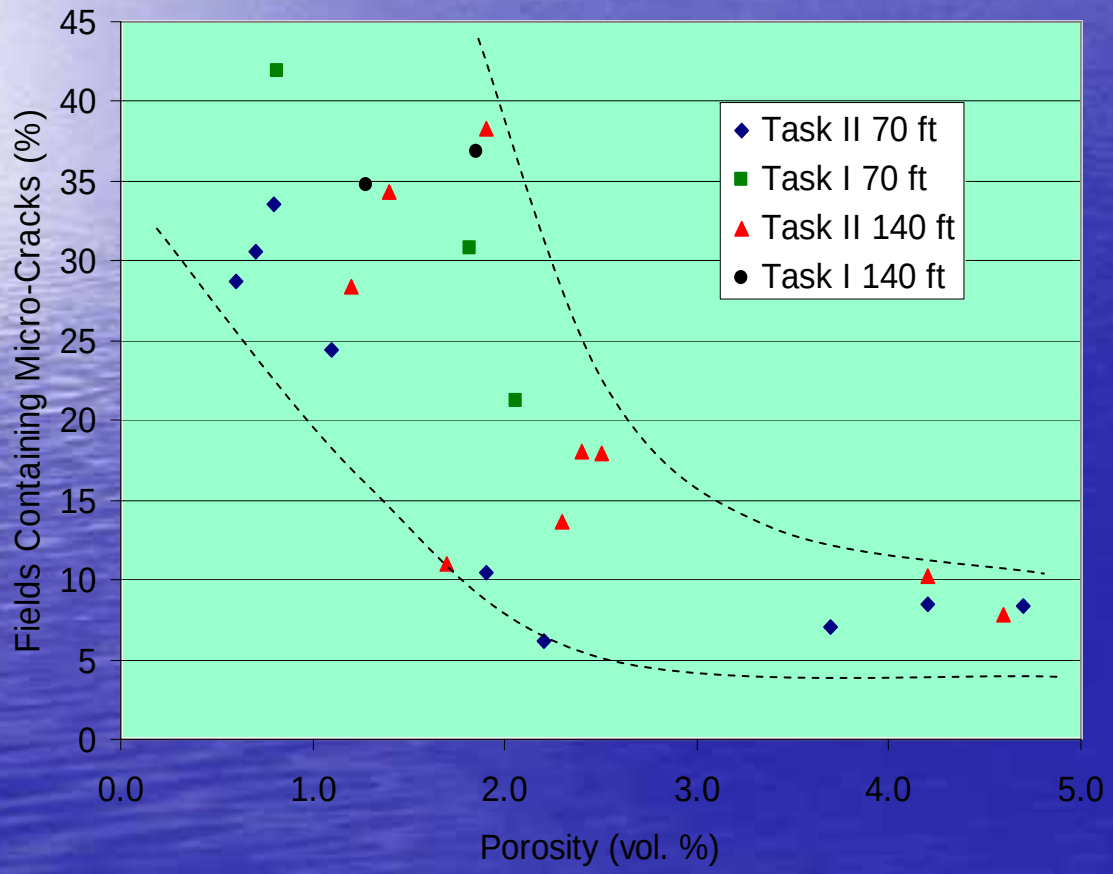
Proposed mechanism of porosity formation in wet welds with covered electrodes



Proposed mechanism of porosity formation in wet welds with covered electrodes



Porosity vs. Microfissures?



- The apparent correlation between microfissuring and porosity must be investigated.

(Rowe and Liu, 2002)

Underwater Welding - Today
A Mainstream Technology

Research Hyperbaric Facilities
(Global Divers & Contractors)
(UFMG – Brazil)
(GKSS – Germany)
(CSM – USA)

Reliable Structural Application