Solid State Joining of Creep Enhanced Ferritic Steels

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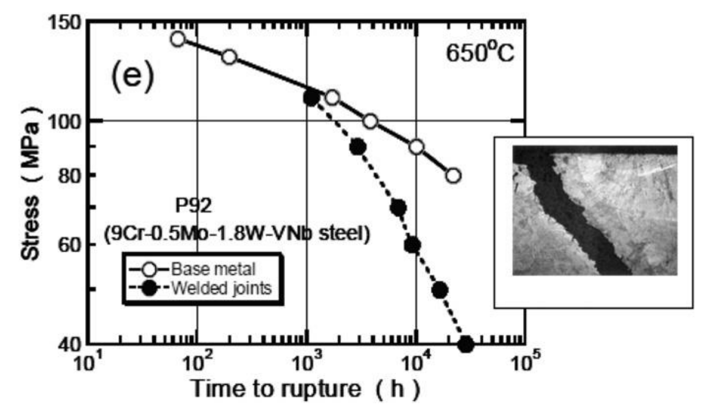
Solid Phase PROCESSING

Pacific Northwest NATIONAL LABORATORY

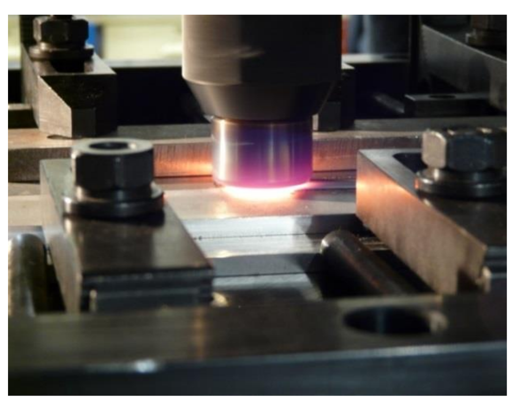
Issue

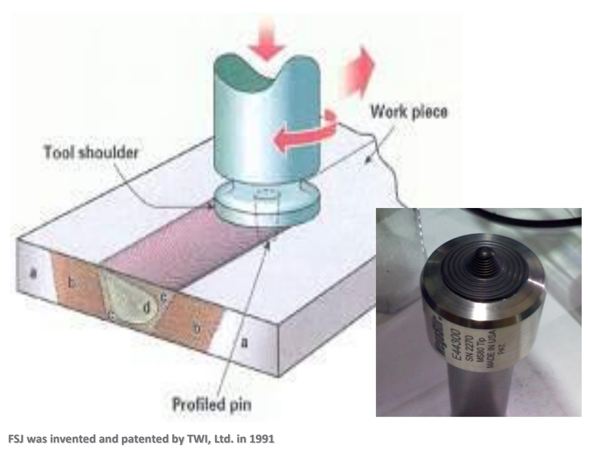
- Creep Strength Enhanced Ferritic Alloys (Grades 91, 92, CPJ-7) are low-cost F-M alloys for power plant (piping, waterwall / membrane wall, etc.)
- Creep performance compromised by fusion welding - microstructure instability in the HAZ
- WSRF can be as low as 0.50 at long creep times.



Can a new welding process create a microstructure that will show reduced long term microstructure degradation compared to conventional fusion weldments?

Advantages of Friction Stir Welding

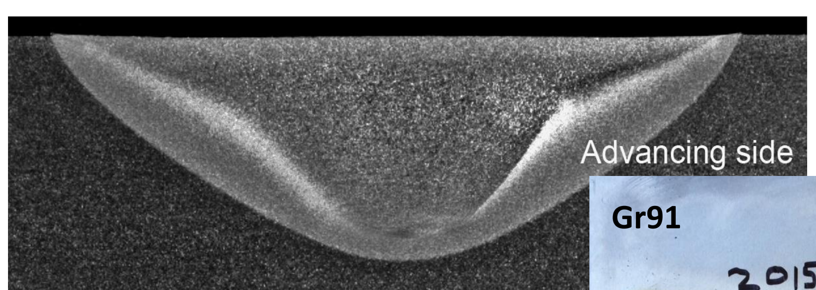


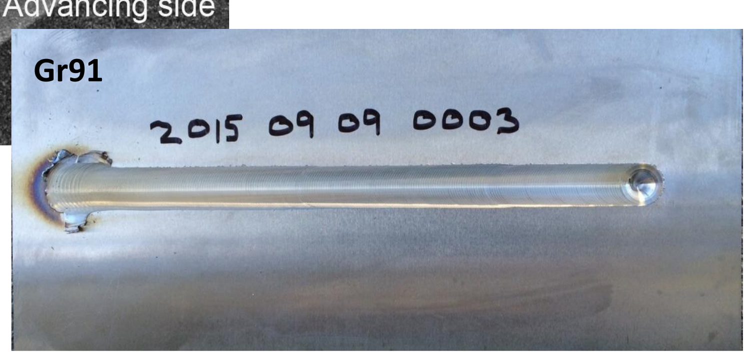


- A low energy solid phase joining method – no melting
- Temperature control and deformation may allow a "tunable" carbide precipitation sequence.
- FSW produces a strained microstructure, both in the nugget and in the HAZ.

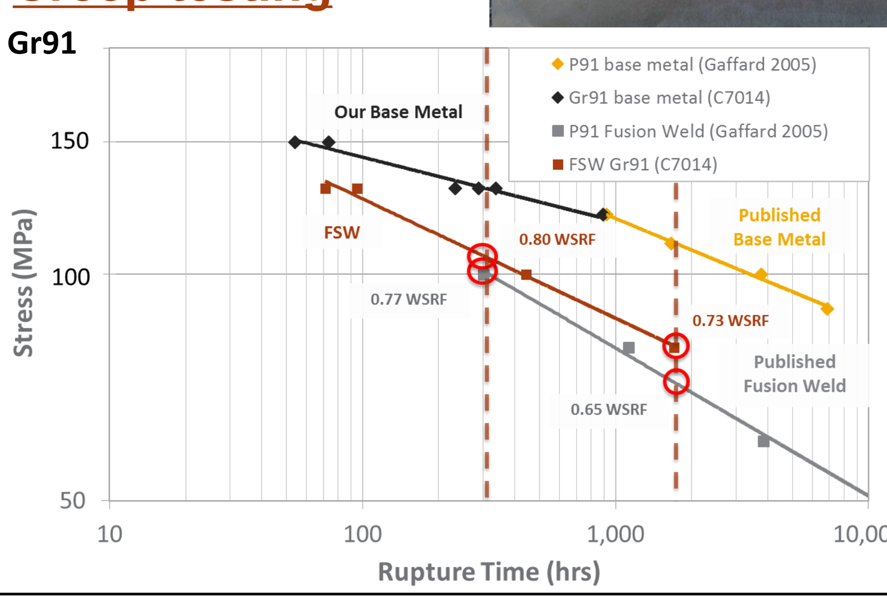
FSW of Gr91, P92, CPJ-7

- Defect free welds can be made in P91, P92, CPJ-7 at a wide range of conditions and weld temps 700°C to 1050°C
- Welds are overmatched and can pass ASME Section IX requirements for bend and tensile strengths



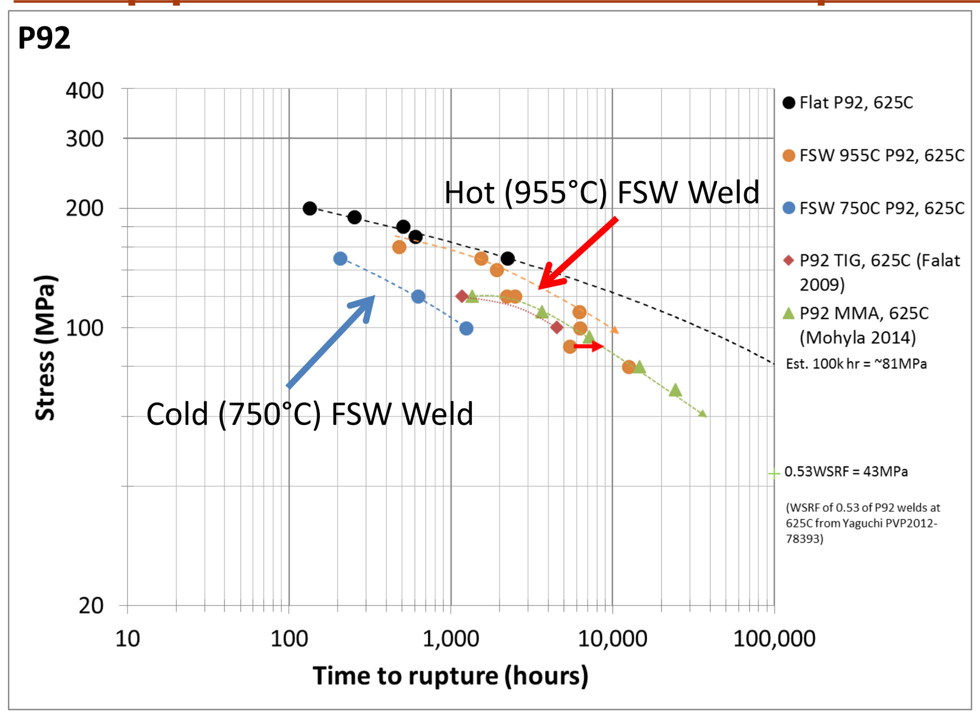


Creep testing



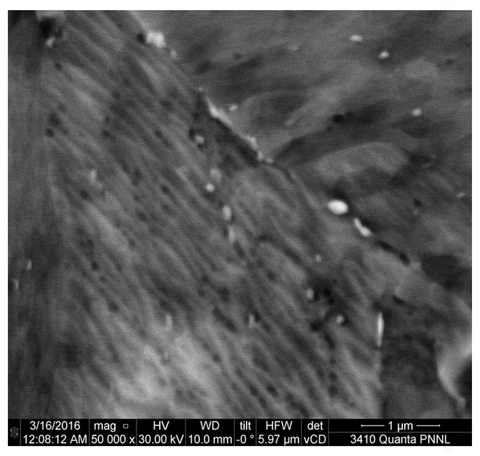
For some welding conditions the weld strength reduction factor (WSRF) can be raised from 0.68 for SMAW to 0.82 for FSW

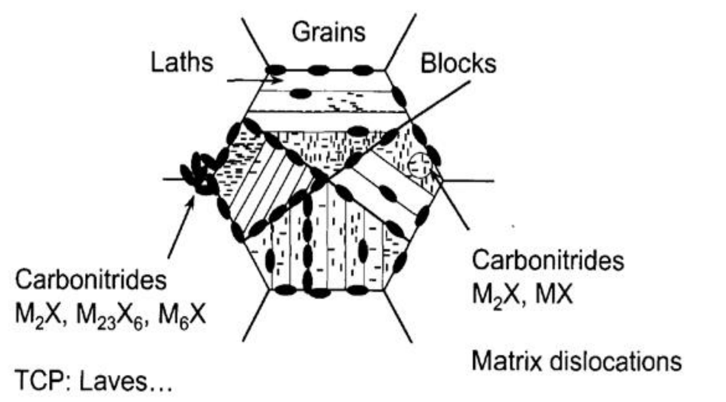
Creep performance with weld temperature



Discussion - Mechanisms

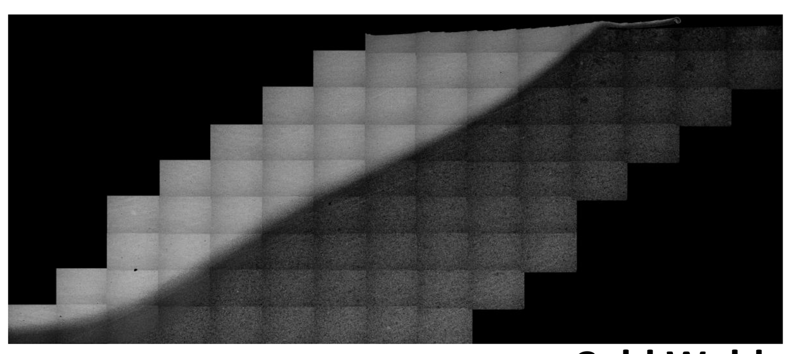
- Fine carbides and carbonitrides M23C6 and MX precipitates play a critical role in creep strength.
- Where these precipitates are located and their size are key parameters.
- It is hypothesized that a well distributed network of preferably intergranular (or on martensitic lath boundaries) MX precipitates forms the ideal microstructure.





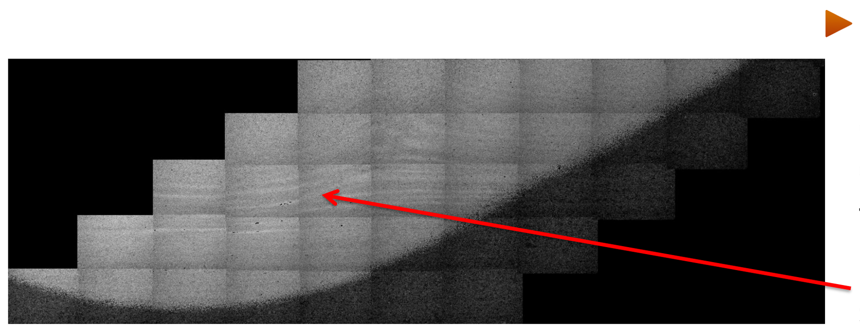
Schematic representation of non-uniform precipitation states in tempered martensitic 9-12%Cr steels (Gocmen et al., 1998)

Why does FSW have better creep performance?



Cold Weld WSRF 0.61

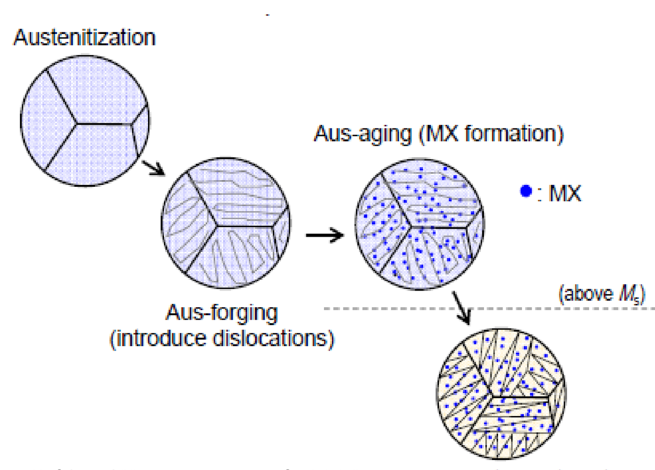
- FGHAZ is narrow and does not extend far from nugget (DRX zone). Strained area is narrow, most of the weld margin is ICHAZ



Hotter Weld WSRF 0.81

- FGHAZ fully extends into a wide strained area (seen as convoluted bands from original plate rolled structure). This strain is introduced during the time the region is above AC3.

- Ausforming? – strain induced dislocations from FSW in the austenite phase field may help to retain or create a dispersed MX distribution on dislocations upon cooling
- The hot welds, which performed better, had wide FGHAZs that underwent straining above AC3. The cold welds had transformed regions that barely extended past the DRX (nugget) zone and had only narrow areas of material that was strained above AC3.



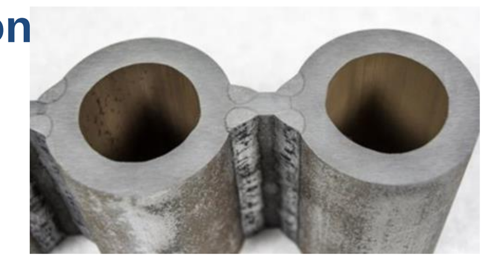
Yukinori Yamamoto, et al., 2014

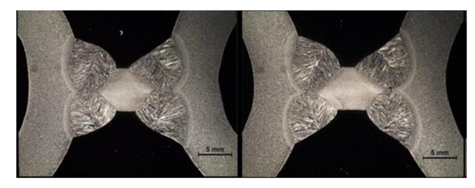
Next Steps

- Finish creep testing of P92 and start CPJ-7
- Creep fatigue

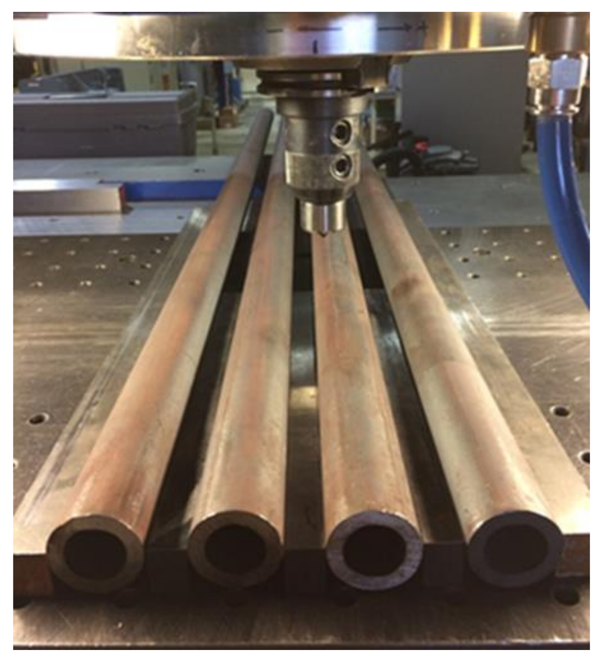
Final Task – Water Wall Prototype Demo

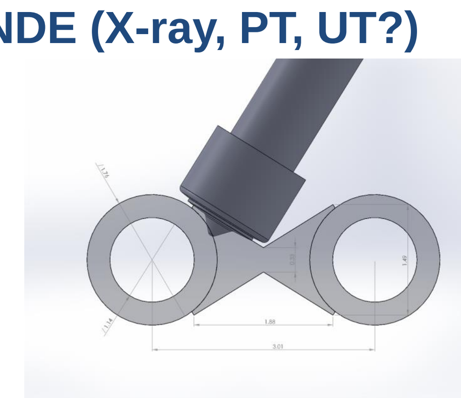
- Will use FSW to fabricate a prototypic P-92 membrane wall
- Possible advantages of FSW over fusion welds:
  - Better creep and fatigue
  - Low distortion due to lower residual stress
  - Less weld penetration

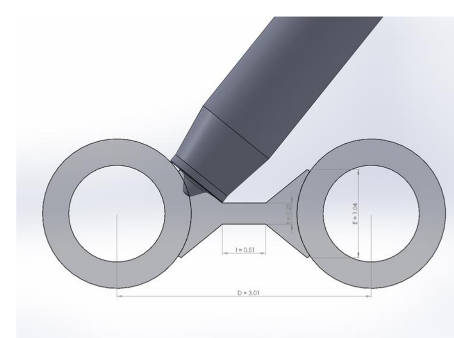




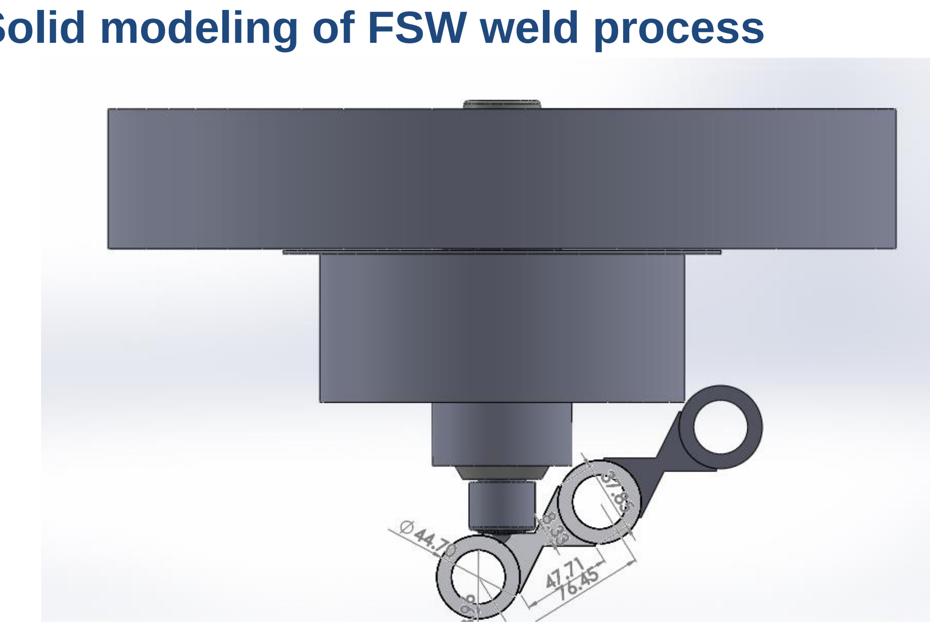
- Approach
  - ASTM A213-T92 (Vallourec, 62" long x 1.75" OD x 0.3" wall thickness) from GE/Alstom Power Inc. Grade 91 strip for webbing
  - Weld development for Gr91 web to T-92 tube
  - Two tool types
  - Measure distortion, NDE (X-ray, PT, UT?)







- Solid modeling of FSW weld process



Conclusions

- Creep performance of FSW welded P91 is very good, both of the weld metal and in cross weld tension – current results indicate that tool temperatures greater than 865°C are beneficial and can reach WSRF of 0.82
- WSRF can be raised by more than 10% from fusion welded equivalents
- FSW allows for enough knobs to be turned in the process to customized heat input.
- It may be possible to follow a path through thermo-mechanical space that will leave the weld region, and especially the strained part of the HAZ, with a customizable carbide distribution appropriate for better creep resistance, and much closer to the parent microstructure than if it is fusion welded.

Acknowledgement

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