Joining and Processing Issues for Ferritic/Martensitic Steels

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Strategic Planning Meeting

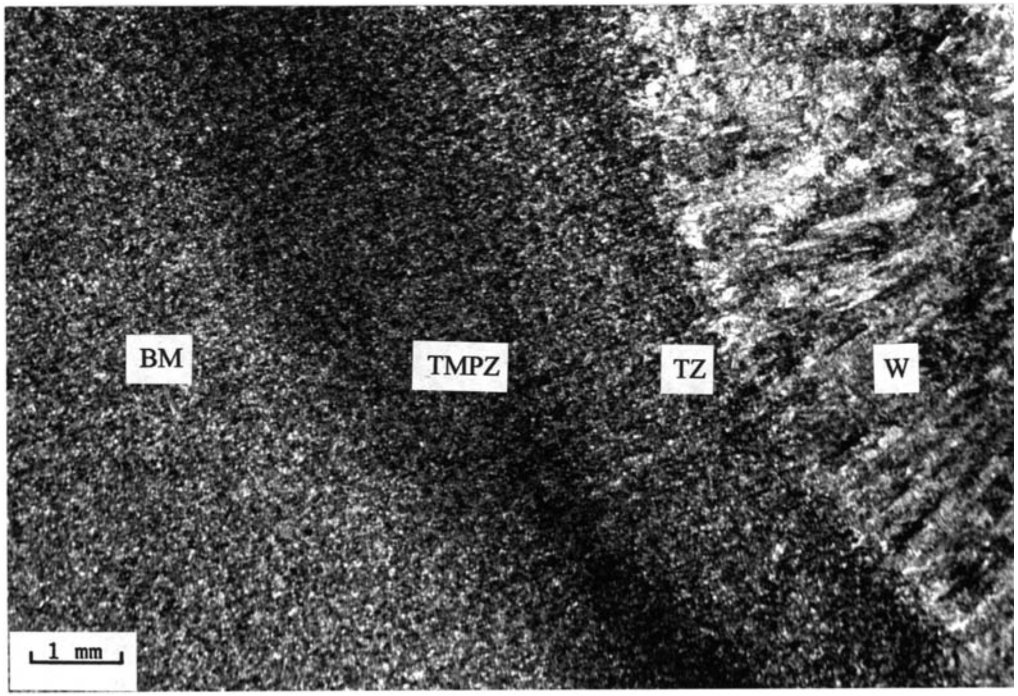
University of California at Santa Barbara

August 26-30, 2002

Ferritic/Martensitic Steel Welds: Necessary for Fusion Structure

- High-Cr ferritic/martensitic (F/M) steel welding processes are established.
  - Steels can be welded by conventional techniques—SMAW, GTAW, GMAW, TIG, SAW, etc.
  - Electron beam and laser welding also developed
  - F/M steels are more difficult to weld than austenitic stainless steels
    - Pre-heat and post-weld heat treatment required
    - Complicated microstructure of F/M weldment affects properties and failure mechanisms

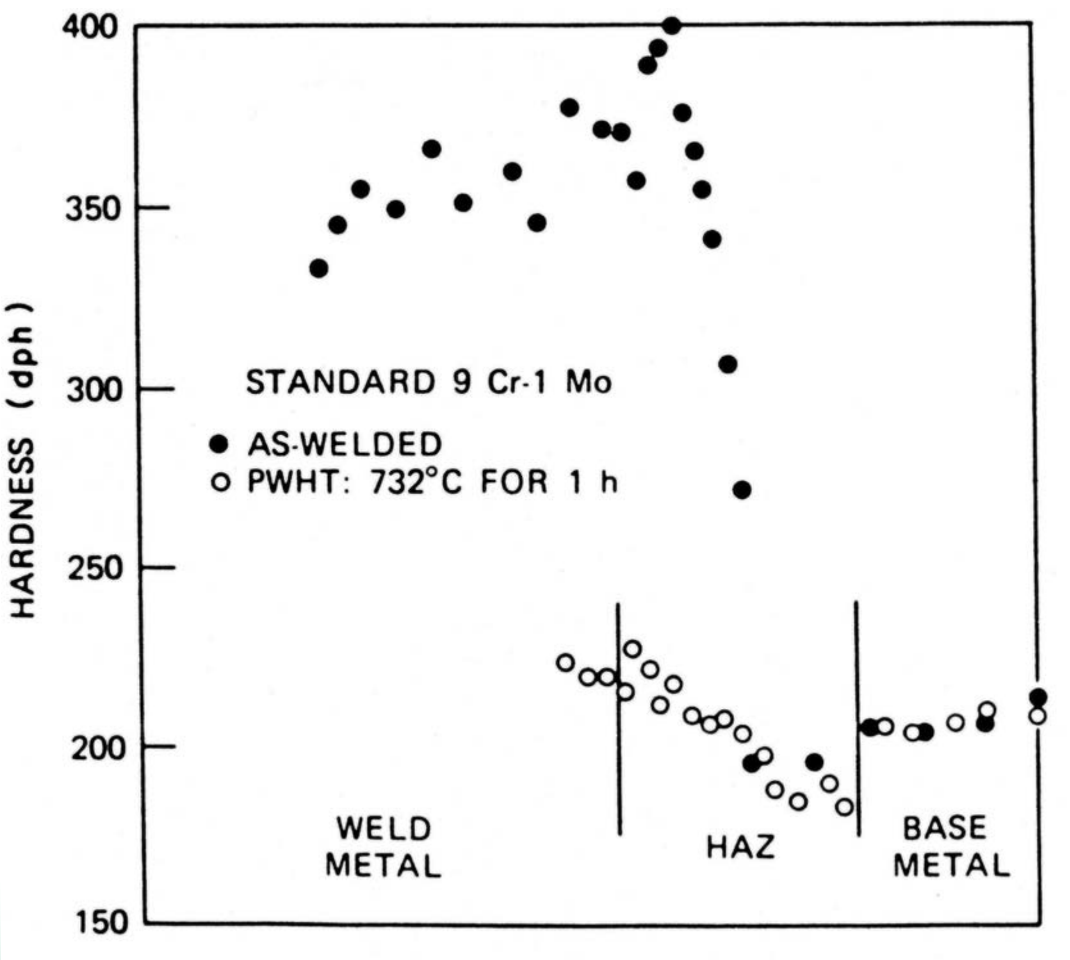
Weldment Structure of a Ferritic-Martensitic Steel is Complicated



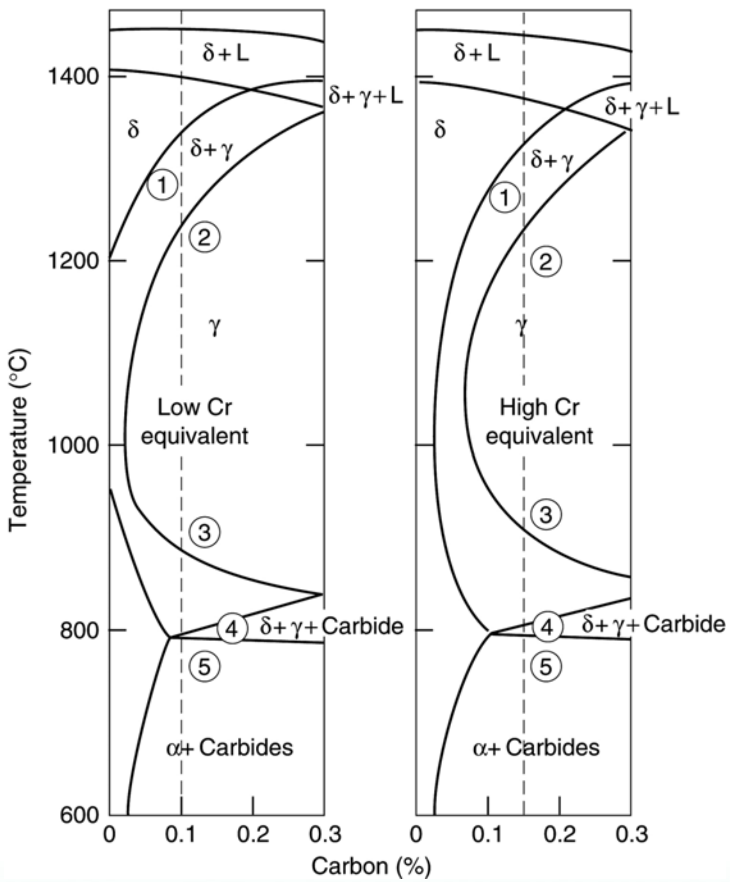
BM: Base Metal, TMPZ: Tempered Zone

TZ: Transformation Zone, W: Weld Metal

Hardness Varies with the Microstructure of Weldment

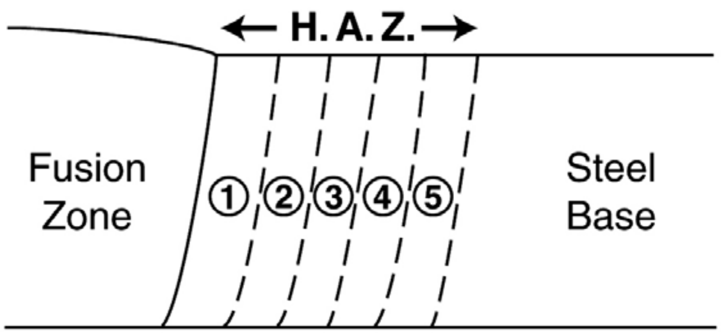


Microstructural Zones Are Determined by Heating-Cooling Process



Phase Diagram
for High-Cr Steel

Five Different Microstructural Regions Form in the Heat-Affected Zone

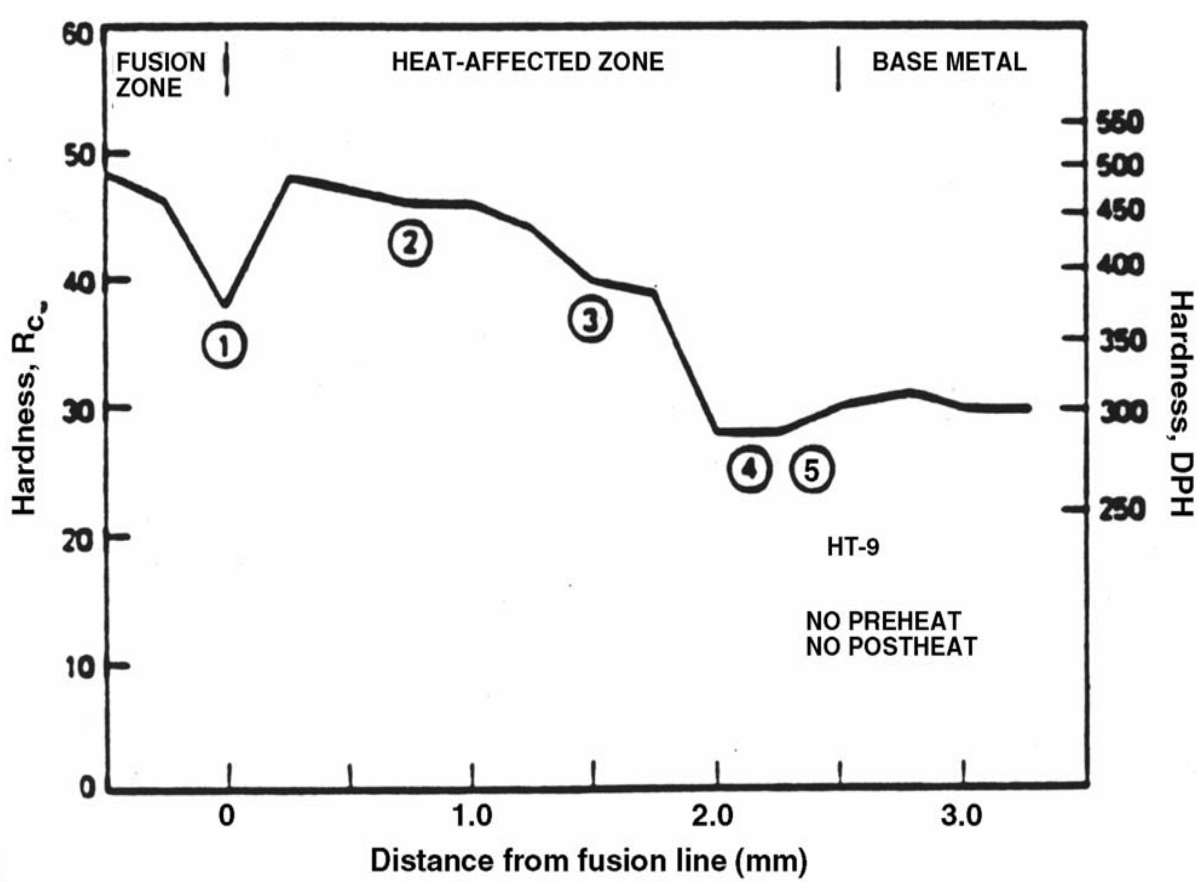


Fusion Zone (FZ): $T > T_m$

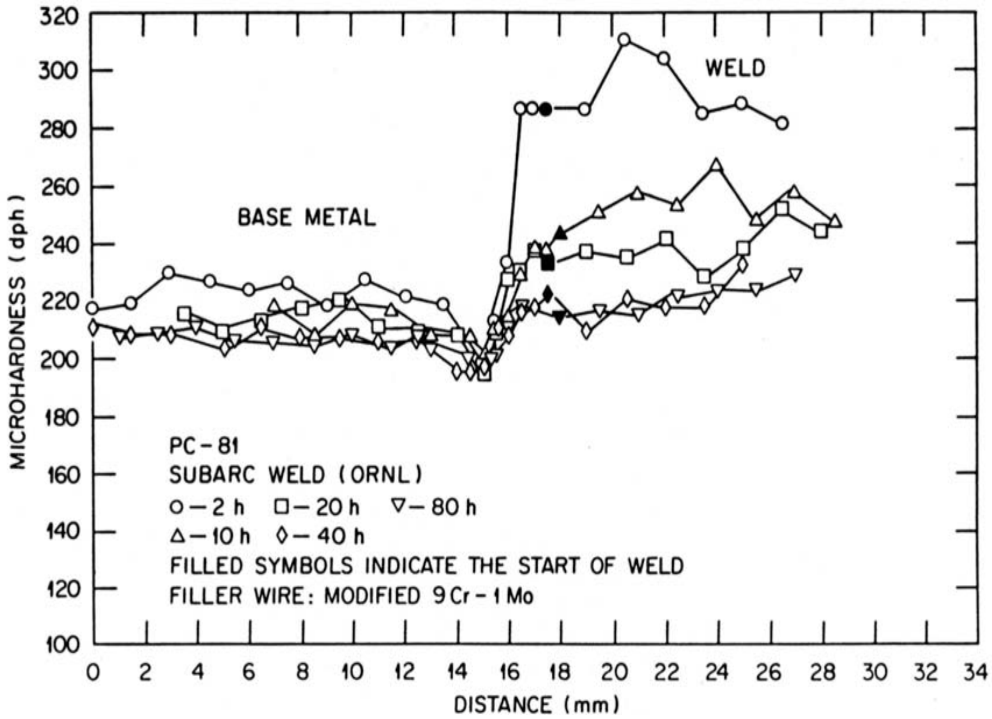
Heat - Affected - Zone (HAZ) [as-welded]:

Region 1	$T_m > T > T_{\gamma\delta}$	$\gamma + \delta \rightarrow$ Martensite + δ
Region 2	$T_{\gamma\delta} > T > Ac_3$	Coarse grained $\gamma \rightarrow$ Martensite
Region 3	$T_{\gamma\delta} > T > Ac_3$	Fine grained $\gamma \rightarrow$ Martensite
Region 4	$Ac_3 > T > Ac_1$	$\gamma \rightarrow$ Martensite + Overtempered Martensite
Region 5	$Ac_1 > T > T_T$	Overtempered Martensite

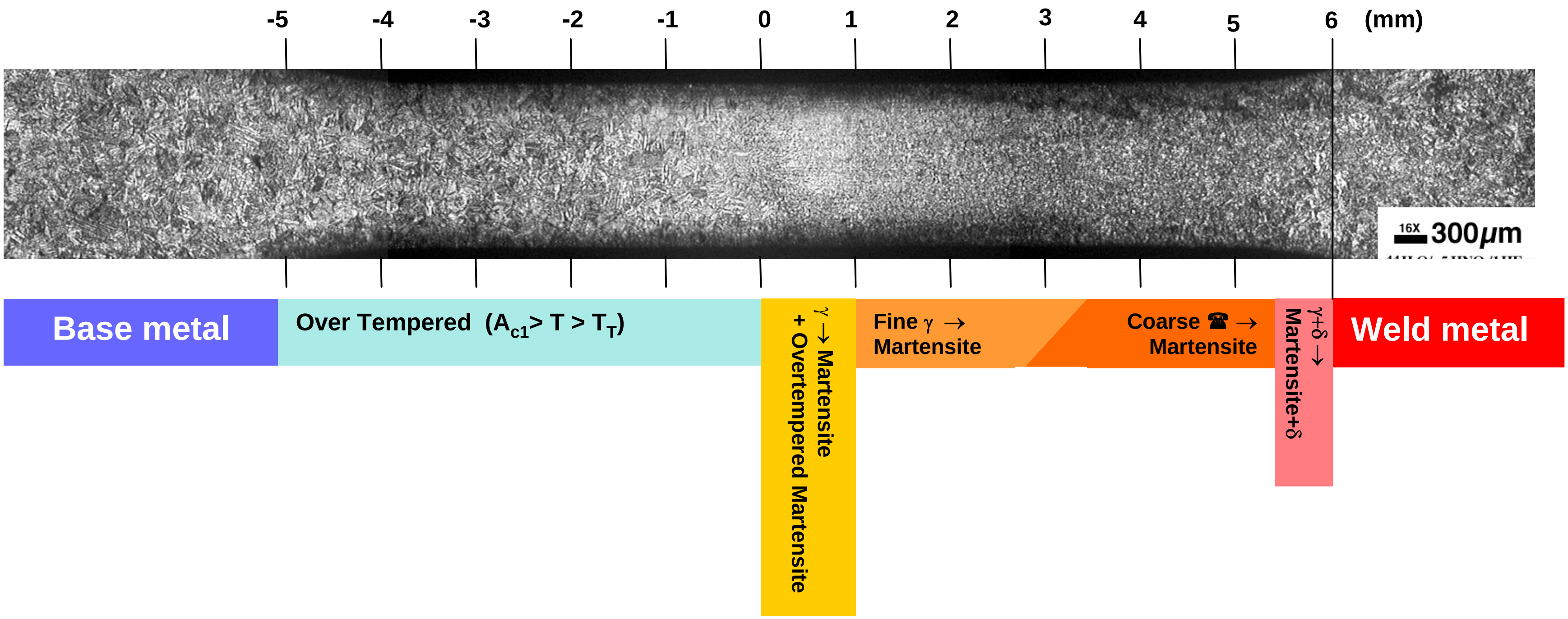
Hardness Across Weldment Determined by Microstructure



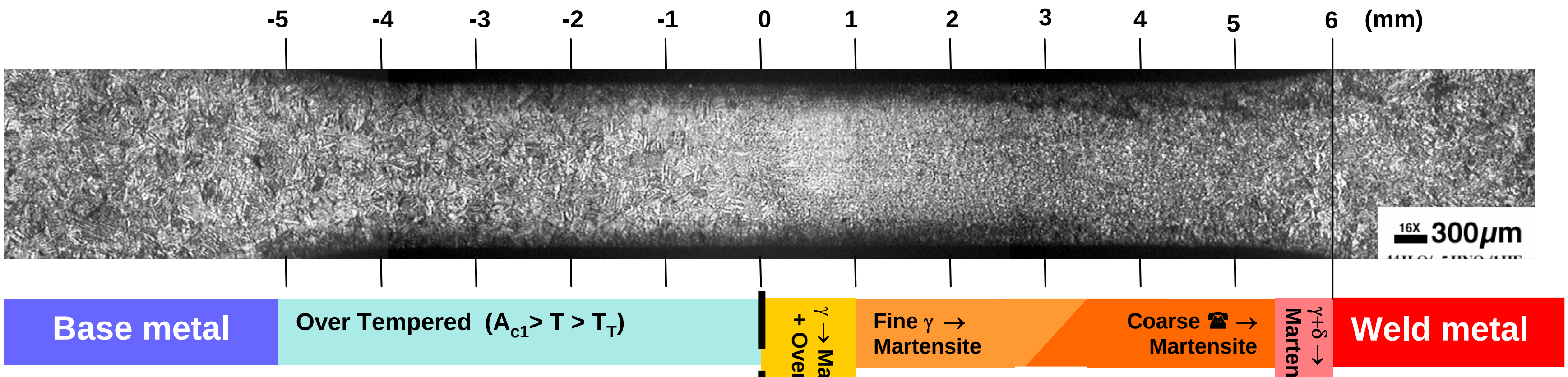
PWHT Tends to Smooth Out Hardness (Strength) Differences



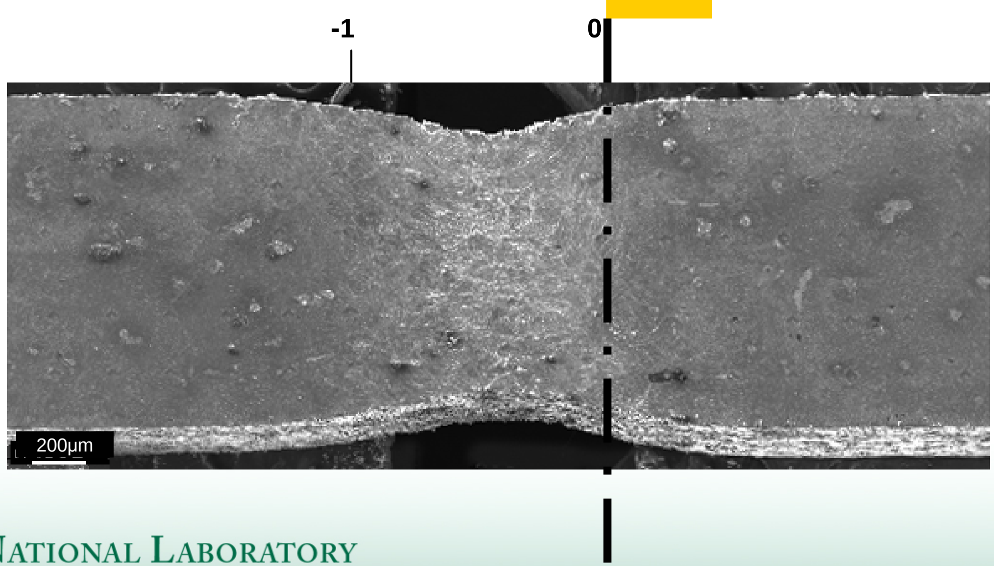
- Dip in hardness of HAZ remains after PWHT

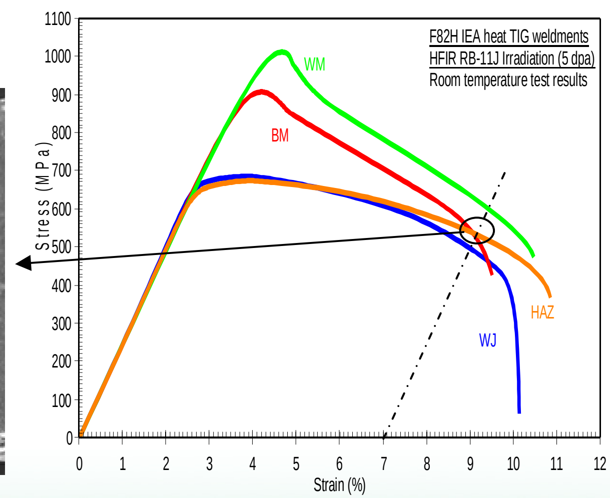


F82H Weldment

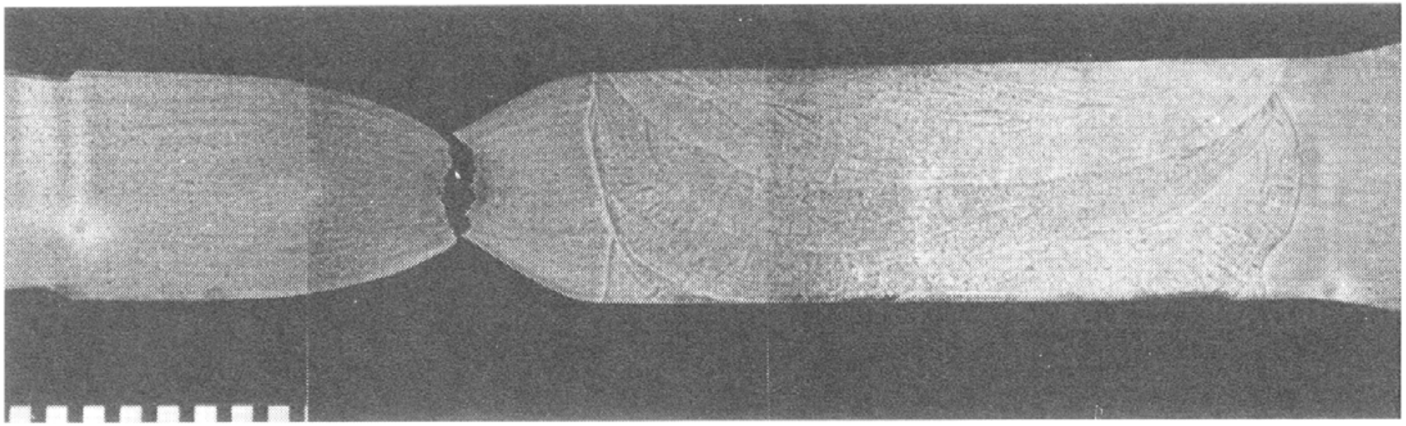


F82H Weld and Deformation



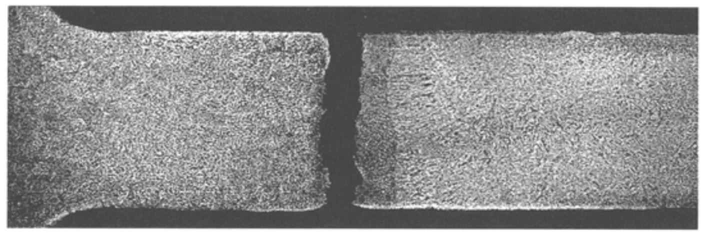


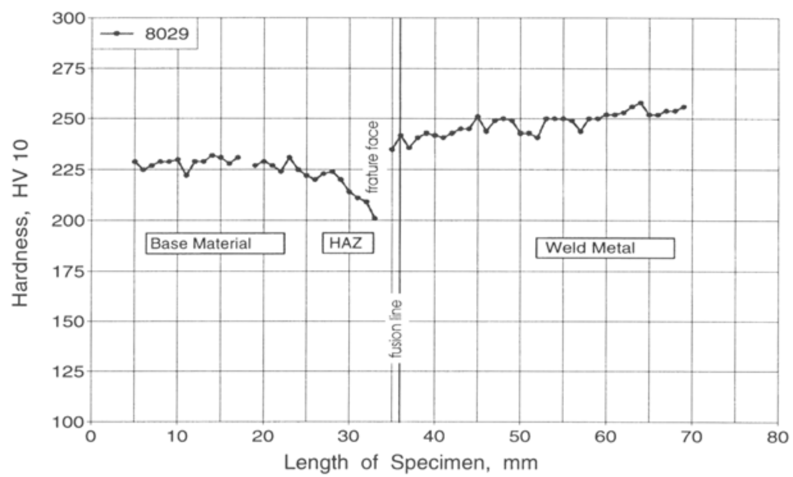
Failures in Base Metal or Over-Tempered Region at High Strain Rate



•Ductile failure occurs for tensile test and high-stress, short-time creep test

Low-to-Moderate Stress Failures Can Occur with Little Ductility



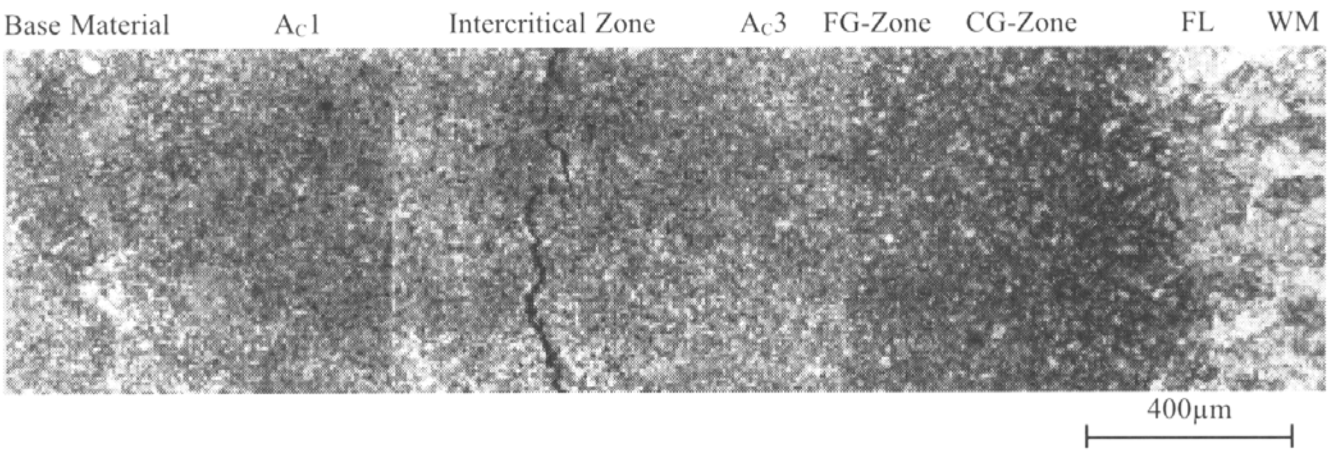


Creep Failure

Type IV Cracking—A Problem for Ferritic/Martensitic Steels

- Type IV cracking has become a major inspection problem in power plants worldwide
- Evidence suggests cracking results from high stress across weldment and accumulation of creep cavitation damage in intercritically transformed zone—region that was heated between the A_{C1} and A_{C3} temperatures

Type IV Failures—Low Ductility



9Cr-1Mo-1WVNbN (E911) Steel

70 MPa, 650°C, 4295 h

Effect of Irradiation on Weldments Needs to be Evaluated

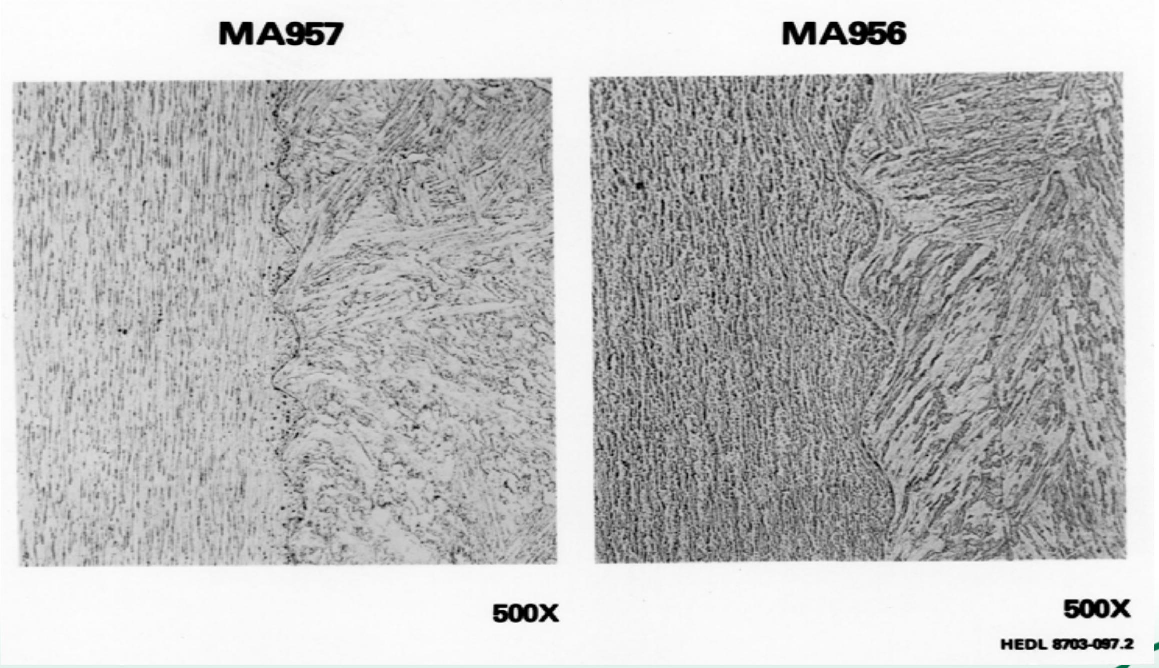
- The effect of irradiation hardening at low temperatures on fracture needs to determined
  - Tensile studies
  - Impact and fracture toughness studies
  - Fatigue (high-cycle and low-cycle)
- The effect of properties of weldments above temperature where hardening occurs needs to be evaluated
  - Type IV cracking

Alternate Welding Techniques Need to be Evaluated

- High-frequency induction welding
- Diffusion welding
  - –Used on F82H and MANET in fusion materials programs
  - –Leak-tight bonds with strength almost equivalent to base steels were achieved
- Explosive Welding
  - –Process has been commercially developed
  - –Used to advantage in fast reactor programs
- Pulsed-Magnetic Welding

Pulsed-Magnetic Welding is Method for Joining ODS Steels

- Pulsed Magnetic Welding Studies for FFTF
  - Traditional fusion welding techniques do not work
    - Due to flocculation of Y_2O_3
    - flaring of tubing critical



Repair Welds on Fusion Plant Will be Affected by Helium in the Steel

- Limited data exist for HT9 with 0.3 and 1 appm He inserted by “tritium trick” and welded
- No weld defects on controls or with 0.3 appm He
- Discontinuous micro-cracks formed at prior austenite grain boundaries in steel with 1 appm He
- Cracking occurred at high temperatures by shrinkage stresses in constrained plates during cooling from growth and coalescence of grain boundary He bubbles

Processing of Steels: Techniques are Well Established

- Processing of conventional and reduced-activation steels is well established
- Variation on Processing May Provide Route to New Steels
- Conventional processing techniques were used to produce A-21 precipitation-strengthened steel

A-21 IS STRENGTHENED BY CONVENTIONAL PROCESSING

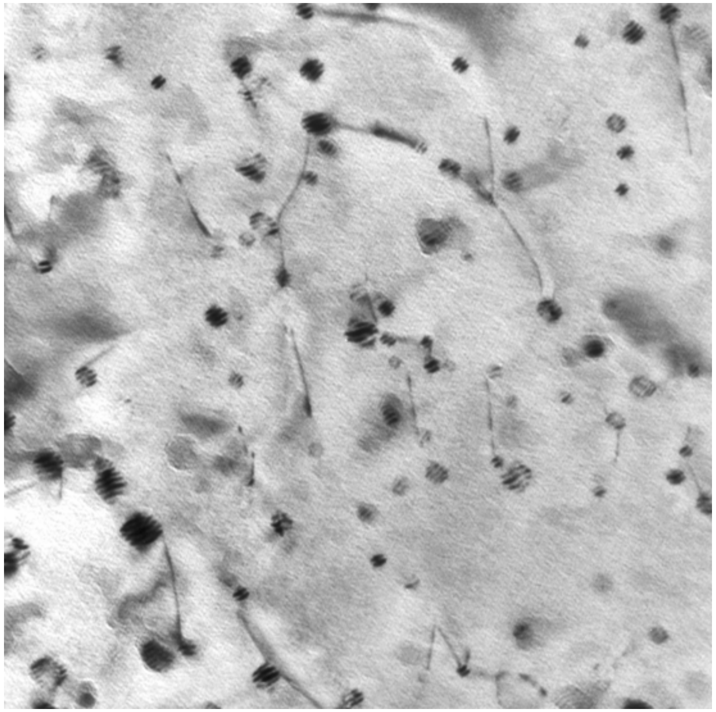
- A-21 steel: Fe-9.5Cr-3Co-1Ni-0.6Mo-0.3Ti-0.07C*
- Processing of A-21 Steel
  - austenitized at T>1100°C
  - hot worked at 700-900 °C
  - cooled to ambient temperature to form martensite
  - tempered 1 h at 650-750 °C

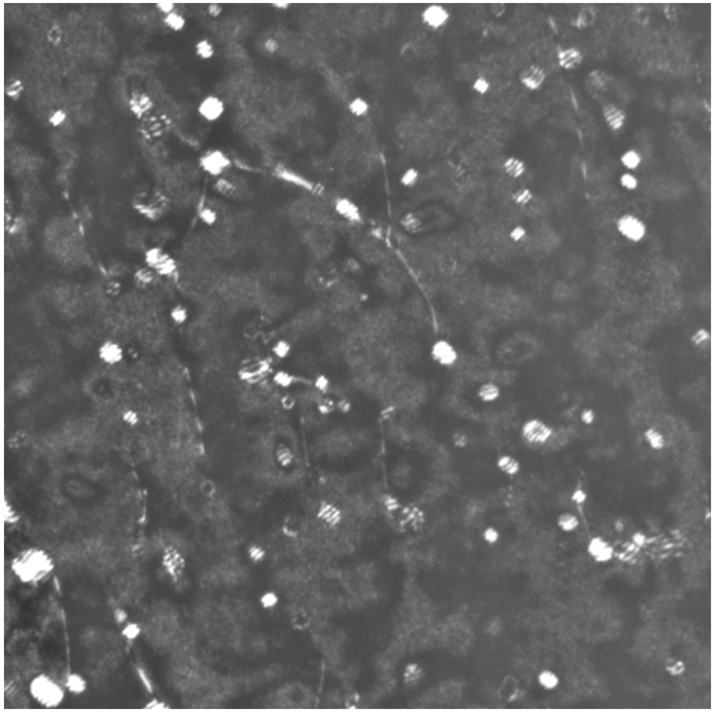
*Cobalt-free A-21 steel has been developed

PROCESSING PRODUCES FINE DISPERSION OF TiC

- Carbides dissolve at austenitization temperature (>1100°C)
- Hot working at 700-900°C produces dislocations on which a fine distribution of TiC precipitates
- Cooling to ambient temperature produces low-carbon martensite (most of the carbon is in TiC)
- During tempering, which may not be needed, no large $M_{23}C_6$ precipitates form (carbon tied up in TiC precipitates

A-21 CONTAINS HIGH NUMBER DENSITY OF FINE PRECIPITATES





•Particle size: 5-20 nm; Number Density: 4.7 x 10^{21} m^{-3}

Welding Issues: Summary and Conclusions

- Complicated microstructures of conventional welds in ferritic/martensitic steels affects fracture behavior
- Effect of irradiation on weld failures needs to be established for reduced-activation steels
- Alternate welding techniques need to be explored
- Welds on steel containing helium need investigation to develop repair welding techniques

Processing Issues: Summary and Conclusions

- Conventional processing techniques for conventional and reduced-activation steels are well established
- Variation on the processing of steels may offer another route to steels with good elevated-temperature strength