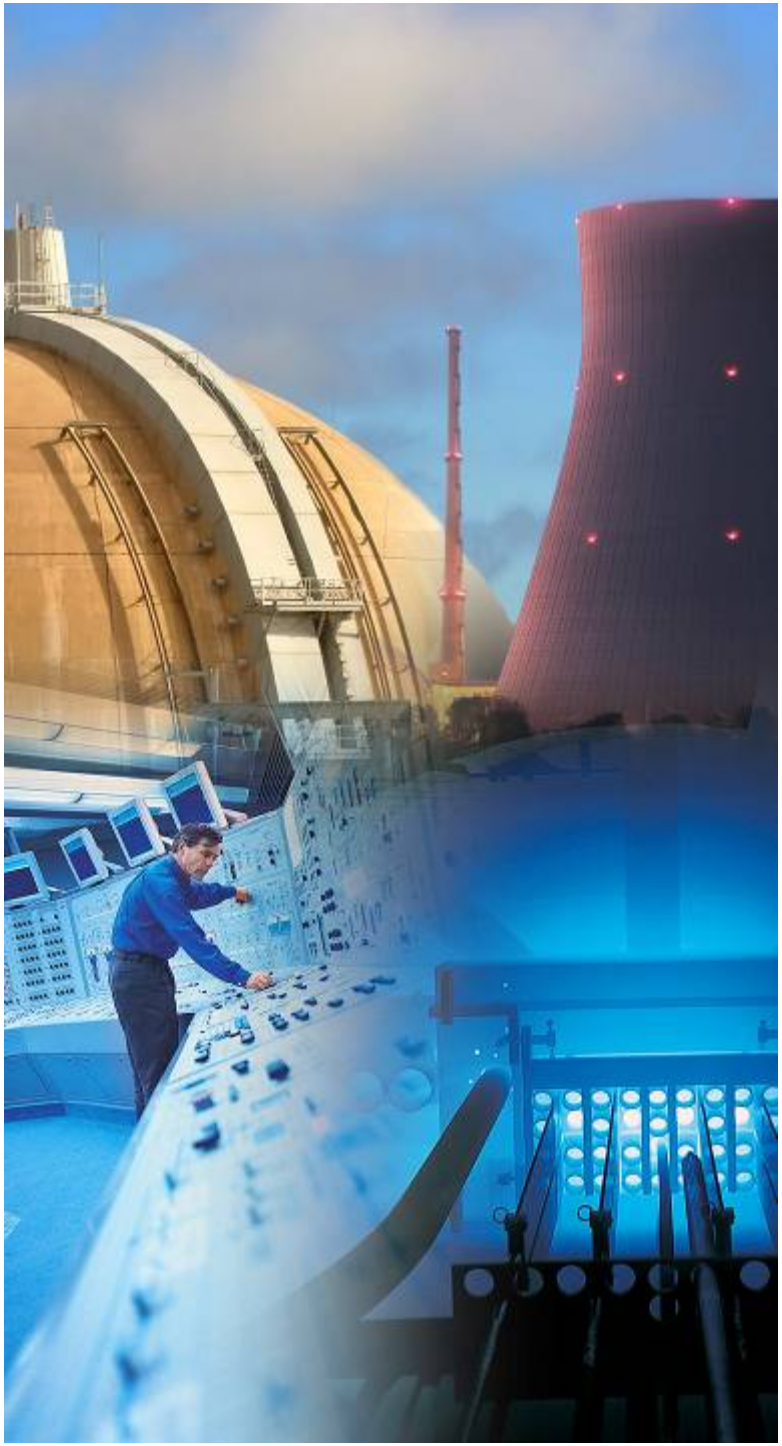

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Alloy 52 Filler Metal Weldability Testing

Preliminary Results Solidification (hot) Cracking

NRC/Industry Alloys 690/52/152 PWSCC Research Collaboration Meeting

Rockville, MD
August 2009

Steve McCracken
EPRI Welding & Repair Technology Center

Evaluation of New Alloy 52 Filler Metals

- New formulations have been developed to improve resistance to ductility-dip cracking (DDC)
- New compositions may unfortunately increase susceptibility to solidification (hot) cracking
- Field experience indicates high dilution with stainless steel, high S & P, and high Si may increase propensity for solidification cracking
- Methods for evaluating solidification crack susceptibility
  - Transverse varestraint test
  - Cast-pin-tear test (CPTT)
  - Solidification range measurement / simulation
    - Single sensor differential thermal analysis (SS DTA)
    - Scheil-Gulliver simulation (JMatPro / ThermoCalc)

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Alloy 52 Heats / Classifications in WRTC Test Matrix for Solidification Crack Evaluation

Element	52M	52MSS-A	52MSS-B	52MSS-C	MLTS-27
Al	0.09	0.07	0.24	0.13	0.06
B	0.0004	-	-	0.001	0.0002
C	0.02	0.03	0.018	0.023	0.031
Co	0.011	<0.001	0.003	<0.01	-
Cr	**30.11**	**29.92**	**29.20**	**29.49**	**26.88**
Cu	0.03	0.06	0.055	0.05	-
Fe	**8.87**	**8.31**	**8.63**	**8.79**	**3.00**
Mn	**0.72**	**0.19**	**0.70**	**0.31**	**3.16**
Mo	**0.05**	**3.83**	**3.68**	**3.51**	**-**
Nb	**0.87**	**2.57**	**2.4**	**2.51**	**2.65**
Ni	59.21	54.67	54.67	52.36	63.84
P	0.002	<0.001	0.016	0.004	0.003
S	0.0005	0.001	0.0006	<0.0005	0.0006
Si	0.11	0.12	0.15	0.11	0.15
Ta	<0.01	0.017	0.013	0.01	-
Ti	0.16	0.19	0.21	0.18	0.19
Zr	0.001	-	-	0.007	0.0002

- MLTS-27 *
- EN52i ***
  (large production melt)

- 52M (ERNiCrFe-7A) *
- 52MSS-*A&B* (ERNiCrFe-13) *
  (experimental melts)
- 52MSS-C (ERNiCrFe-13) **
  (large production melt)

** Testing nearly complete*
*** Testing in progress*
**** Testing in fall 2009*

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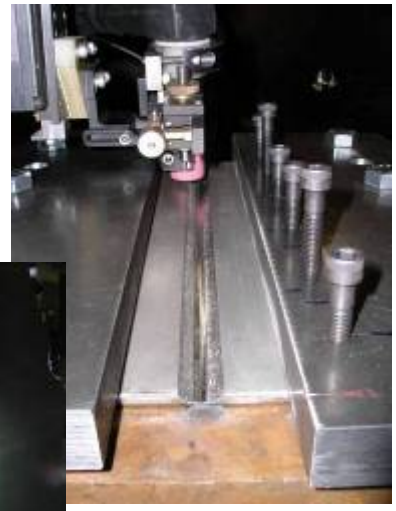
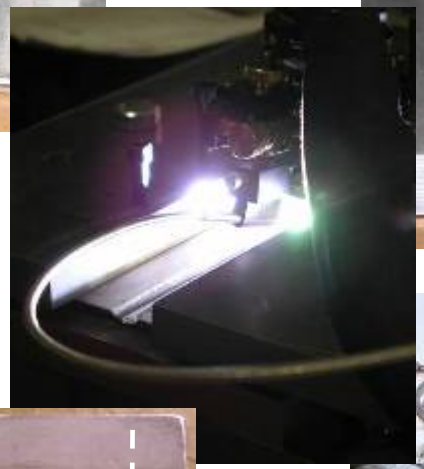
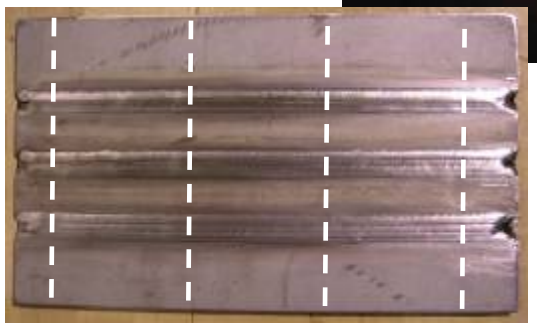
Transverse Varestraint Test Specimens

- Machine GTAW used to install multi-pass groove weld on test specimen
- Bead placement & Alloy 600 plate used to minimize effect of dilution
- Test coupon is machined and cut to ¼”x3½”x9”







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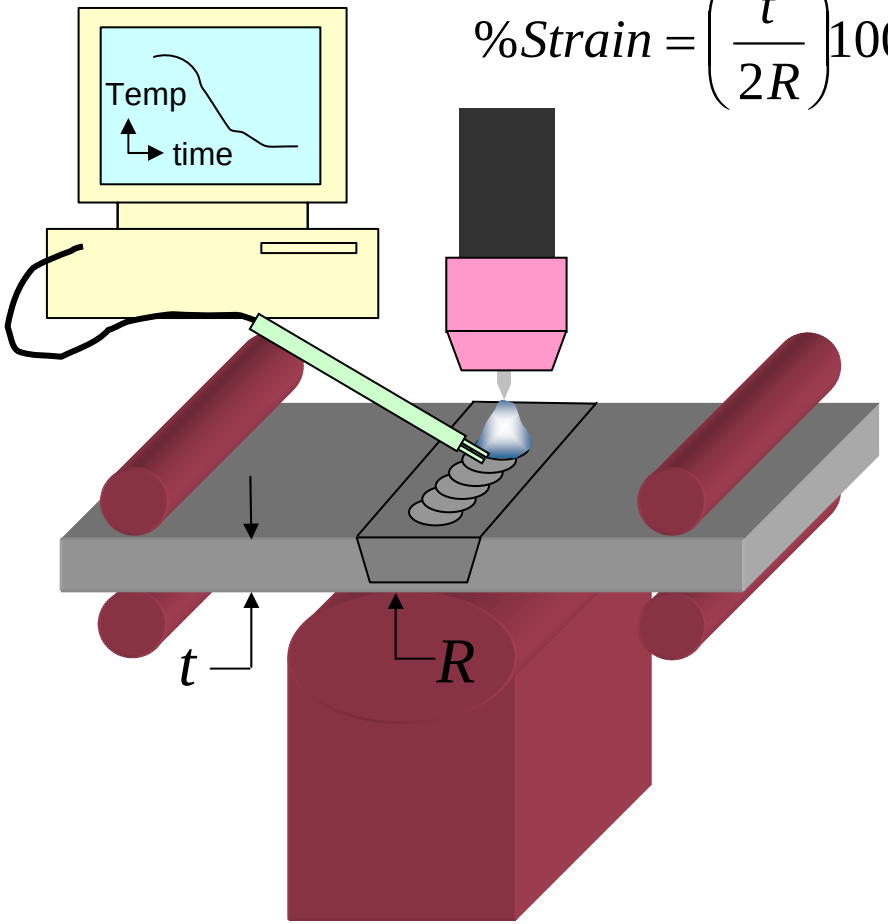
Transverse Varestraint Test Setup

- Testing performed on MTV 2500 machine at Ohio State University
- Ram moves up to bend specimen during welding which applies augmented strain as autogenous weld solidifies
- Thermal couple is plunged into weld puddle to measure cooling rate

$$\%Strain = \left(\frac{t}{2R}\right)100$$



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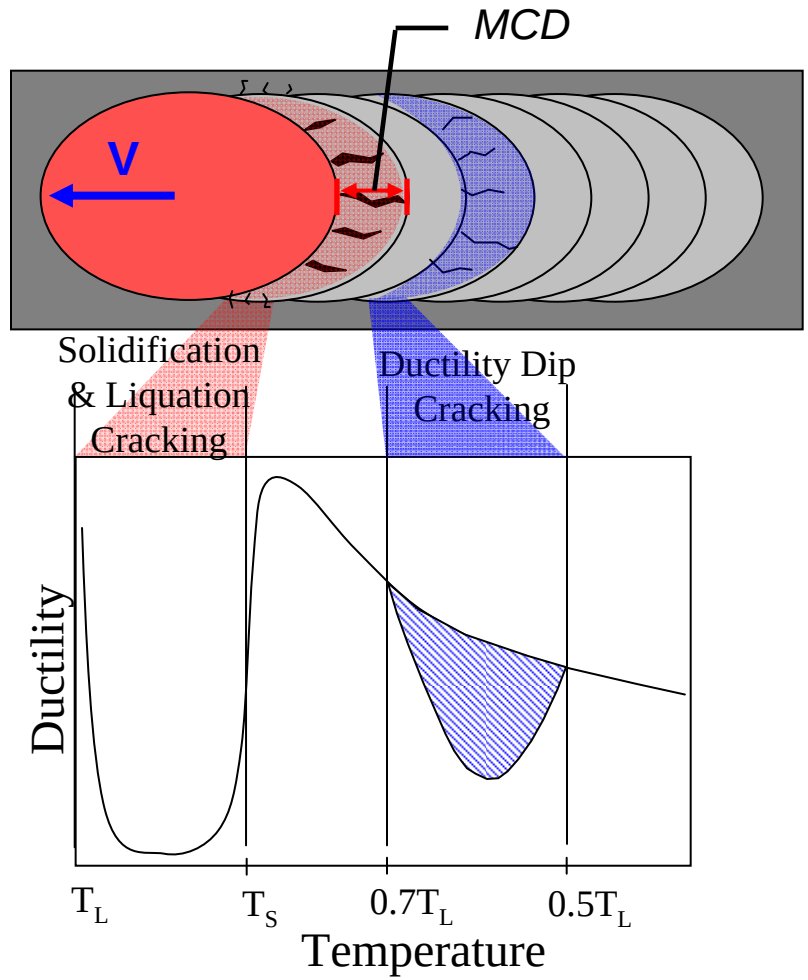
Transverse Varestraint Testing

- Crack length reaches a maximum and is essentially constant above saturated strain
- Maximum Crack Distance (MCD) is maximum crack length (MCL) at saturated strain

Test Parameters

Current, A	***180***
Voltage, V	***10***
Arc Length, in	***0.08***
Travel Speed, in/min	***5.0***
Augmented Strain Range, %	***0.25 – 7.0***
Ram Travel Speed, in/min	***6.0***
Pre-Bend Weld Length, in	***1.5***
Total Weld Length, in	***2.0***



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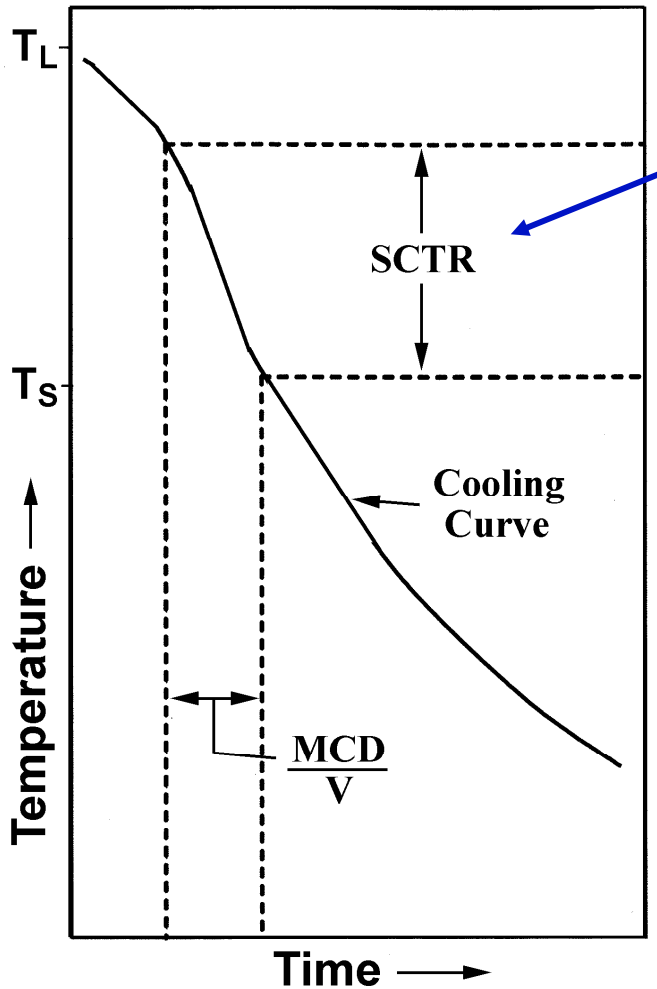
Solidification Crack Susceptibility Index Determined from Varestraint Data



- Solidification crack temperature range (SCTR) is a relative index of crack susceptibility
  - SCTR determined graphically
  - Wide SCTR indicates potential for hot crack susceptibility
- Maximum crack distance (MCD) is crack length determined measured at saturated strain
- Velocity (V) is weld travel speed during varestraint testing
- Cooling curve is determined by plunging thermal couple in the weld puddle

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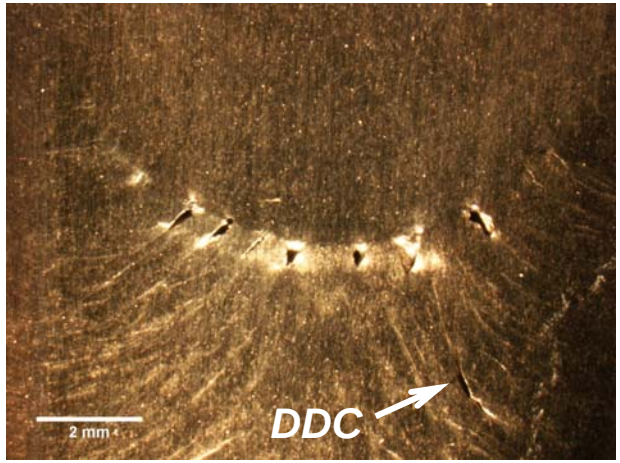
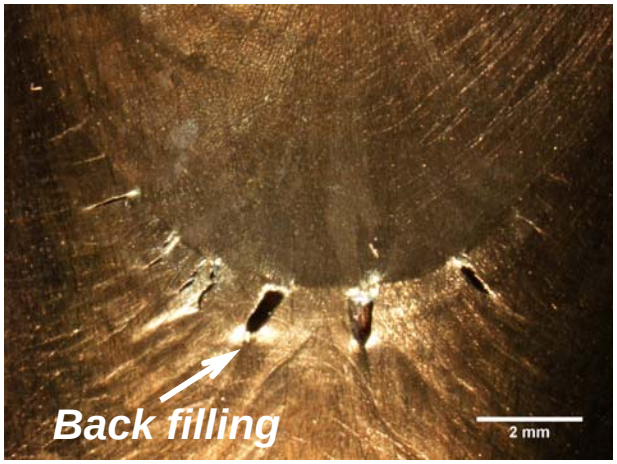
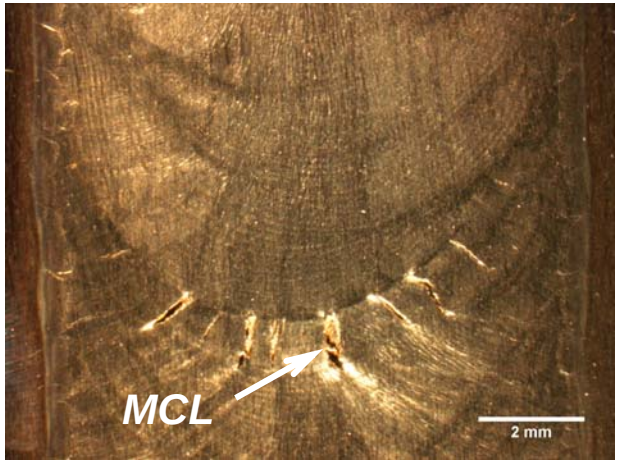
Transverse Varestraint Cracks



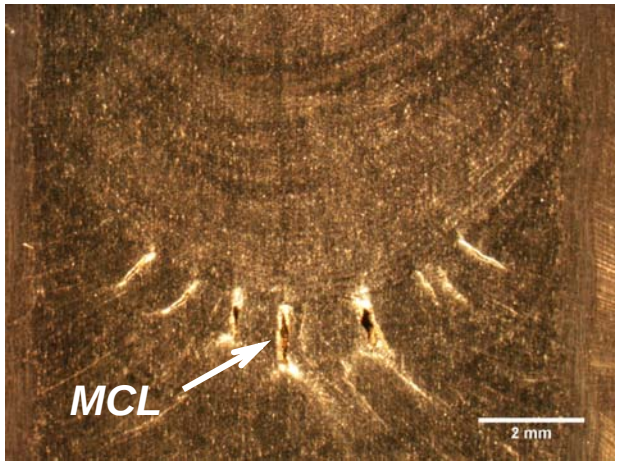
52M at 5% Augmented Strain



MLTS-27 at 5% Augmented Strain



52MSS-A at 3% Augmented Strain



52MSS-B at 3% Augmented Strain

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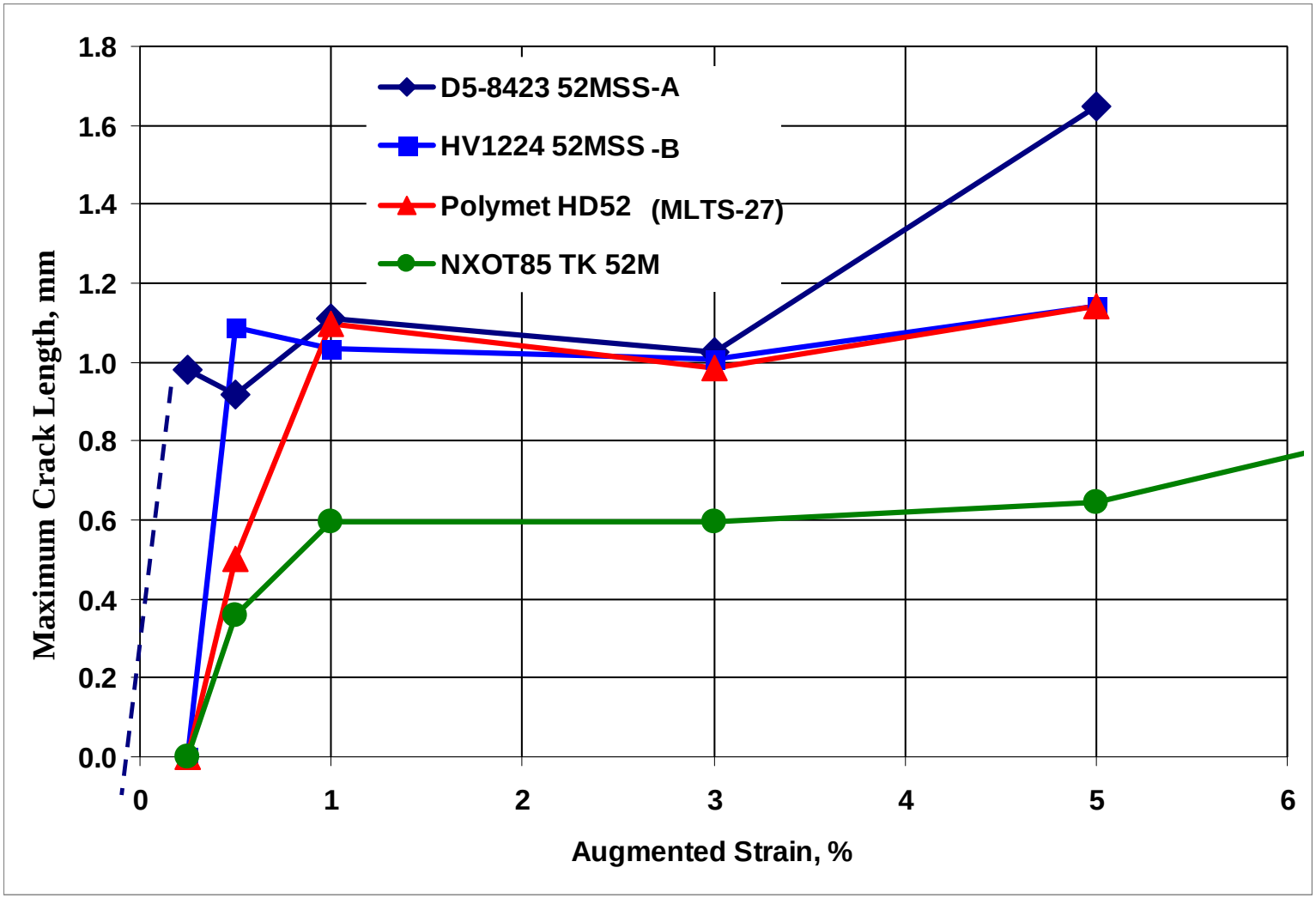
Transverse Varestraint Data
Maximum Crack Length vs Augmented Strain



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Cast Pin Tear Test (CPTT) Description

- CPTT evaluates solidification and liquation crack susceptibility
- Alloy charge is cast into a 3/8” diameter mold
- Charge may be adjusted for weld metal dilution
- Longitudinal tensile strain occurs in pin as it solidifies and cools
- Strain increases as pin length increases

OSU cast pin tear test apparatus

Set of buttons is prepared for each heat

Button is melted by electric arc and cast into pin mold

3/8” diameter pins are cast from 3/8” to 2-1/8” gauge length in 3/8” increments. Head and foot of pin restrain gauge length during cooling

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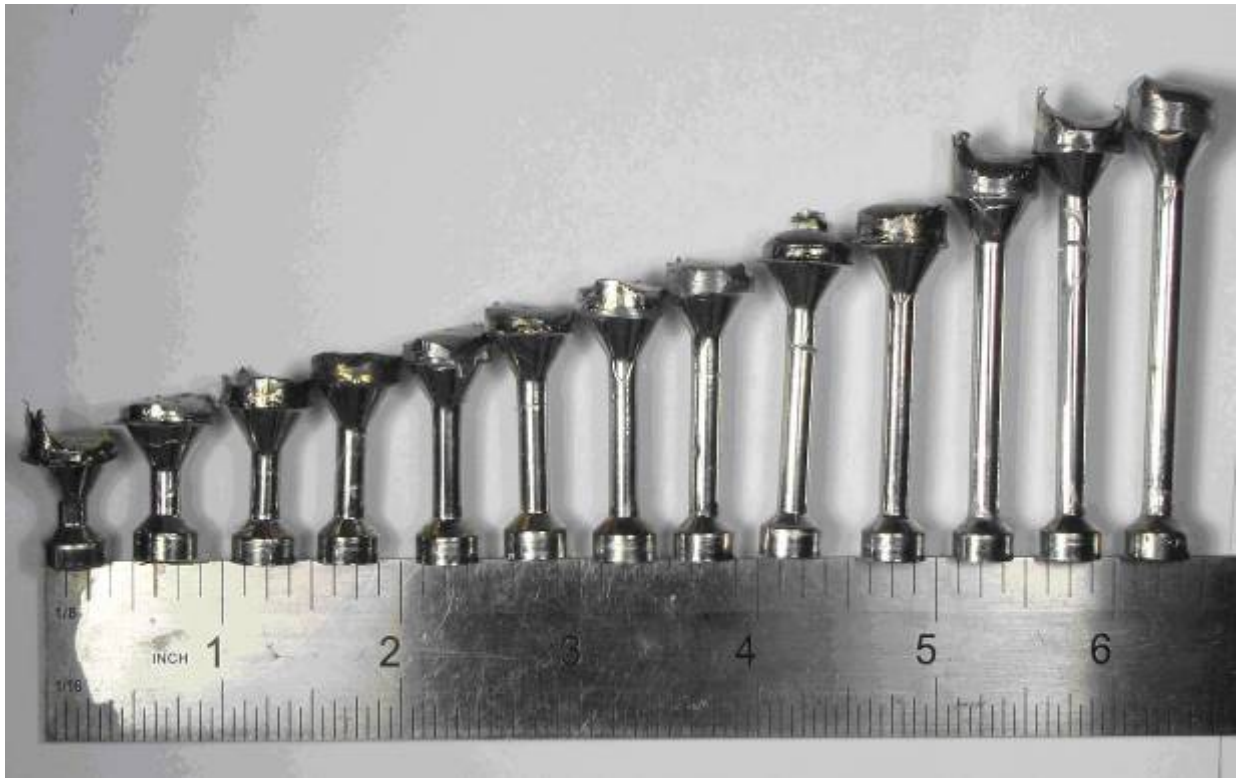
Set of Cast Pin Tear Test Specimens

- Circumferential crack size (% of 360) is measured for each pin length
- % crack size versus pin length is plotted
- Different heats of Alloy 52 are indexed



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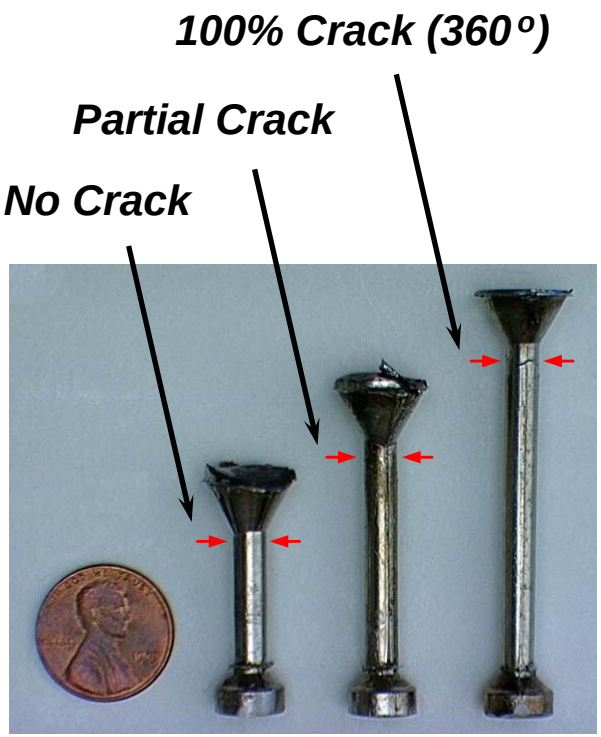
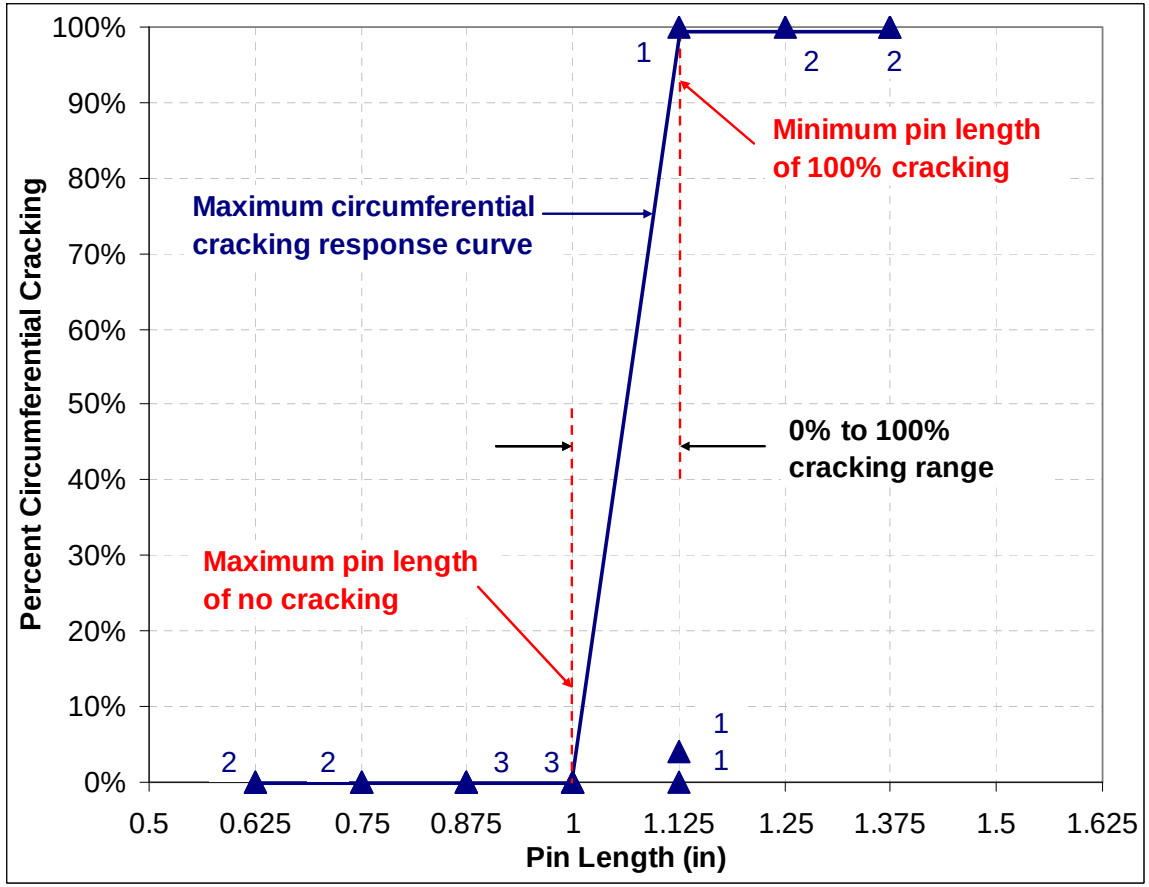
CPTT Maximum Circumferential Cracking Response Curve



$$\%Cracking = \frac{L_T^{\,0}}{360} \times 100$$



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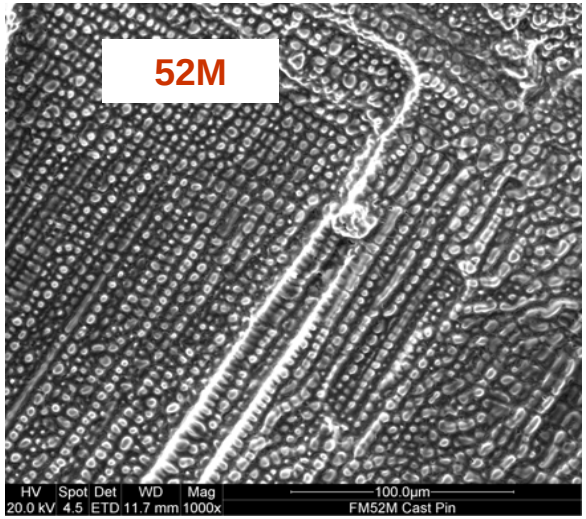
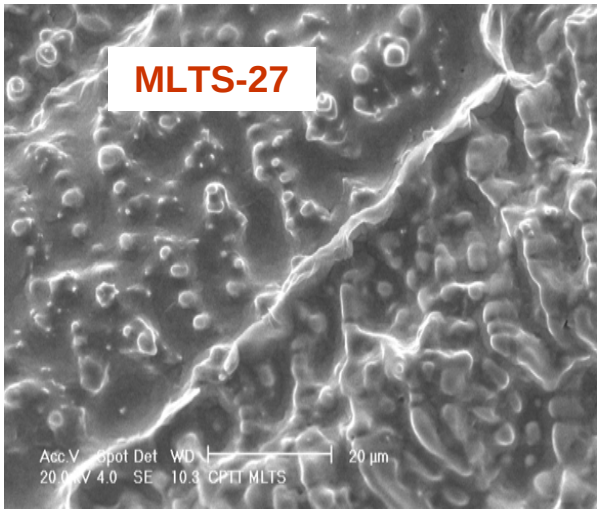
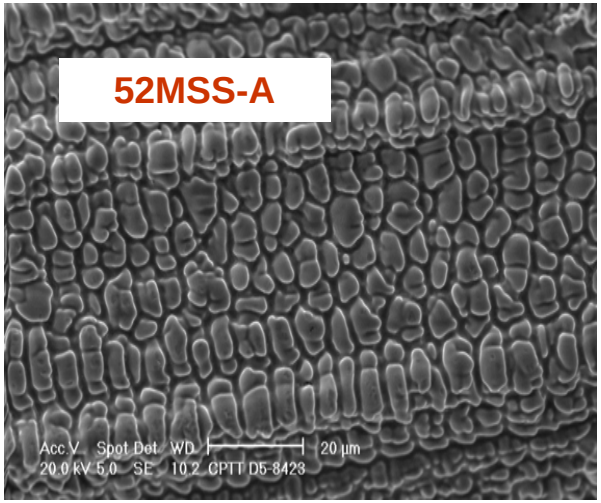
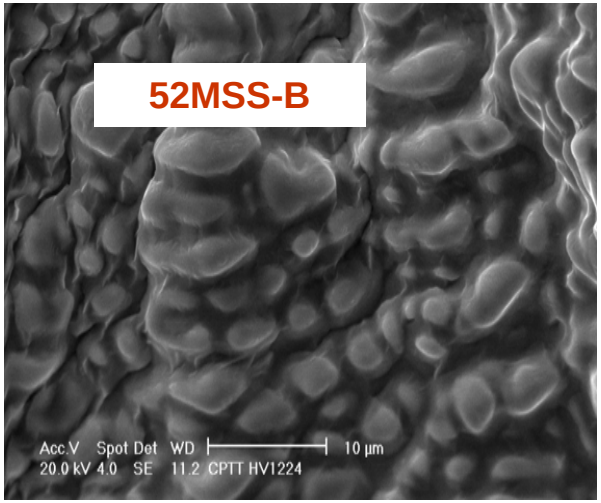
CPTT Fracture Surface Morphology









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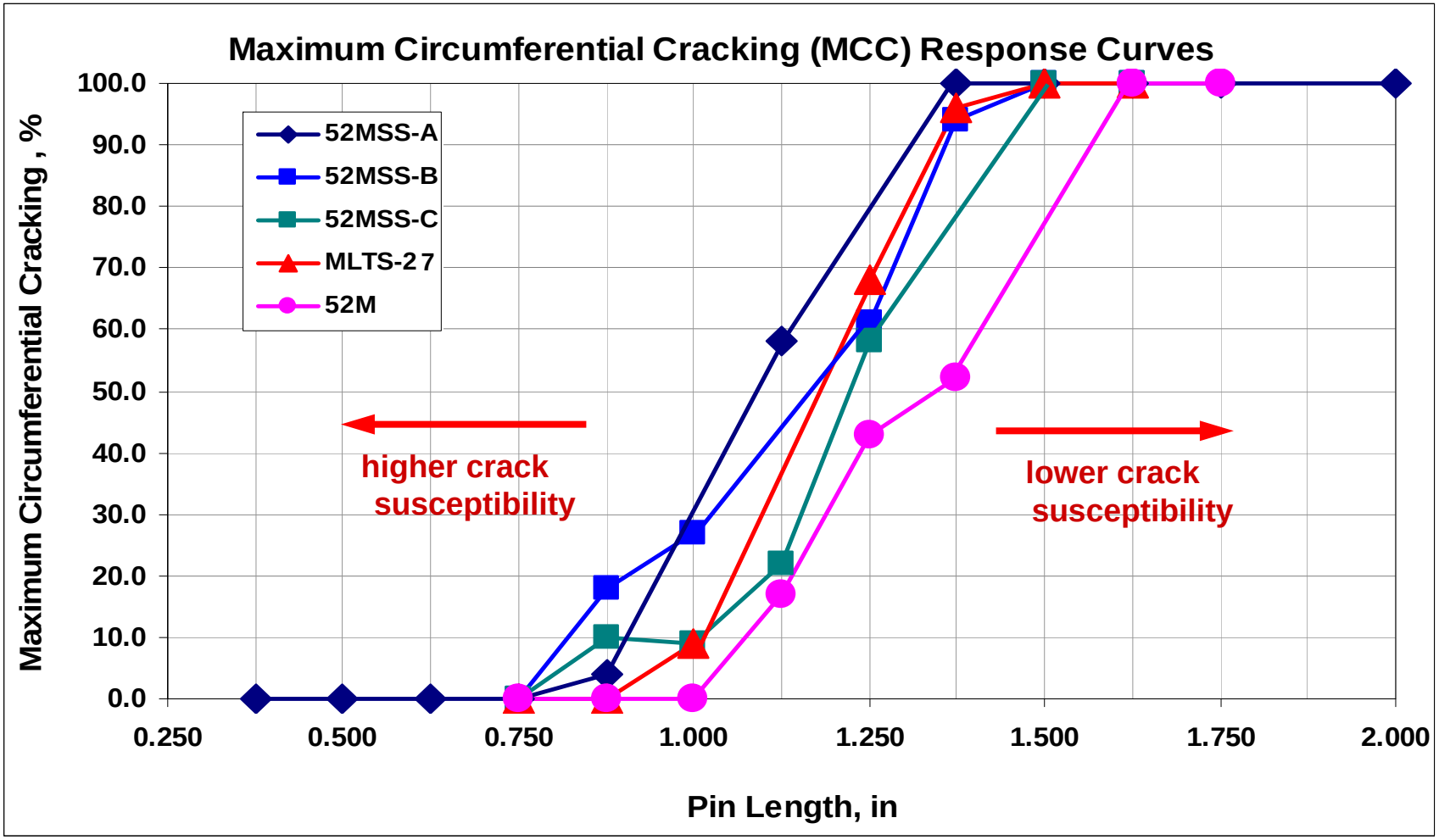
Cast Pin Tear Data
Maximum Circumferential Crack vs Pin Length



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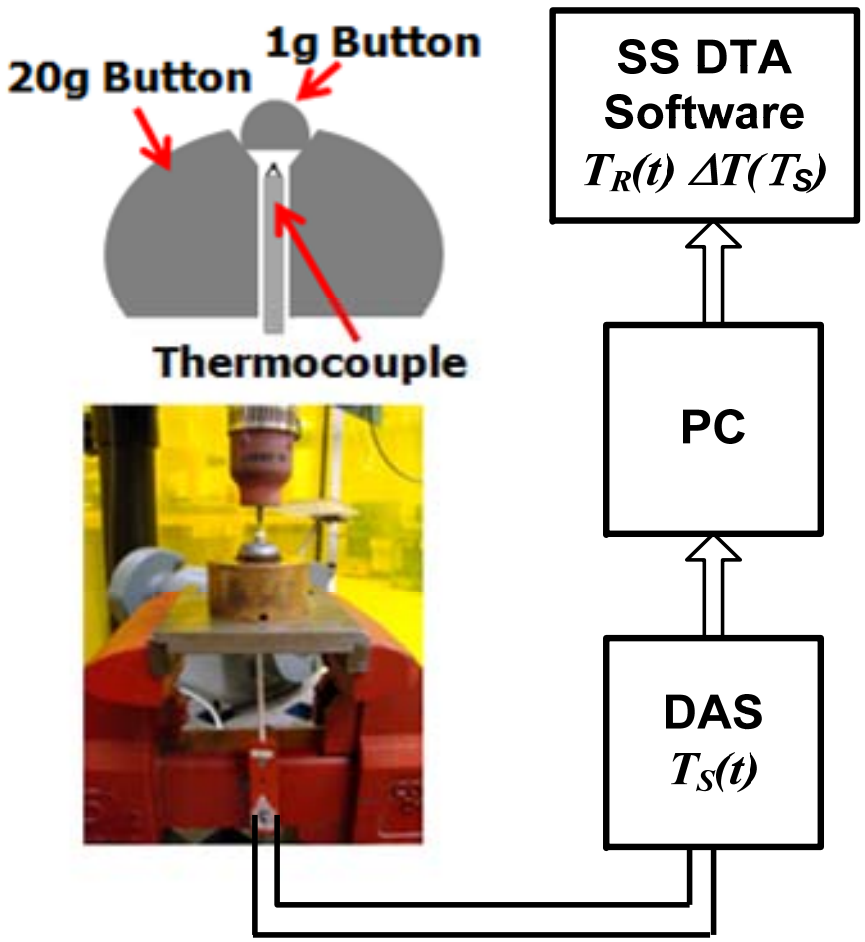
Single Sensor Differential Thermal Analysis (SS DTA) Procedure



- SS DTA method developed at OSU
- Simulates GTA weld microstructure
  - Epitaxial growth from base material
  - Columnar dendrite microstructure
  - Interdendritic precipitation
  - Dendrite arm spacing
- SS DTA can be used to simulate weld dilution compositions

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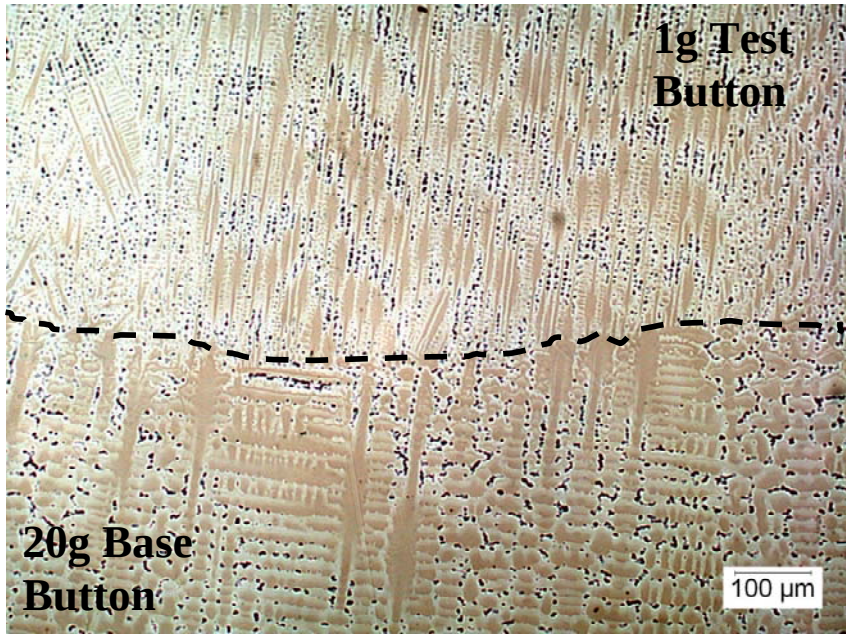
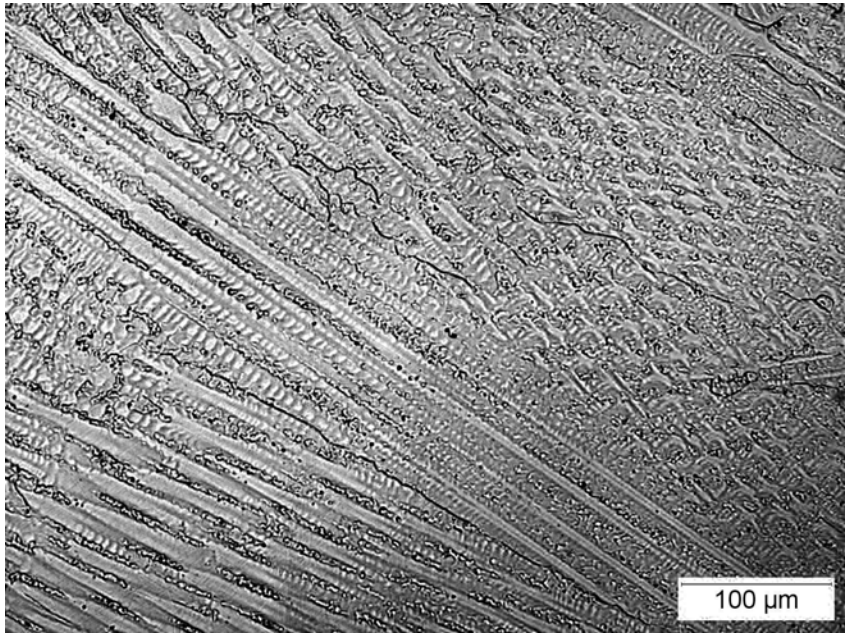
Comparison of SS DTA 1g Test Button and Varestraint Specimen Microstructure



SS DTA Button (52MSS-A)



Transverse Varestraint (52MSS-A)

SS DTA method accurately replicates GTA weld microstructure

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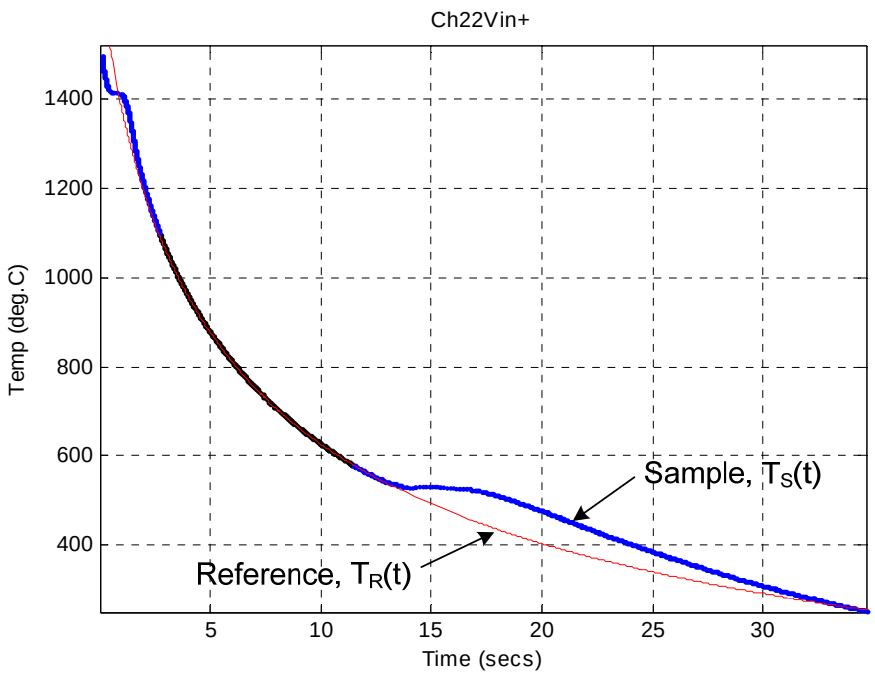
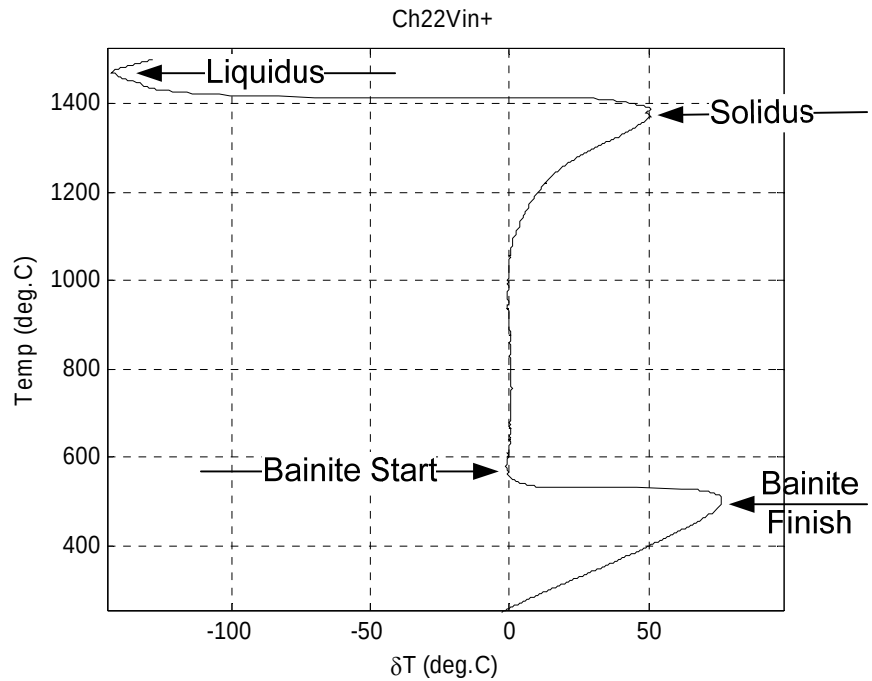
SS DTA Description



Calculated reference curve $T_R(t)$



$$\Delta T(t) = T_S(t) - T_R(t)$$

- Determines enthalpy changes caused by phase transformations
- Utilizes single temperature sensor
- Applicable during actual and simulated processing

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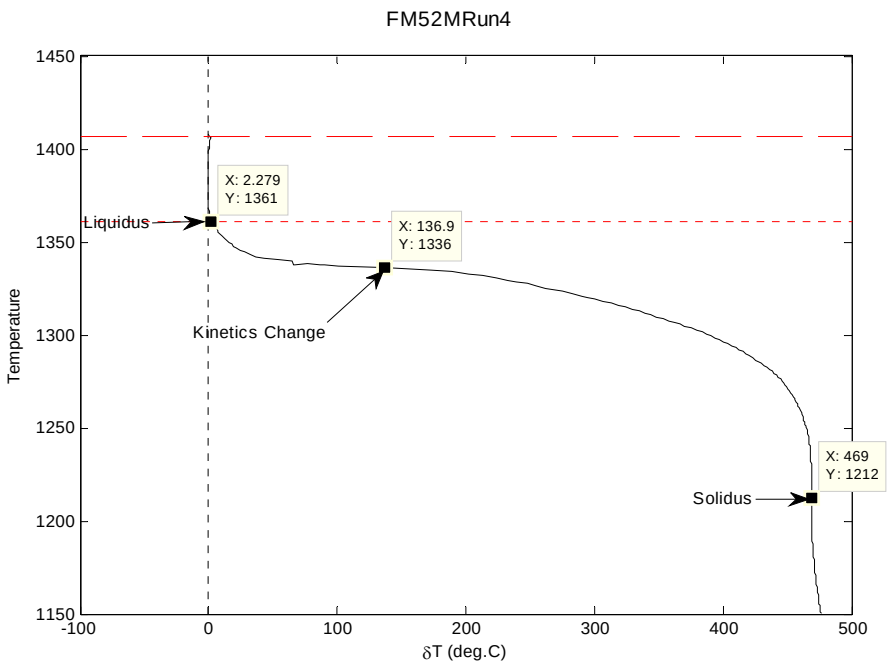
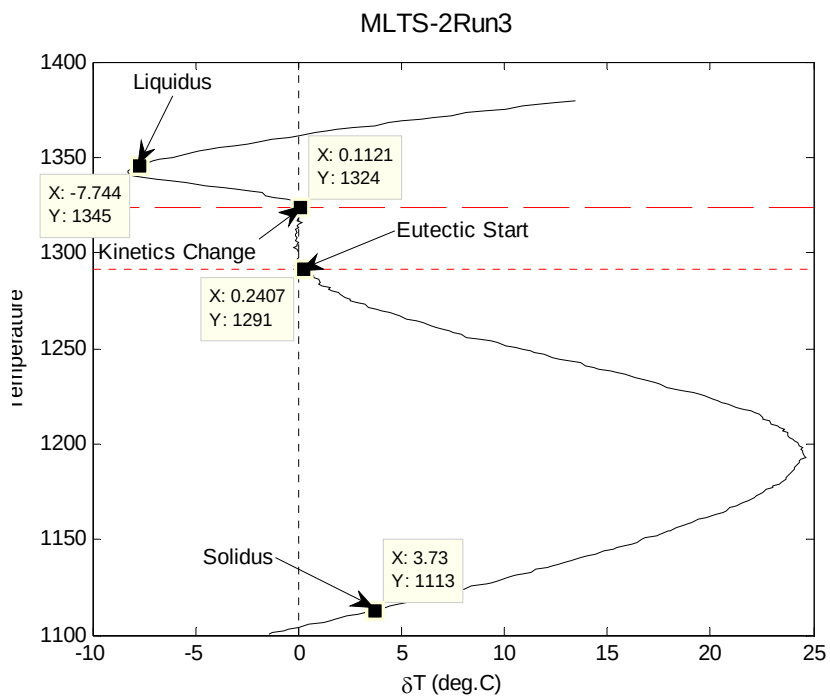
Solidification Behavior – 52M and MLTS-27



52M



MLTS-27

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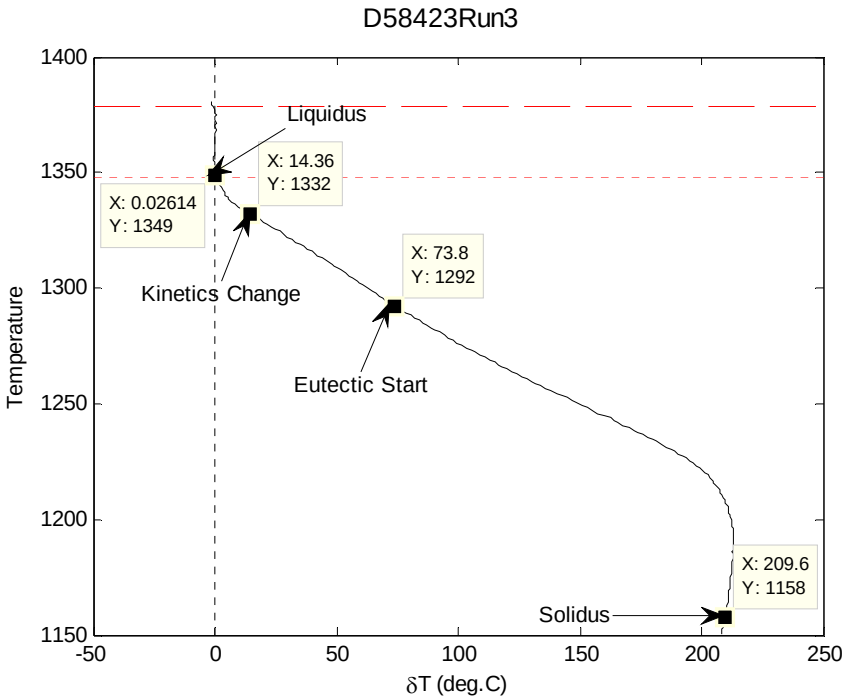
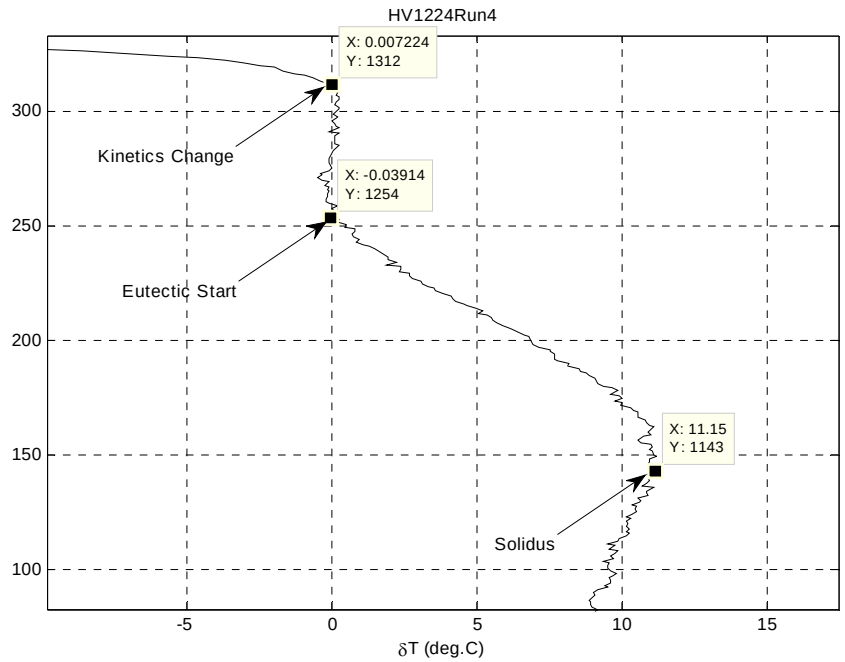
Solidification Behavior – 52MSS A & B



52MSS-A



52MSS-B

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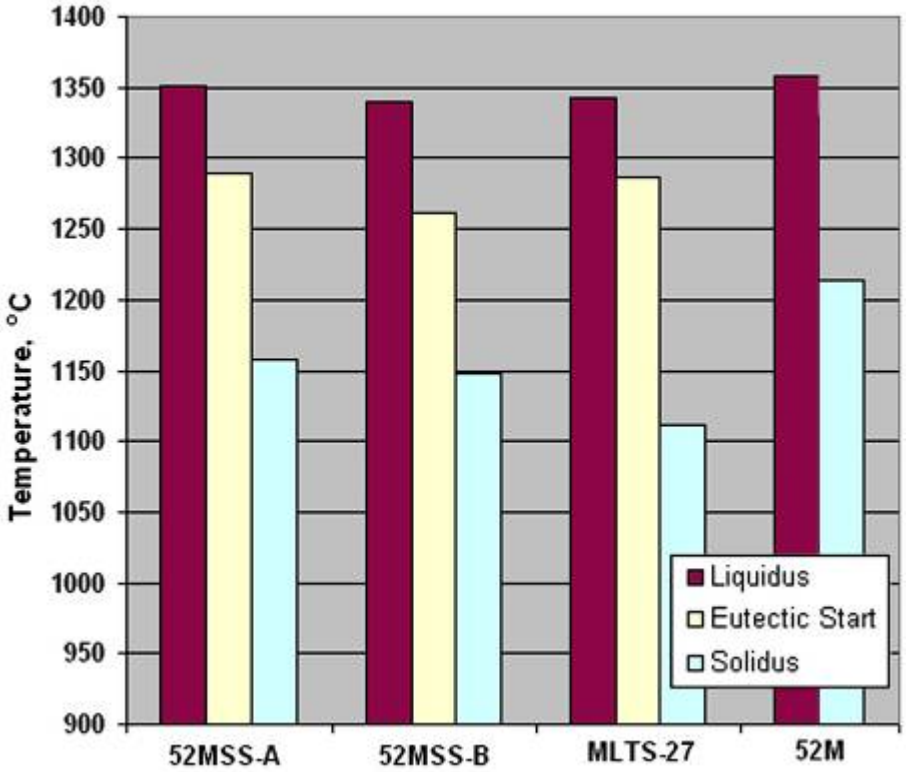
Comparison of SS DTA Solidification Behavior



	52 MSS-A	52 MSS-B	MLTS-27	52M
Eutectic Range, ºC	132	113	174	N.D.
Solidification Range, ºC	192	192	232	144

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Comparison of Crack Susceptibility

- CPTT (cast pin tear test) results
  - 52MSS-A > 52MSS-B > MLTS-27 > 52M
- Transverse varestraint results
  - 52MSS-A > 52MSS-B > MLTS-27 > 52M
- Solidification temperature range evaluation results

  By SS DTA (single sensor differential thermal analysis)
  - MLTS-27 (232 ºC) > 52MSS-B (206 ºC) > 52MSS-A (192 ºC) > 52M (144 ºC)

  By ThermoCalc / JMatPro calculation
  - MLTS-27 (231 ºC) > 52MSS-B (272 ºC) > 52MSS-A (267 ºC) > 52M (145 ºC)

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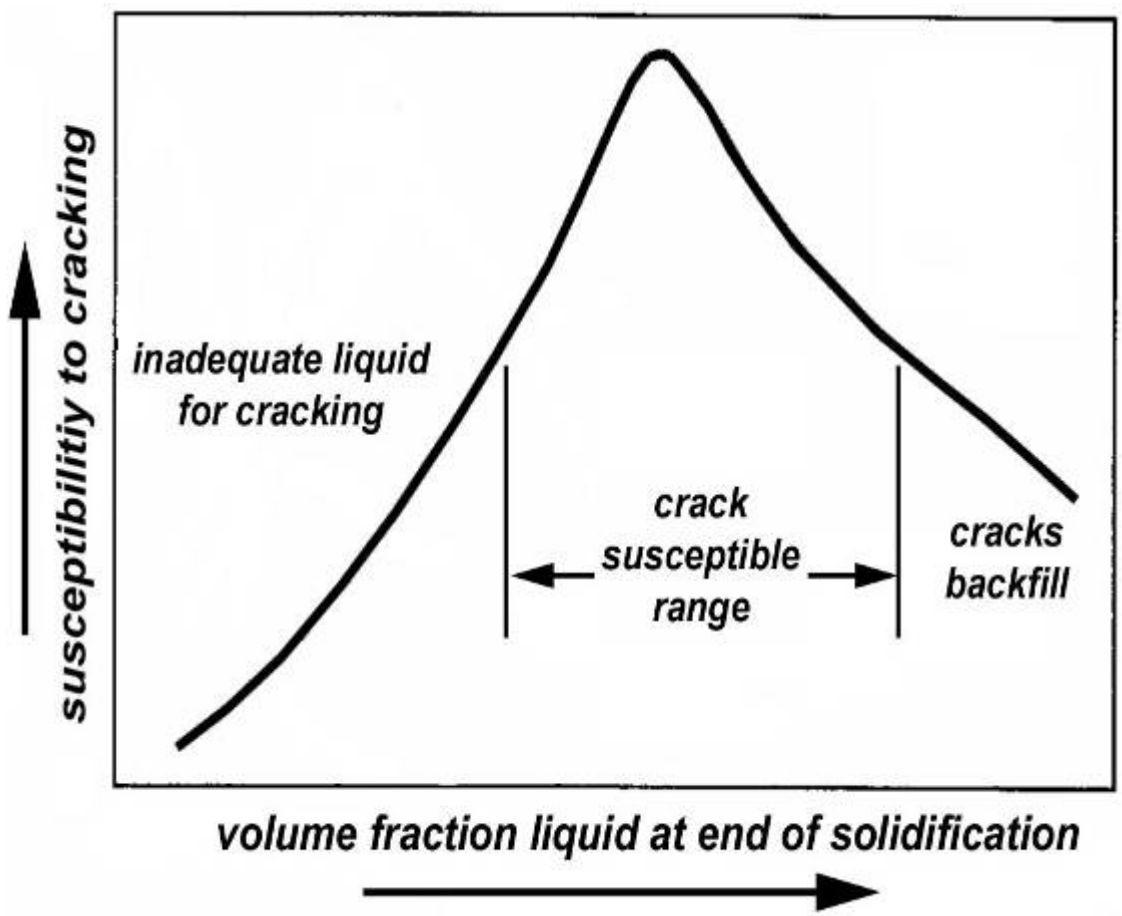
Adequate Volume % Liquid at End of Solidification May Heal / Backfill Cracks

- Wide solidification temperature range indicates higher volume fraction liquid at end of solidification
- MLTS-27 has widest solidification range but is less susceptible to cracking
- Reduced susceptibility to cracking is likely due to adequate volume fraction of liquid to cause crack 'healing' (back filling)



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Conclusions

- Solidification and Eutectic Ranges
  - Widest in MLTS-27, Nb rich eutectic
  - 52MSS-A wider than 52MSS-B, higher C & Nb
  - Narrowest in 52M
- New SS DTA Procedure
  - Accurately simulates Ni-base GTA welds
  - Solidification temperature range for MLTS-27 & 52M by SS DTA are in close agreement with Scheil-Gulliver simulations
- Solidification Crack Susceptibility Ranking
  - 52M least susceptible
  - MLTS-27 less susceptible than 52MSS, potentially due to crack healing
  - 52MSS-A more susceptible than 52MSS-B, higher C & Nb
  - Close agreement between CPTT and Transverse Varestraint

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Continuing Work

- LOM & SEM
  - crack healing, eutectic phases
- Determine Solidification Cracking Temperature Range (SCTR)
- Complete 52MSS-C & 52i testing:
  - Solidification Behaviour
    - SS DTA
    - Thermal Simulation
  - Cast Pin Tear Testing
  - Transverse varestraint test and determine SCTR
- Strain-to-Fracture (DDC) testing of 52M, MLTS-27, three heats of 52MSS, and 52i

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Future Work

- Evaluate influence of dilution on heats and classifications of Alloy 52
  - Level of dilution with stainless steel that causes solidification cracking
  - wt% of S & P that cause solidification cracking
  - Influence of Si on dilution and potential for increasing risk for solidification cracking
  - Solidification range
  - Solidification cracking / CPTT & varestraint test
  - SS DTA & thermal simulations / calculations
- Test new heats / formulations of Alloy 52

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& J.C. Lippold

The Ohio State University

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S.L. McCracken

EPRI Welding & Repair Technology Center

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