Metallurgical Phenomena Related to the High Temperature Performance of Dissimilar Metal Welds between Austenitic and Ferritic Alloys

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Outline

Metallurgical Phenomena in DMWs

Thermophysical Property Gradient

Composition and Chemical Potential Gradient

Compositional Transition Zone Morphology

Phase Transformations and Hardness Gradient

Thermal Fatigue Behavior & Testing

Prediction of Carbide Precipitation Behavior

Grade 91 / Ni-base Filler Metal / 347H DMWs

Alloy	C	Mn	Cu	Si	Ni	Cr	Mo	V	Al	Co	Nb	Fe
P91	0.11	0.4	0.02	0.36	0.06	8.71	0.94	0.195	0.001	-	0.076	Bal
B91	0.10	0.6	0.05	0.25	0.7	9	1	0.2	-	-	0.05	Bal
625	0.02	0.1	0.01	0.14	Bal	21.7	8.5	-	0.1	-	3.8	0.4
617	0.07	0.4	0.09	0.3	Bal	22	8.7	-	1	12	-	0.3
82	0.04	2.8	0.03	0.09	Bal	20	-	-	-	-	2.4	1.5
P87	0.10	1.5	-	0.3	Bal	9	2	-	-	-	1	38

Metallurgical Phenomena in DMWs

Sharp gradients in the dissimilar transition zone

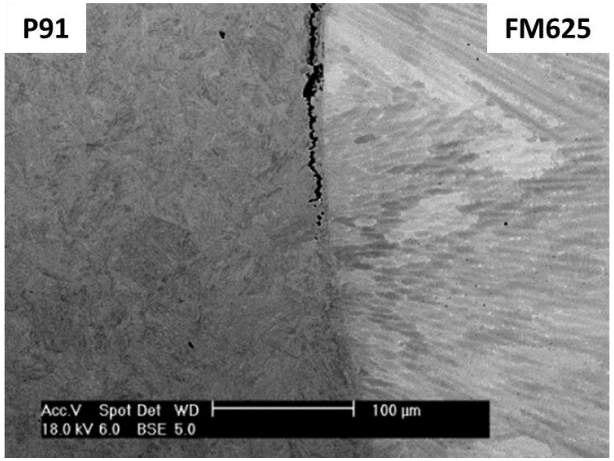
Chemical composition gradient
- Gradient in solidification temperature ranges
  - Epitaxial solidification
  - Partially mixed zones (swirls)
- Reversing austenite-to-martensite transformations

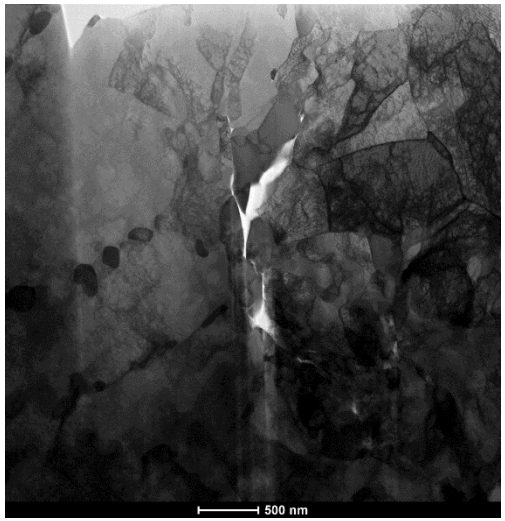
Chemical potential, solubility & diffusivity gradients
- Carbon migration and accumulation, carbide precipitation

Thermal conductivity and heat capacity gradients
- Different temperature gradients in weld metal and HAZ
- Planar growth solidification
- Carbide dissolution in HAZ
- Stabilizing δ-ferrite in ferritic alloy HAZ

Thermo-physical and mechanical property gradients
- Thermal fatigue loading
- Strain concentration in carbon depleted regions

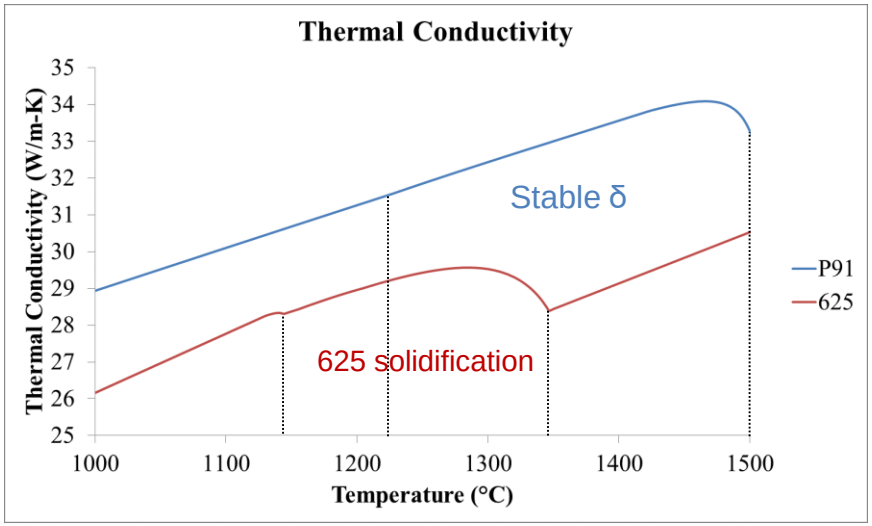
Thermal fatigue cracking in service

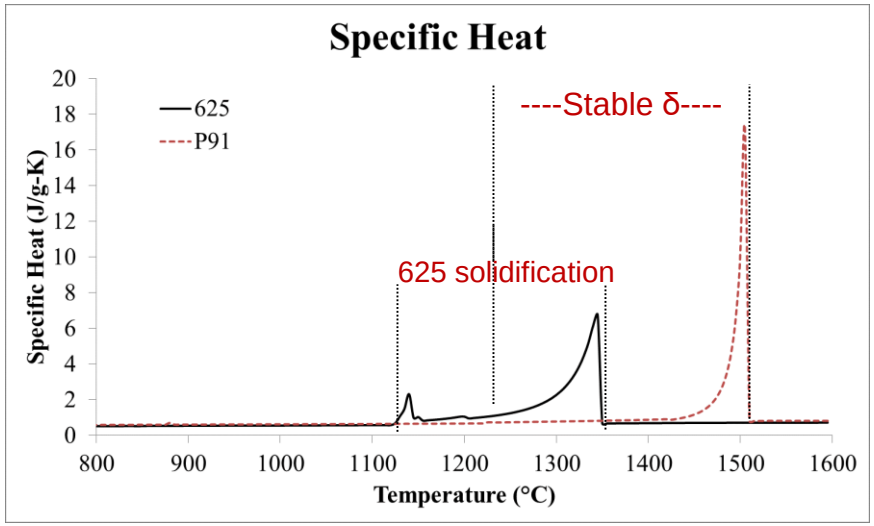




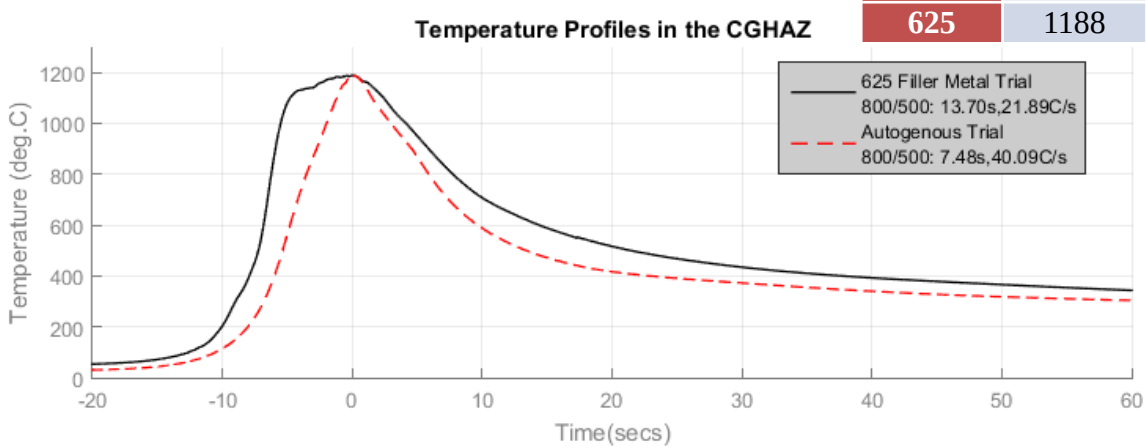
Thermophysical Property Gradient

Effect on Weld Thermal History



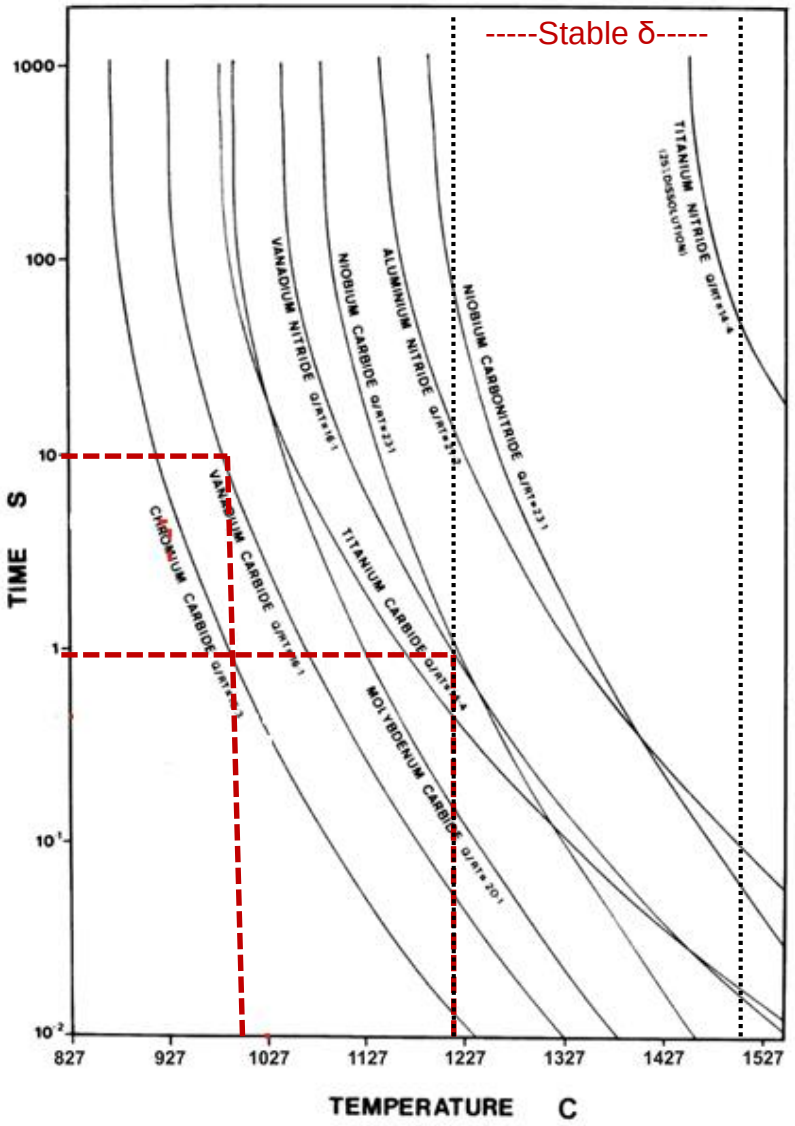


Weld Metal	Peak Temp (°C)	Heating		Cooling		Total Time (s)
		Time (s)	Rate (°C/s)	Time (s)	Rate (°C/s)	
P91	1190	2.00	95.23	2.96	64.19	4.96
625	1188	5.64	33.38	4.53	41.49	10.17



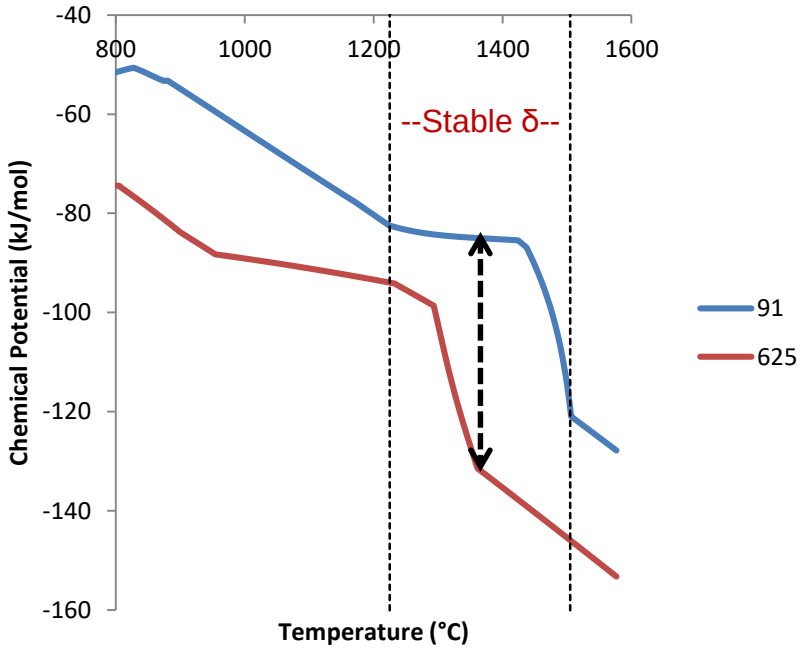
Composition & Property Gradient

Effect on HAZ Carbides Dissolution and Carbon Migration

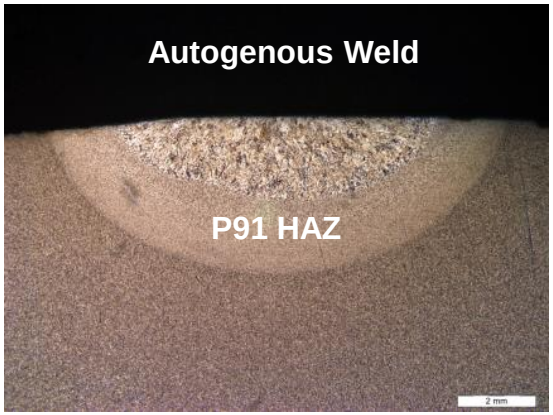


- Cr carbides dissolve rapidly
- Mo carbides dissolve deeper into the HAZ Cr/Mo enrichment (locally)
- Carbon diffuses into weld

Chemical Potential Of Carbon

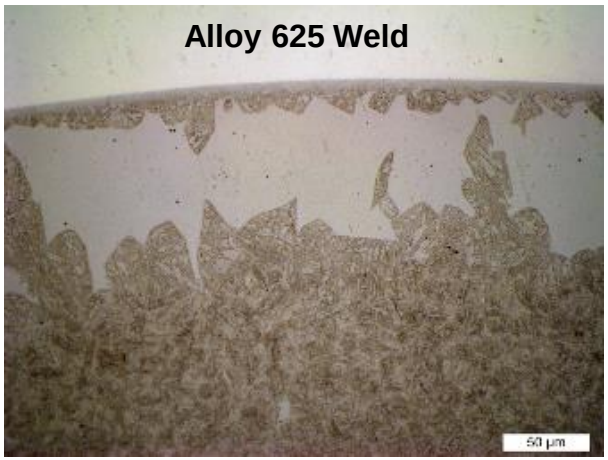


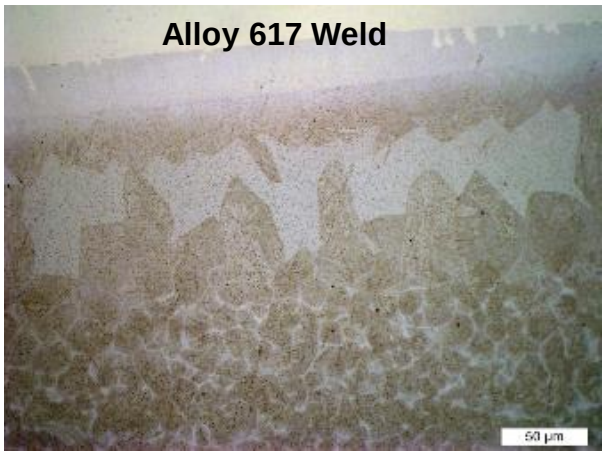
HAZ δ-Ferrite

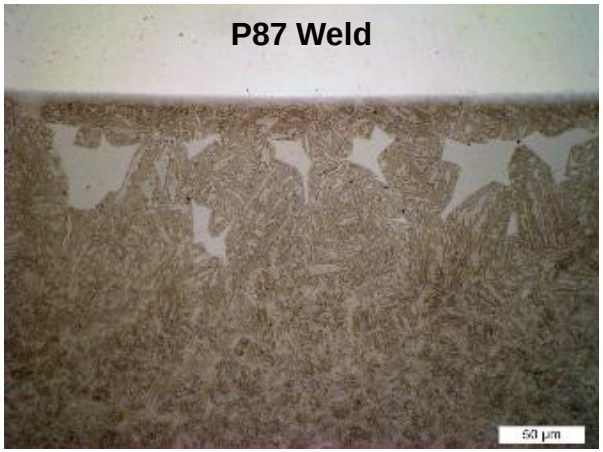


Effect of Filler Metal Composition

Alloy	Total Ferrite Area (mm^2)	Ferrite Area/Fusion Boundary Length (μm)
625	0.348	30.24
617	0.449	25.53
82	0.247	22.12
P87	0.119	11.37

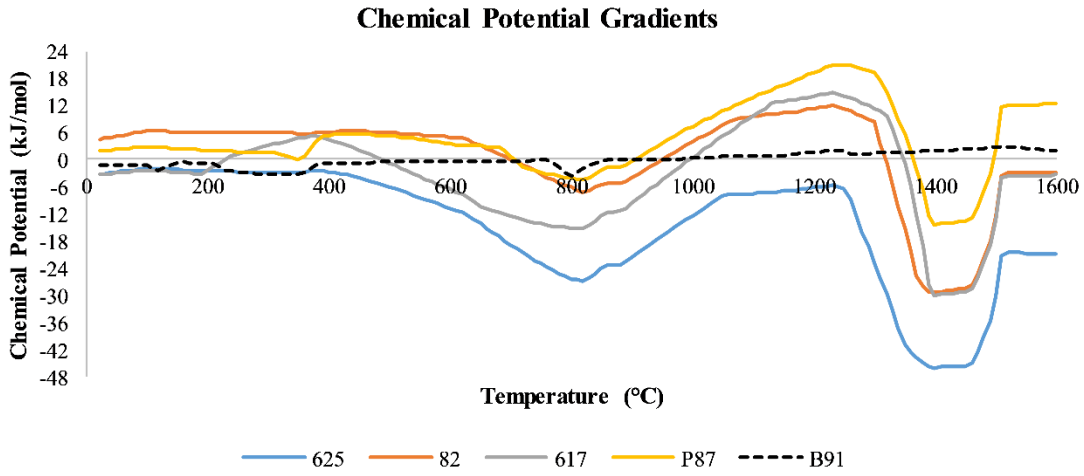




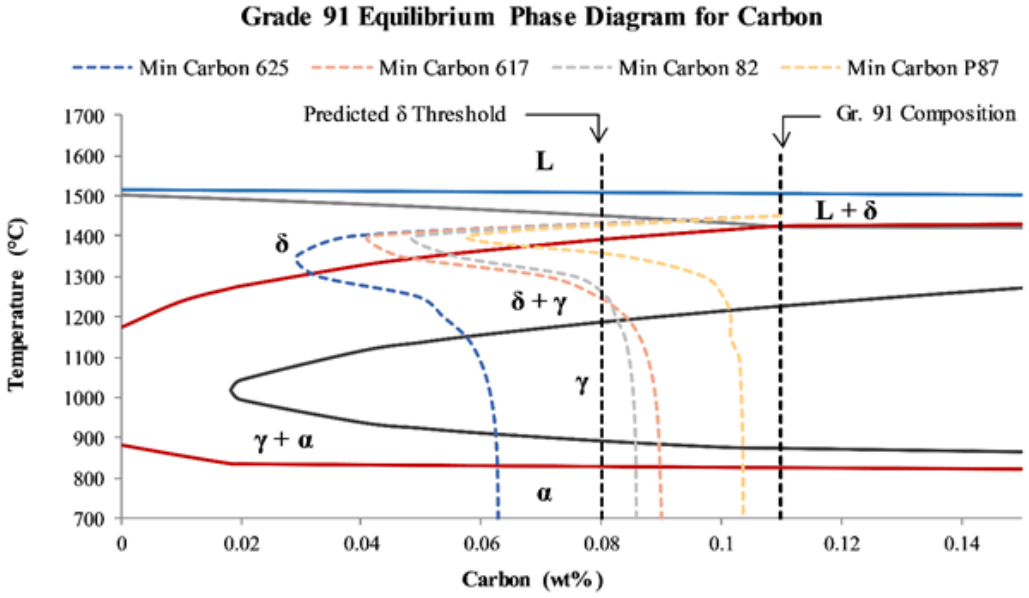


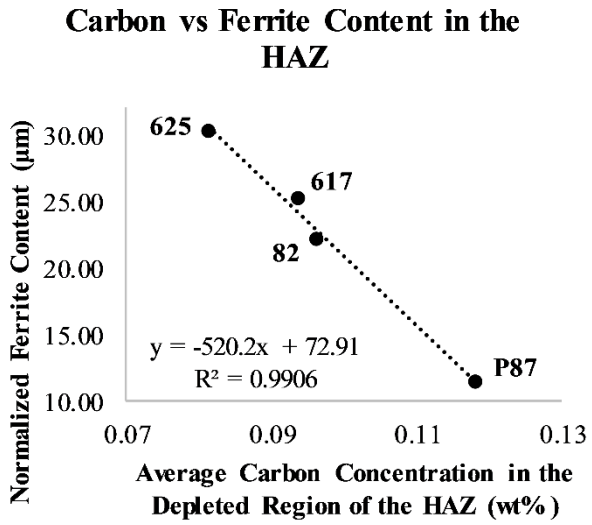
Chemical Potential Gradient

Thermodynamic & Kinetic Predictions of HAZ Carbon Depletion



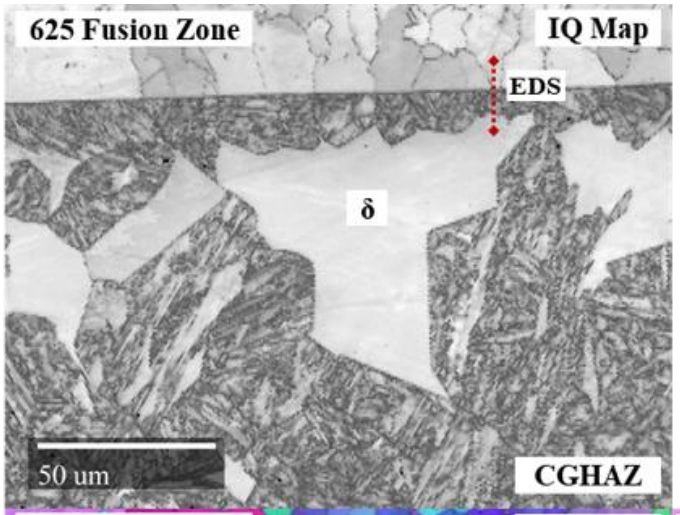
Alloy	Average Carbon Concentration in HAZ (wt. %)
625	0.0778
617	0.0878
82	0.0955
P87	0.1290

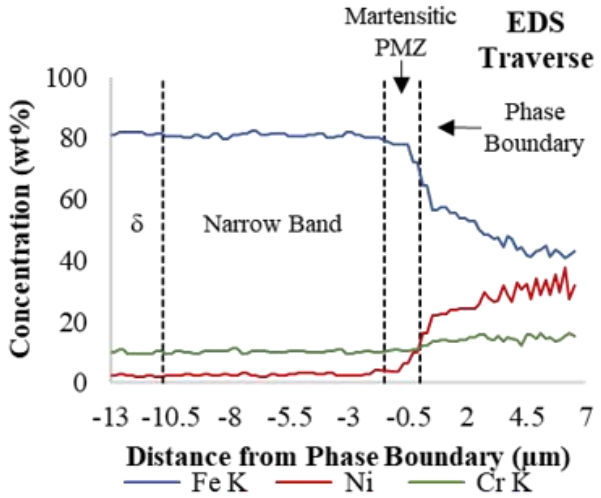


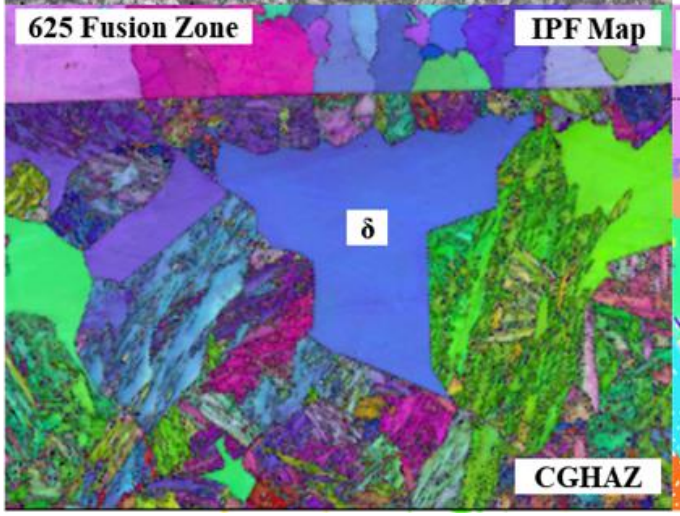


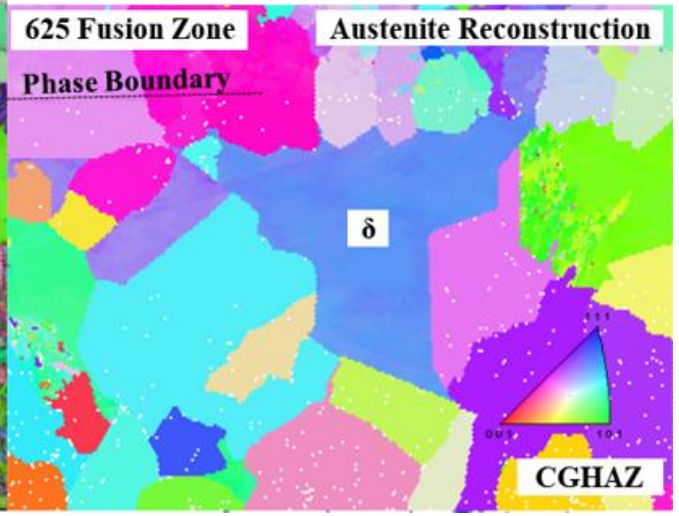
Composition & Property Gradient

Epitaxial Solidification & Planar Growth



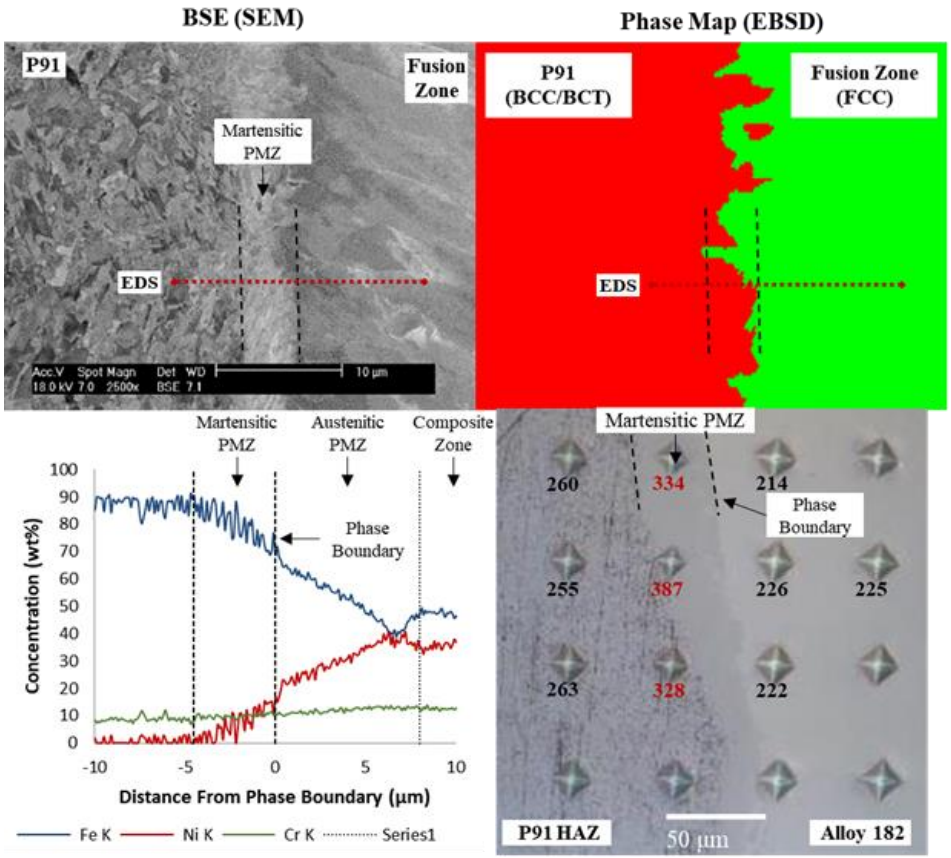


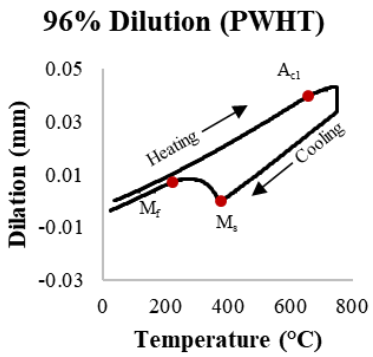


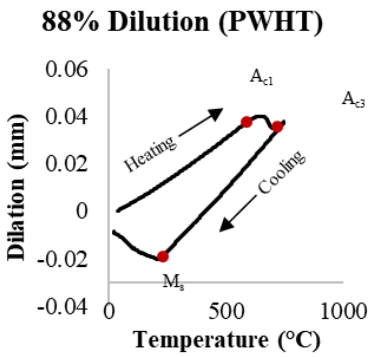


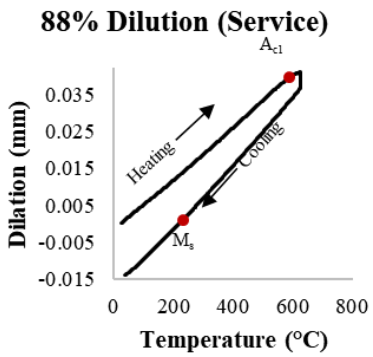
Microstructure Gradient

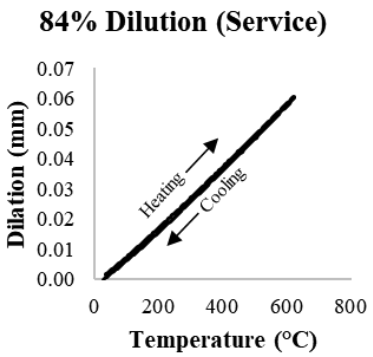
Reversing Austenite to Martensite Transformation in Dissimilar Transition Zone





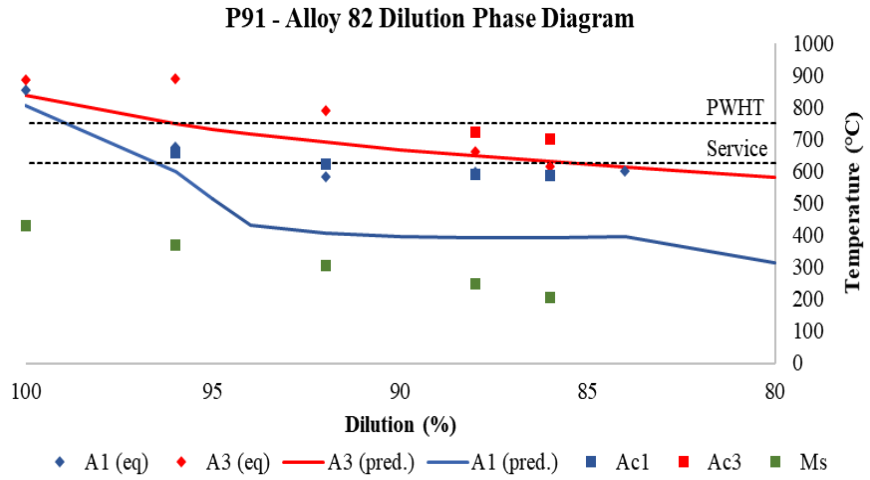


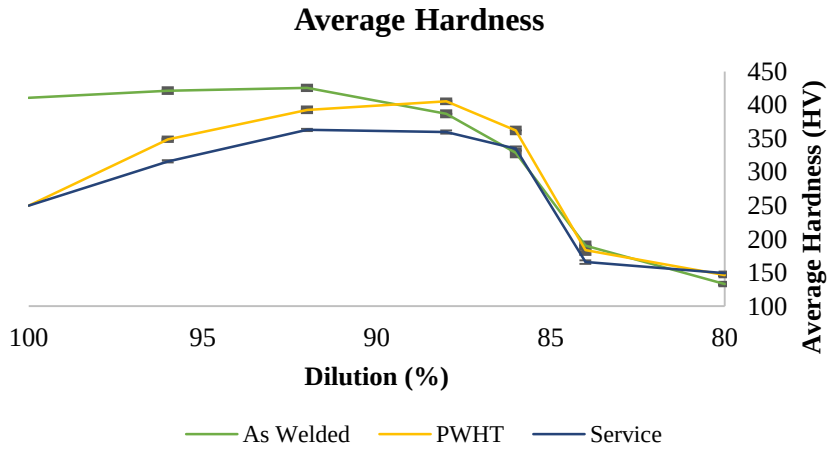


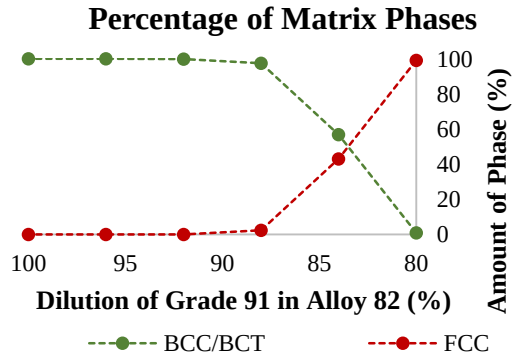


Microstructure & Property Gradient

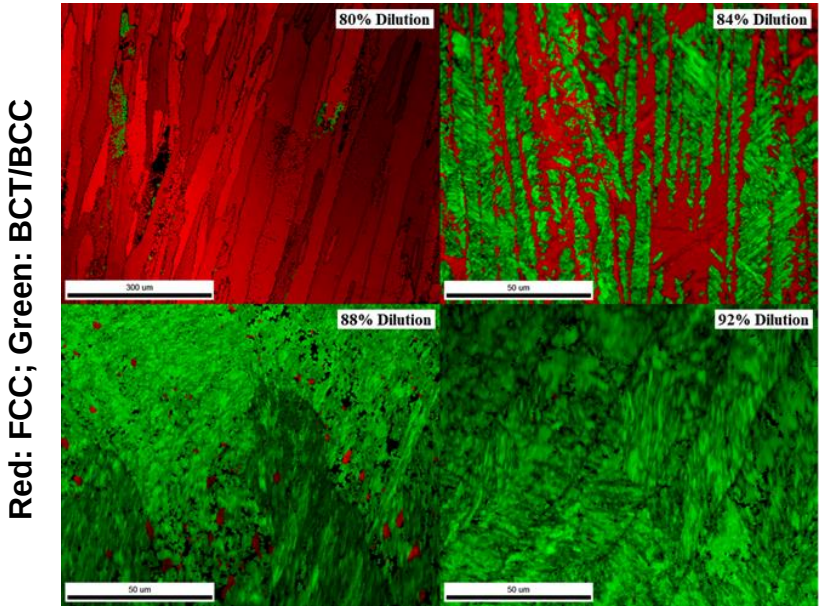
Reversing Austenite to Martensite Transformation in Dissimilar Transition Zone





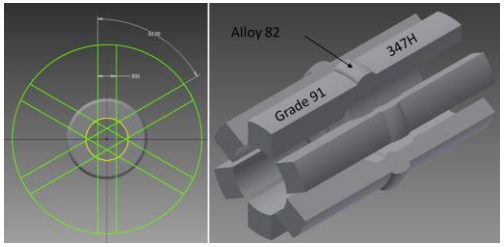


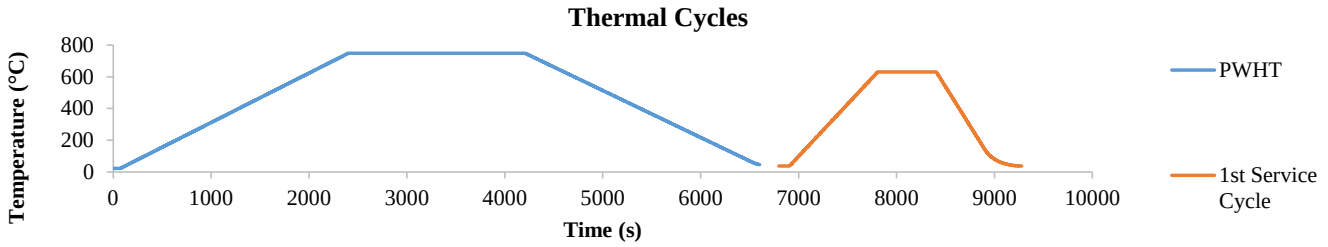
	Dilution (%)						
	80	84	86	88	92	96	100
As Solidified	A	M + A				M	
After PWHT		M + A + TM				M + TM	TM
After Service							

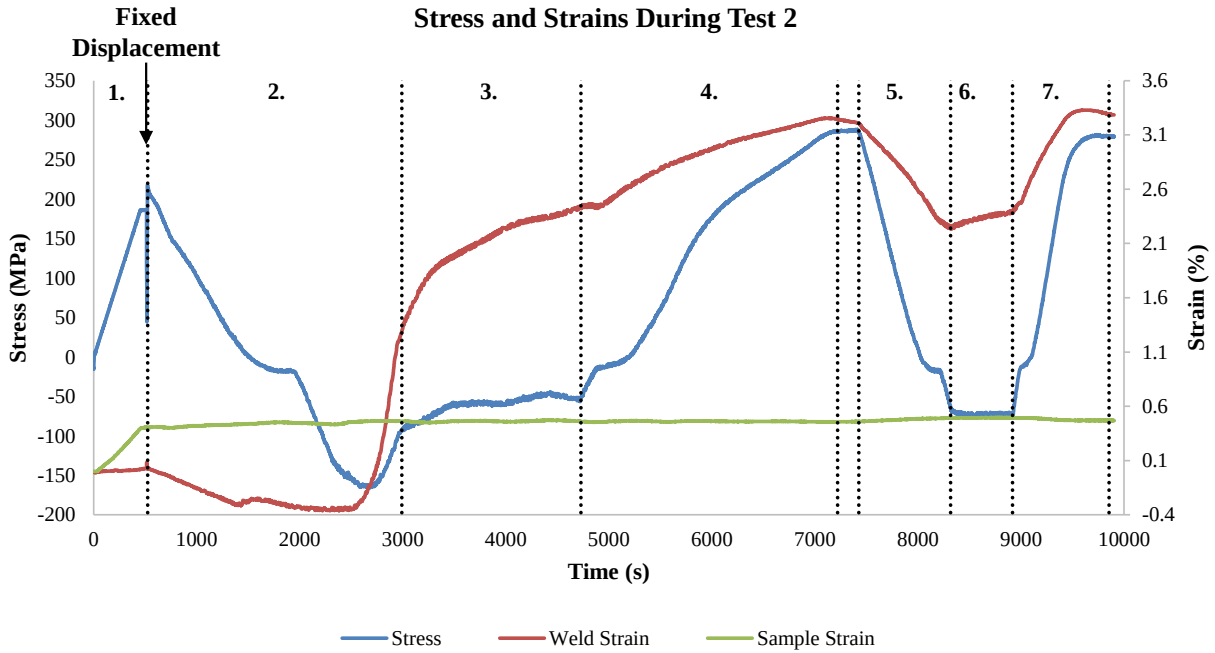


Thermal Fatigue Behavior

Gleeble™ Thermal Fatigue Testing of Grade 91 - Alloy82 - 347H DMW



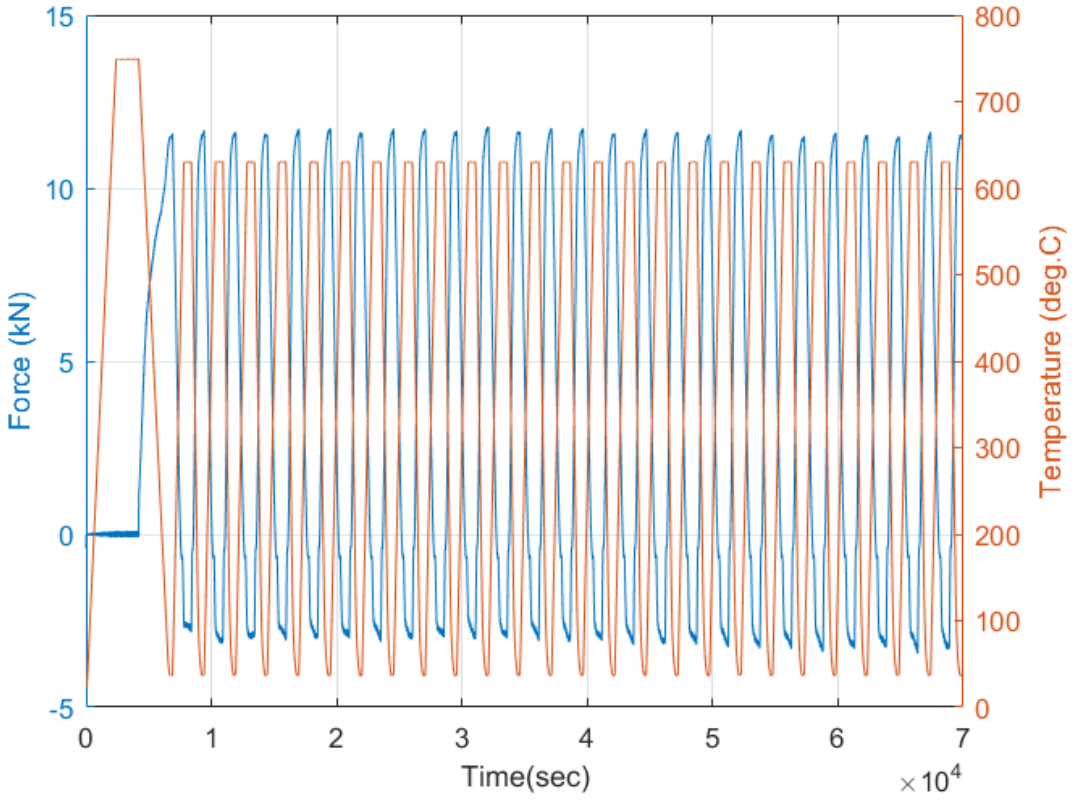


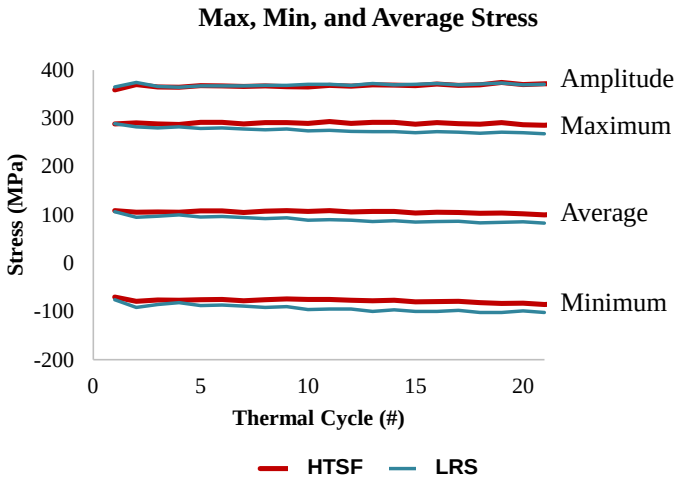


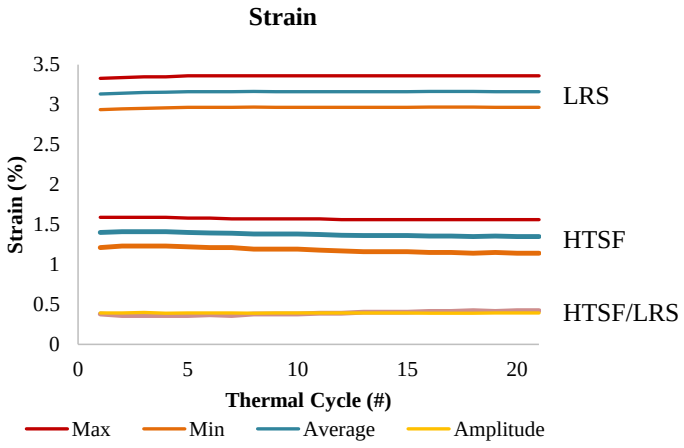
1. Pre-load **2.** Heating **3.** PWHT **4.** Cooling **5.** Heating **6.** Service Hold **7.** Cooling

Thermal Fatigue Behavior

Gleeble™ Thermal Fatigue Testing of Grade 91 - Alloy82 - 347H DMW







HTSF: full residual stress relaxation during PWHT, full restraint during service
LRS: large welding residual stresses not relaxed during PWHT, full restraint during service

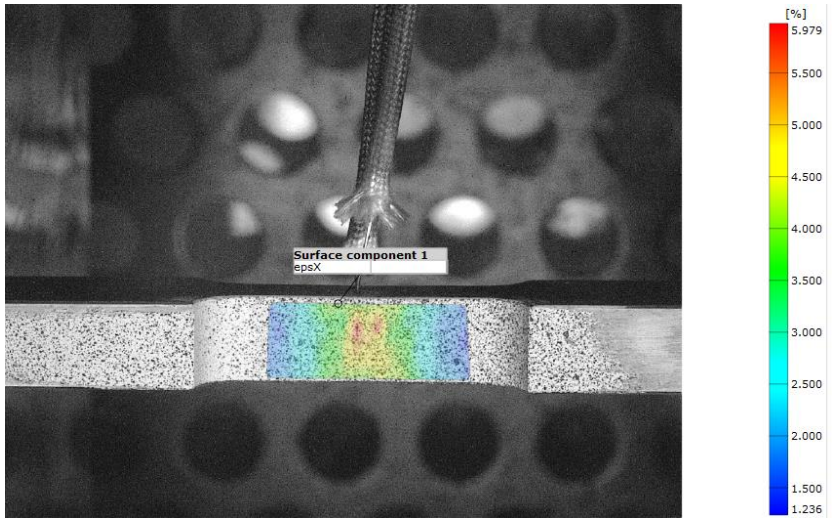
Thermal Fatigue Susceptibility

Thermal Fatigue (TF) Testing Procedure for High Temperature Alloys

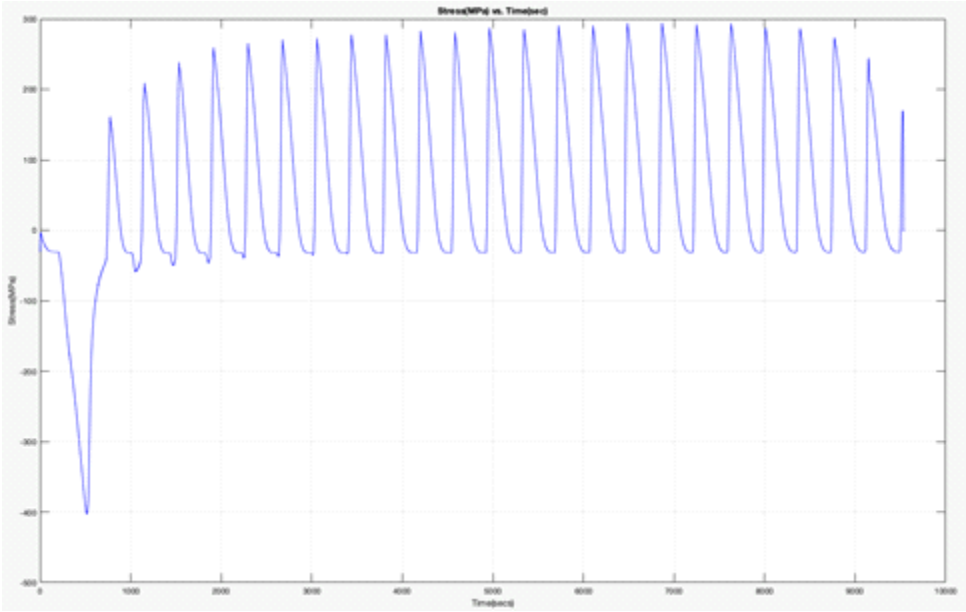
Improved sample restraint leads to TF failures

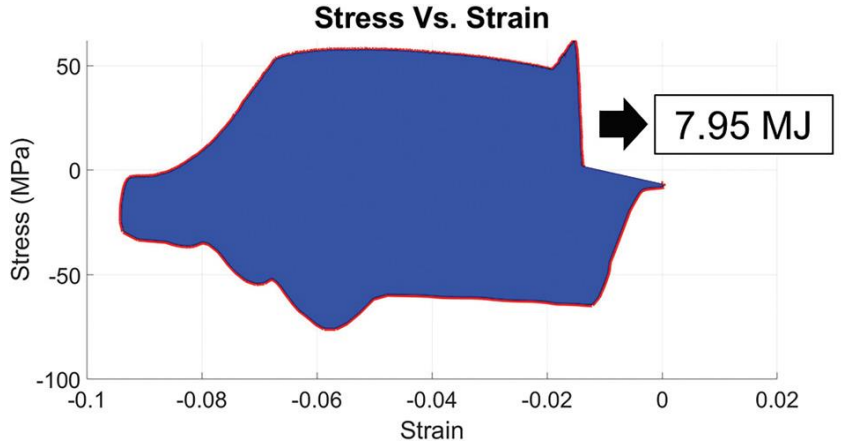
TF susceptibility criteria:

- Number of cycles to failure
- Sustained imposed mechanical energy (IME)
  IME: integrated stress – strain curve



DIC local strain quantification

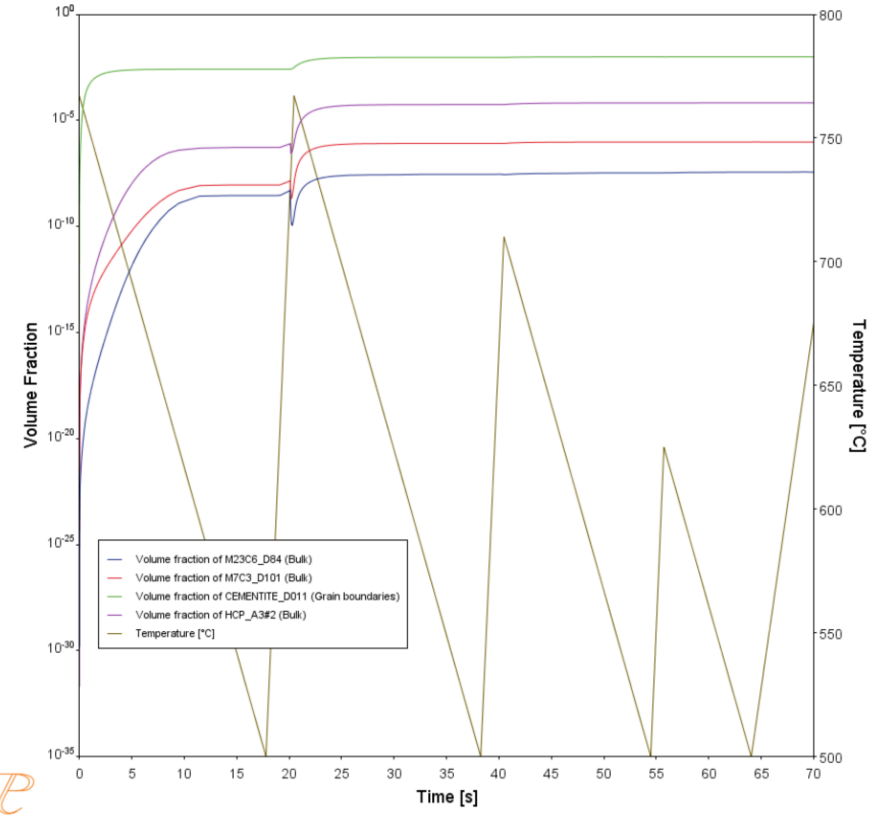


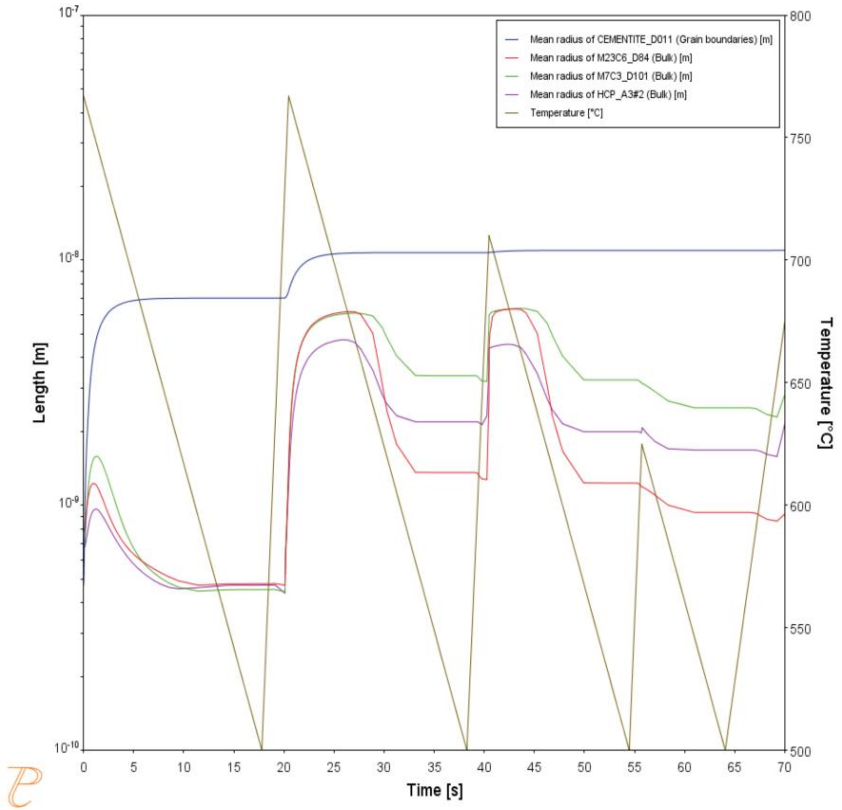


IME calculation

Precipitation Behavior

Thermodynamic and Kinetic Simulation of Carbide Behavior



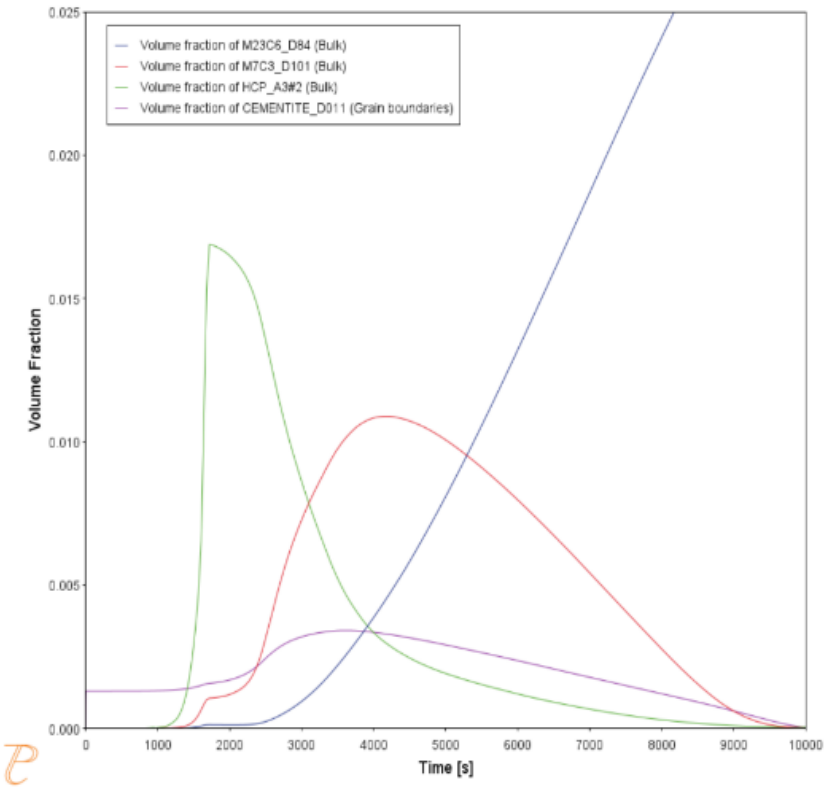


Grade 22 HAZ carbide behavior during temperbead welding

Precipitation Behavior

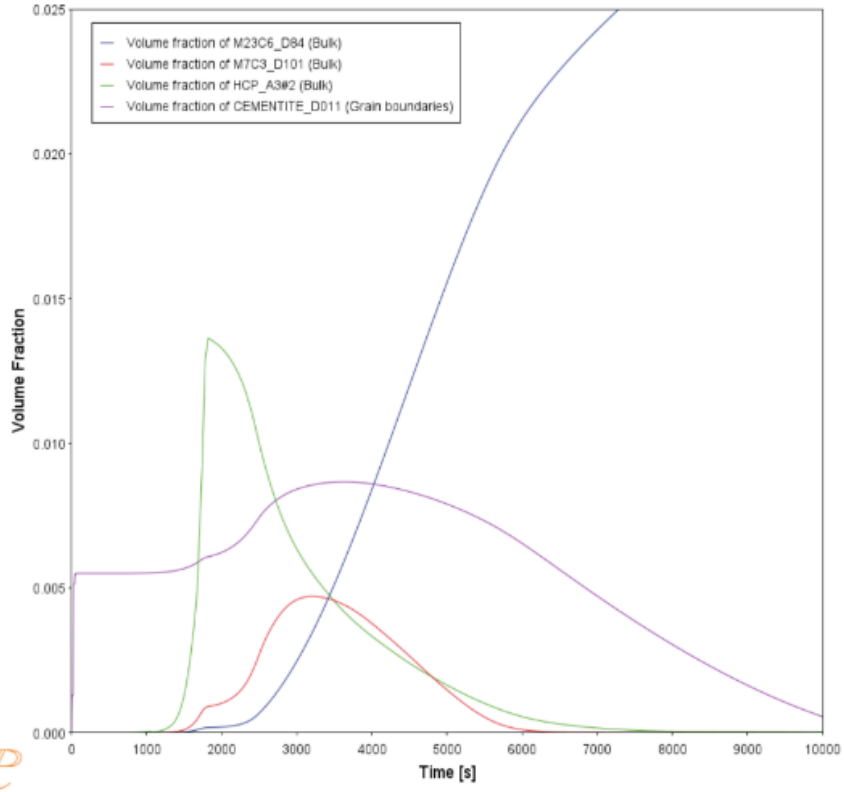
Kinetics of Carbide Precipitation during PWHT

PWHT of Grade 22 CGHAZ



SRC Susceptible

PWHT of Grade 22 after PWHT



SRC Resistant

Acknowledgments

MaJIC
MANUFACTURING & MATERIALS JOINING INNOVATION CENTER

GE imagination at work

Dr. Joshua Burgess and Mr. Rod Vanstone of GE Power
Dr. Jorge Penso of Shell