Development of Spallation-Resistant Coatings: Preliminary Results

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Project Overview

- University of North Dakota Mechanical Engineering and the UND Energy & Environmental Research Center (EERC) are working with Siemens Power Generation to test a new method for joining high-temperature alloys for use in advanced high-hydrogen-gas-burning turbines.
- Will bond thin plates of oxidation- and spallation-resistant Kanthal APMT™ to high-strength CM247LC and Rene® 80 using evaporative metal (EM) bonding.
- Bonded parts, with and without thermal barrier coatings (TBCs), will be tested for oxidation, corrosion, and spallation resistance.

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Alloy Compositions

Composition of Kanthal APMT in wt % – Dispersion-Strengthened						
	Cr	Al	Mo	Mn	Si	Fe
APMT	22	5	3	0.4	0.7	Bal.

Composition of CM 247 LC in wt % – Gamma Prime-Strengthened													
	Fe	Ni	Cr	Al	Ti	Co	Mo	Ta	W	Nb	Hf	Mn	Si
CM247LC	–	Bal.	8.1	5.6	0.7	9.5	0.5	3.2	9.5	0.1	1.4	–	–

Composition of Rene 80 in wt% – Gamma Prime-Strengthened												
	Cr	C	Mo	W	Ti	Nb	Co	Al	B	Fe	Zr	Ni
Rene 80	14.2	0.16	4.0	4.1	5.1	0.03	9.4	3.0	0.02	0.10	0.04	Bal.

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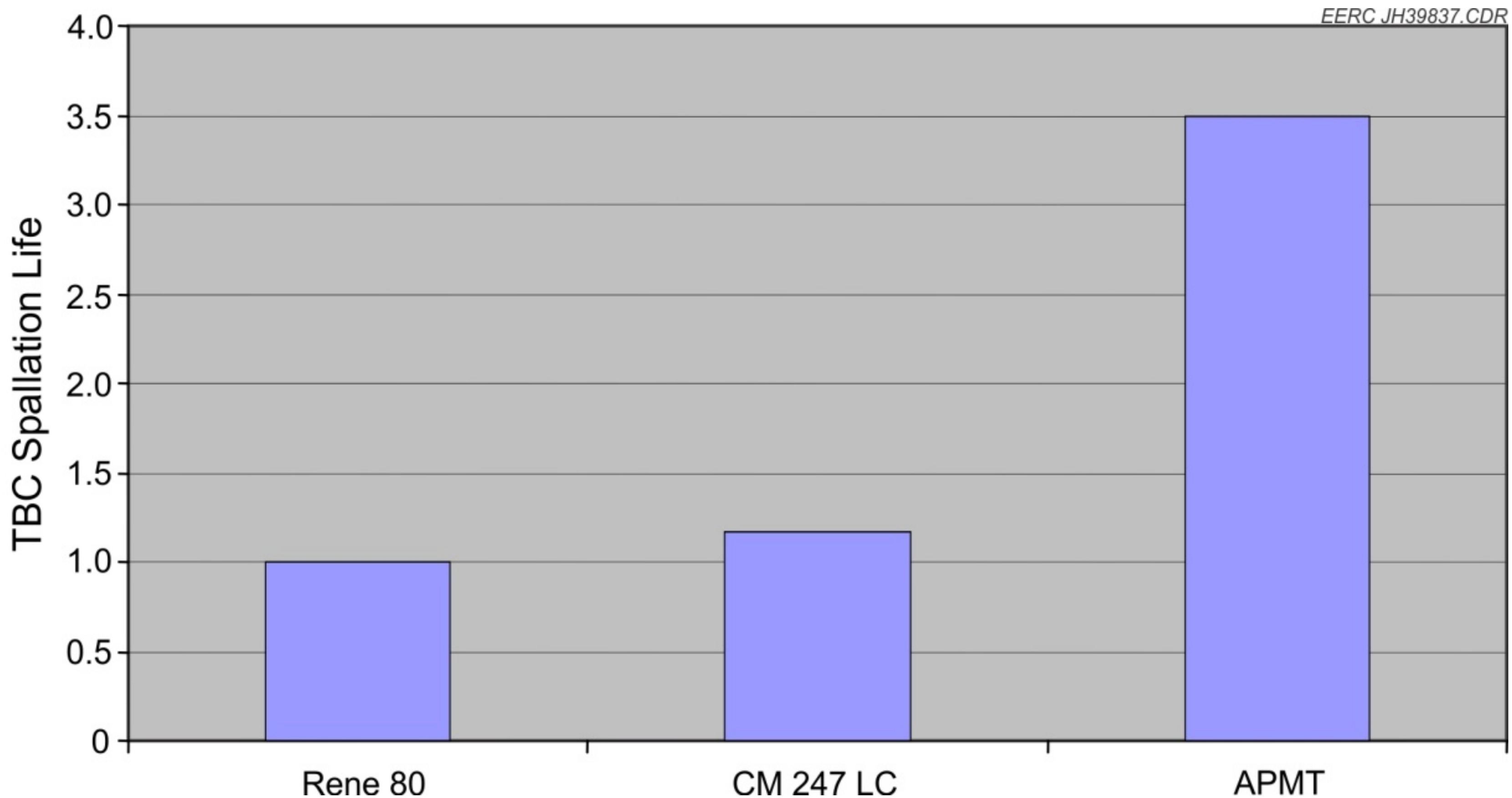
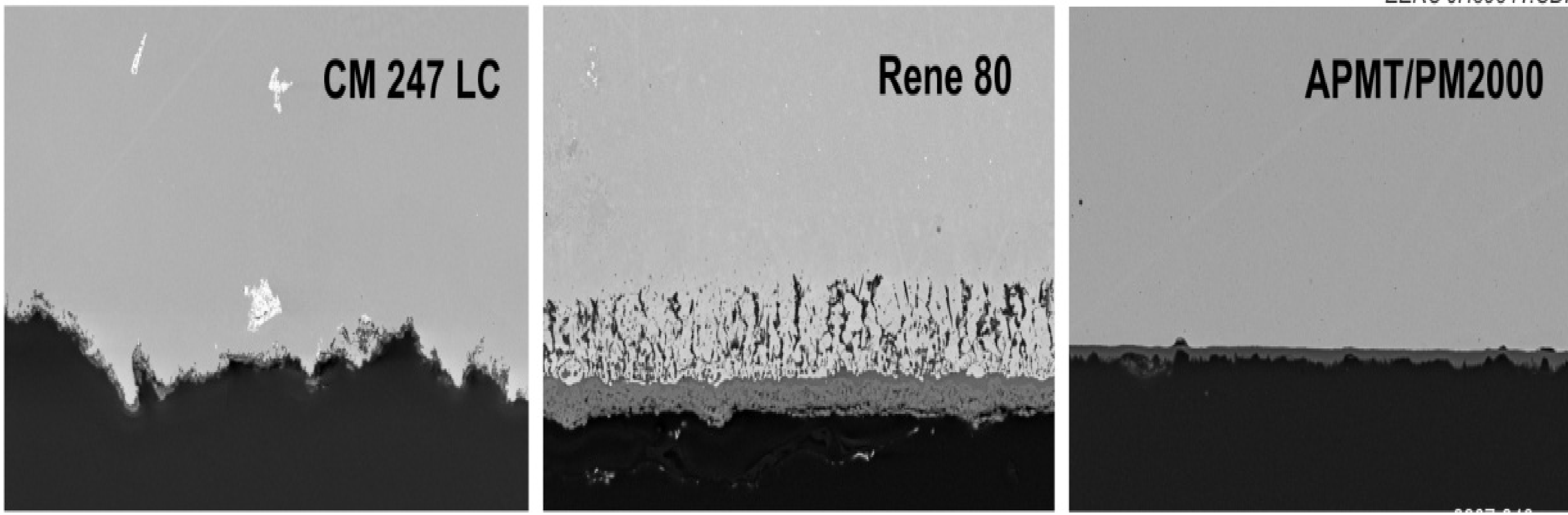
Prior Work: TBC Spallation Lifetimes



Testing at Siemens Energy Inc. shows that the spallation lifetime of TBCs on APMT is three times that of a similar coating on Rene 80 or CM247LC.

Prior Work: Alloy Oxidation Rates

EERC JH39841.CDR



The oxidation rate of APMT is much lower than for CM247LC or Rene 80.

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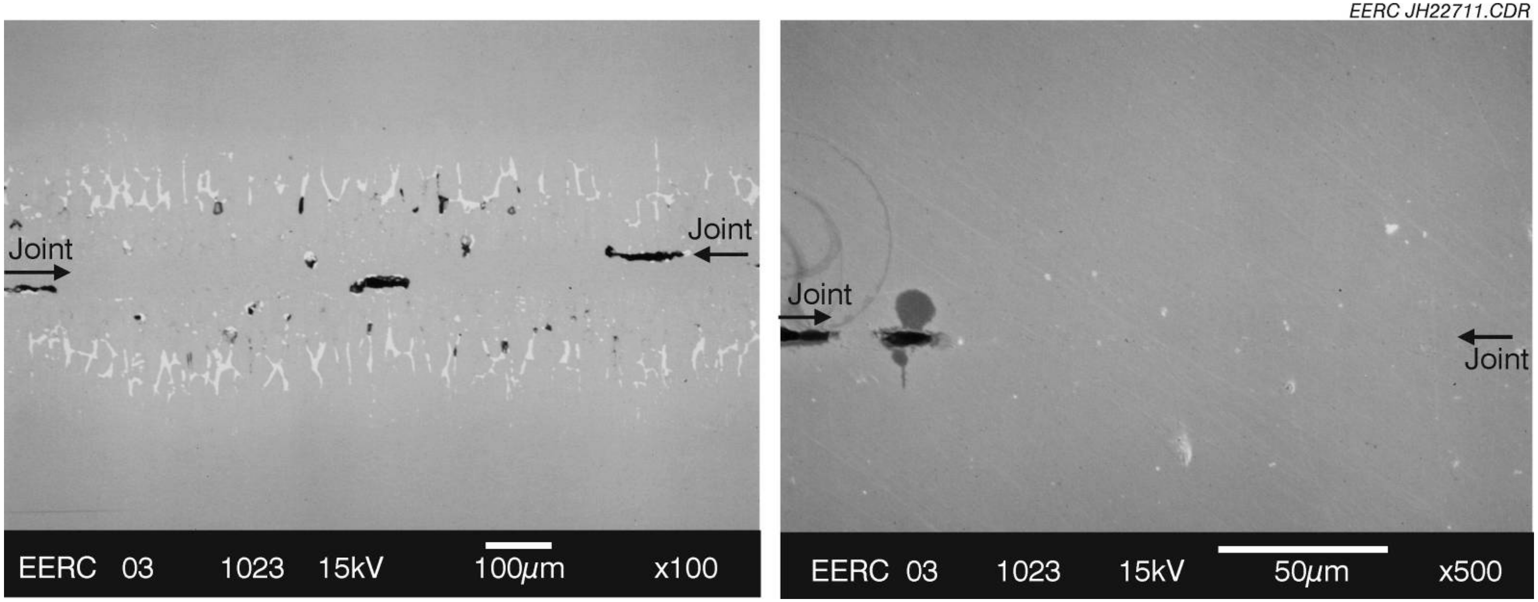
Prior Work:
Transient Liquid Phase (TLP) Bonding

EERC JH22711.CDR



- Welding of advanced alloys is not possible because critical structures are destroyed.
- TLP bonding uses a reactive braze that diffuses away from the joint.
- Bonding alloys need to have low melting points, be soluble, and not form intermetallics.
- Evaporative metal (EM) bonding is an alternative

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Prior Work:
Joining Complex Geometries

- Scanning electron microscopy photo top, x-ray map on bottom.
- Needle growth and interdiffusion create a joint stronger than the APMT.
- Nickel diffuses up to 700 µm into APMT.
- Iron diffuses 200 µm into the CM247LC.

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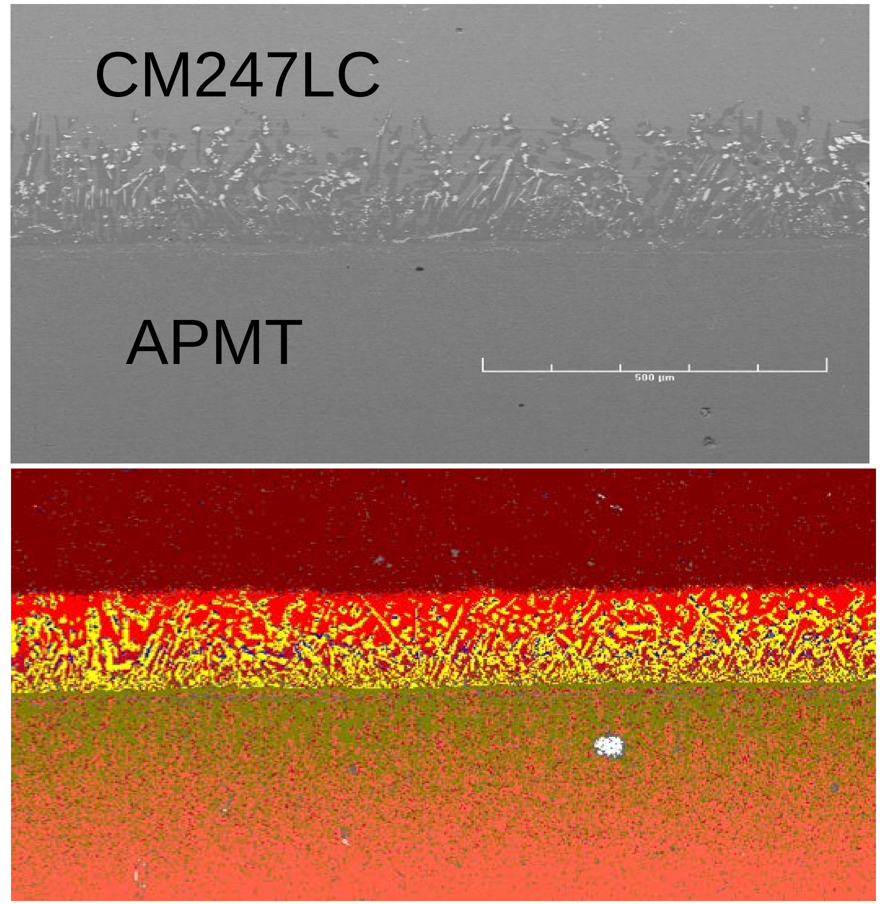

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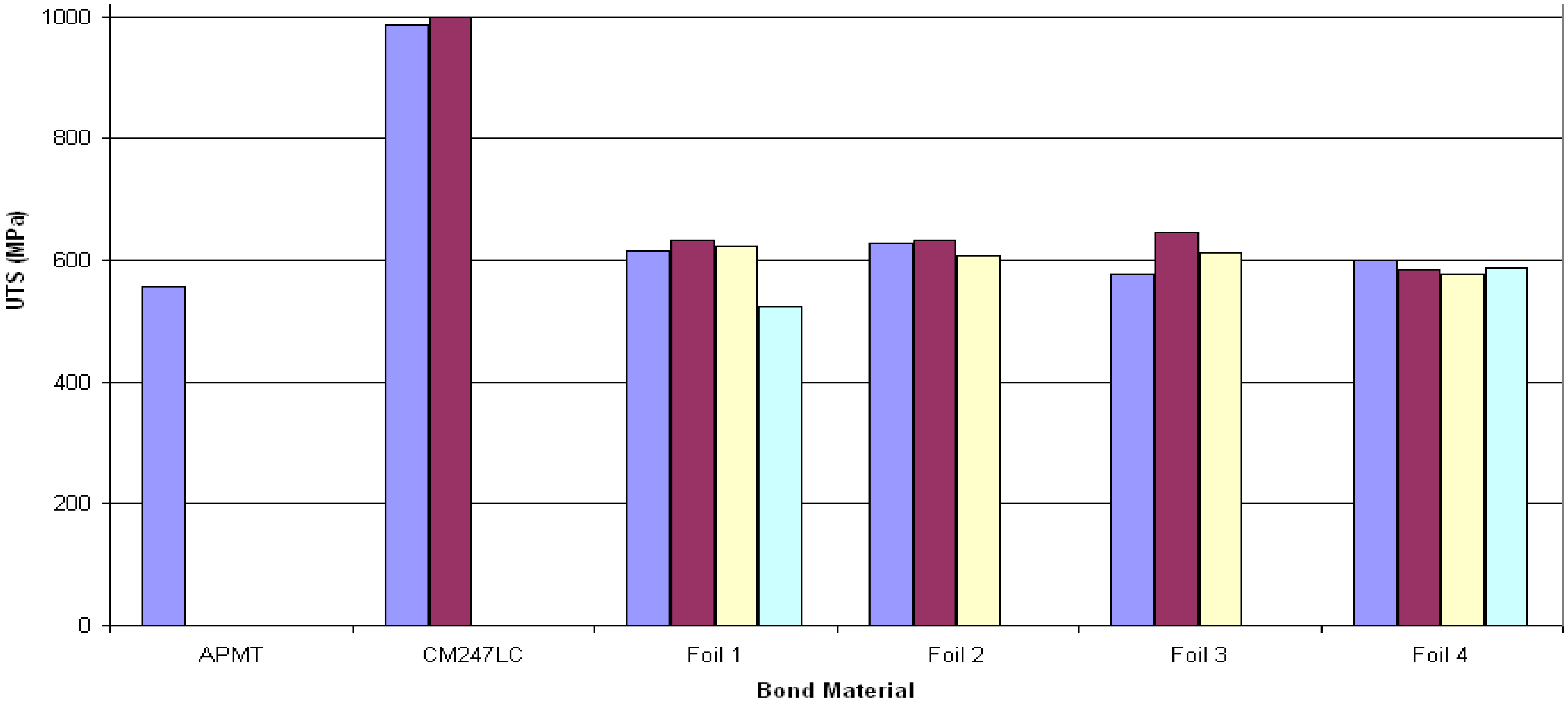
Prior Work: Room Temperature Joint Strengths



- Room-temperature ultimate tensile strength results for joints made with four joining alloys.
- All samples broke within the APMT, showing the joints are stronger than the APMT.

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Prior Work:
950°C Stress Rupture Test

- Stress rupture tests done at 950°C using 20 MPa, the 100-hour APMT rupture stress.
- Samples broke within the APMT, not the joint.
- APMT was much weaker than anticipated.

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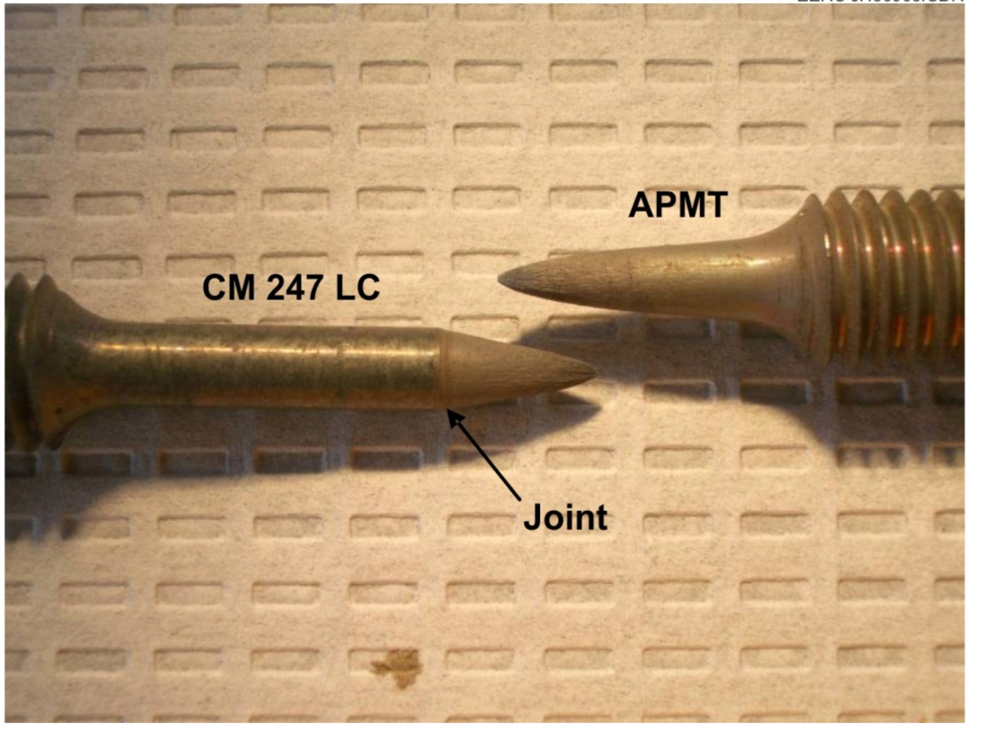

Prior Work:
Joining Complex Geometries

- Joined actual turbine ring segments of CM247LC with APMT sheet in between.
- Demonstrates the ability to cover large areas of superalloys with oxidation- and spallation-resistant APMT using EM bonding.
- Joints were stronger than the APMT.

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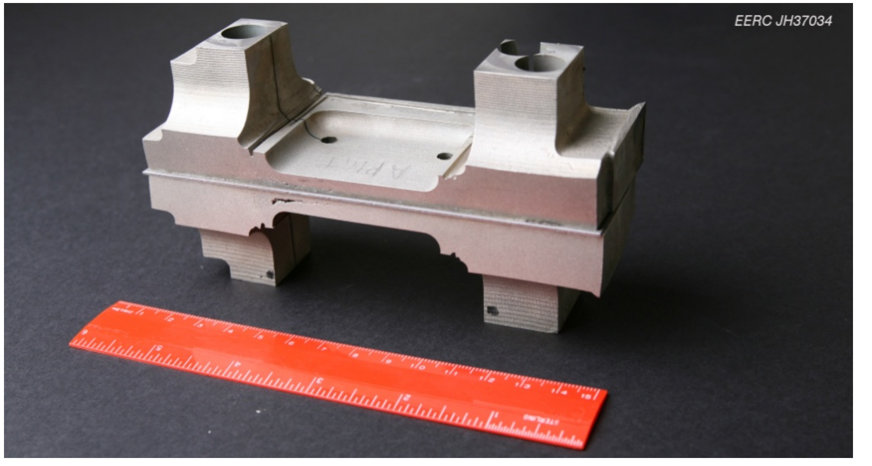

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Articulated Clamping System

- Specimens electro-discharge machined to shaped and then polished
- Bonding surface blasted with silica beads.
- Clamp made from low-CTE metal (Mo).
- Steel hemispheres (E52100) used to articulate the pieces, which is necessary because of the thinness of the foils. Steel used to facilitate modeling.
- Joints of APMT to CM 247 and APMT to Rene 80

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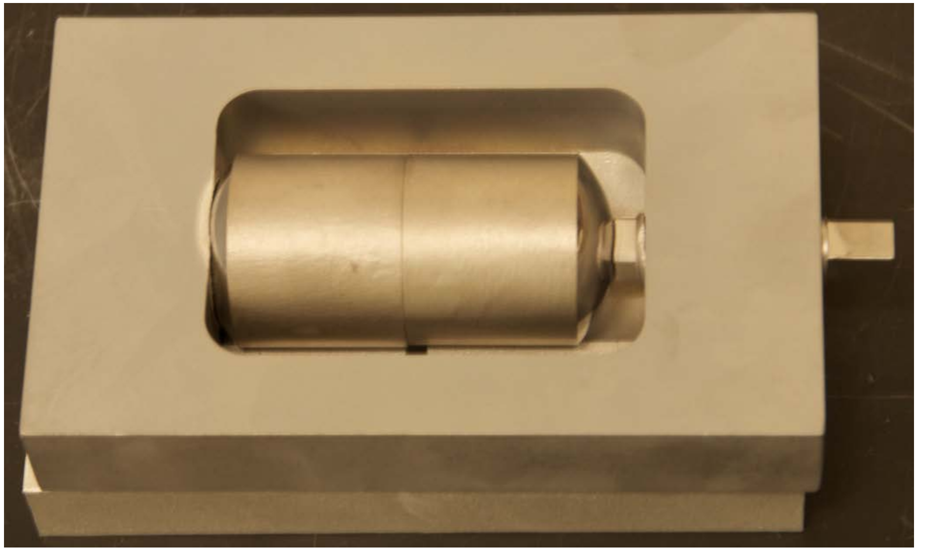

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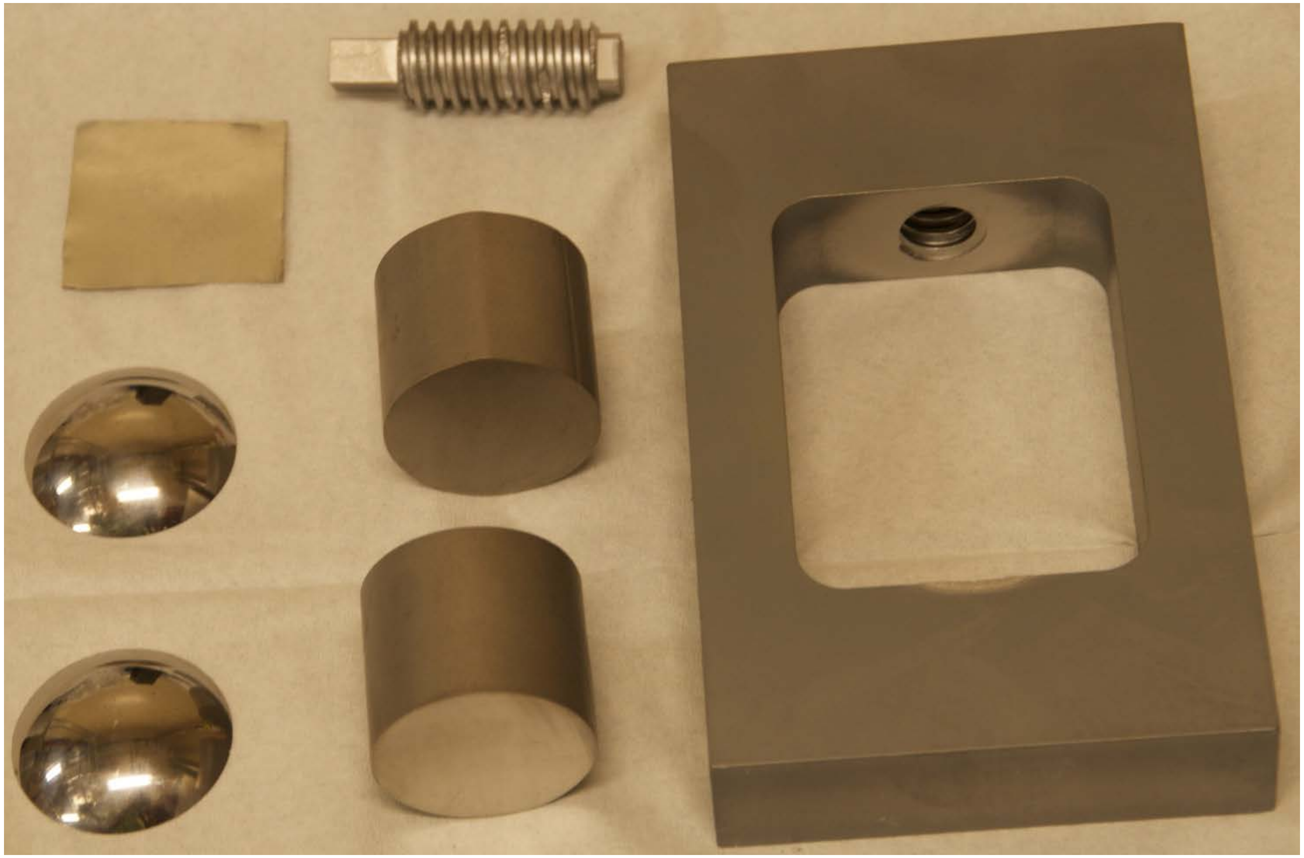
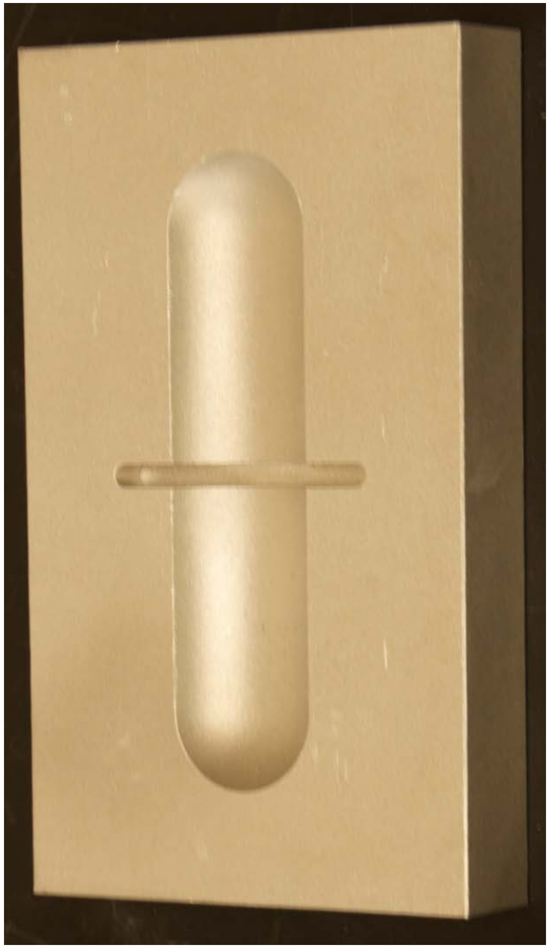
Articulated Clamping System





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UTSR 2011 Award – Task 1

- Task 1 – Determine diffusion rates of evaporative metal through APMT, CM247LC, and Rene 80 as functions of temperature.
  - Prepare bonded rods at different temperatures and times.
  - Cross-section bonded rods, and measure bonding metal concentration gradients.
  - Develop diffusion rate equations as functions of temperature.
  - October 2011 - March 2013

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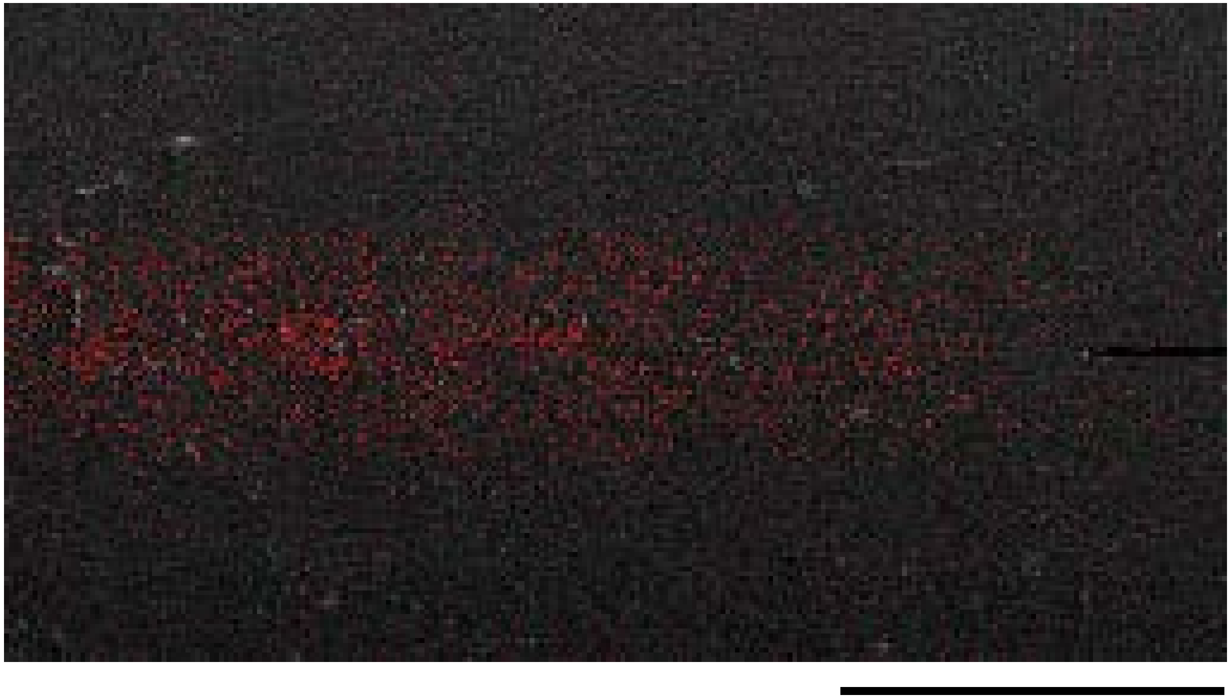
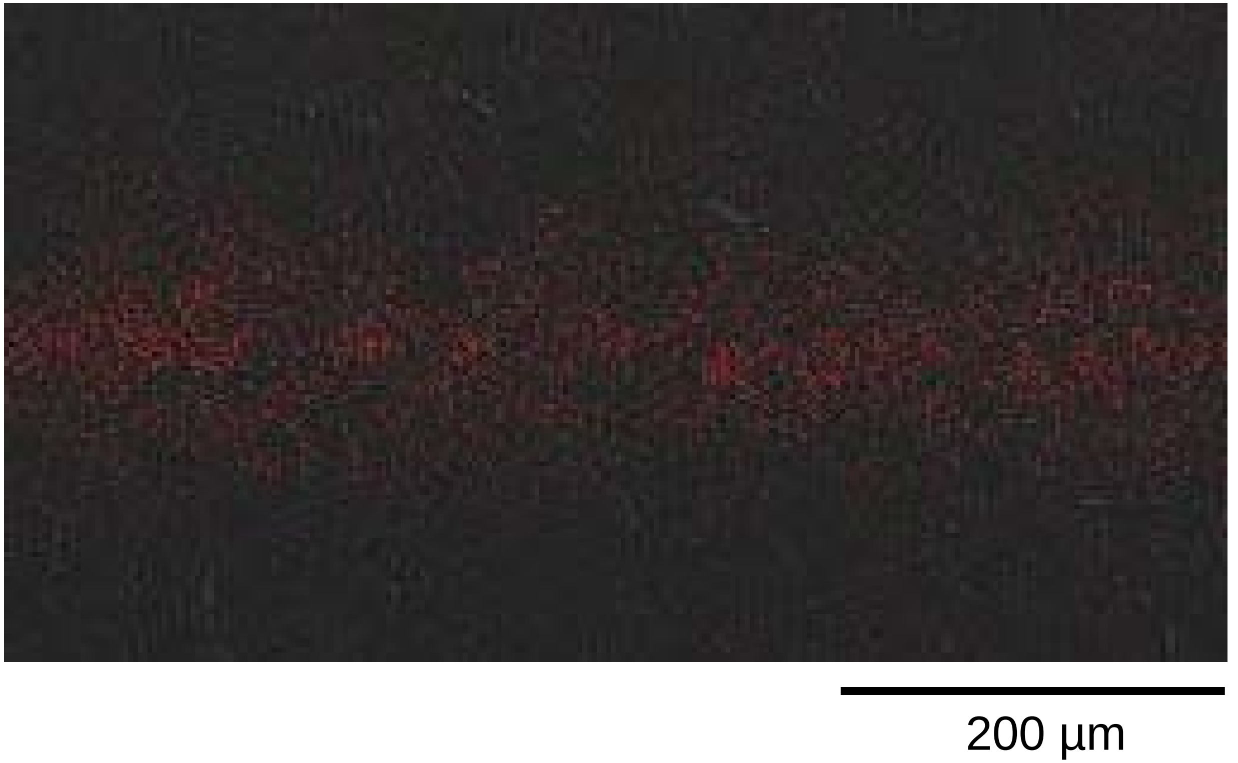
UTSR 2011 Award – Task 1



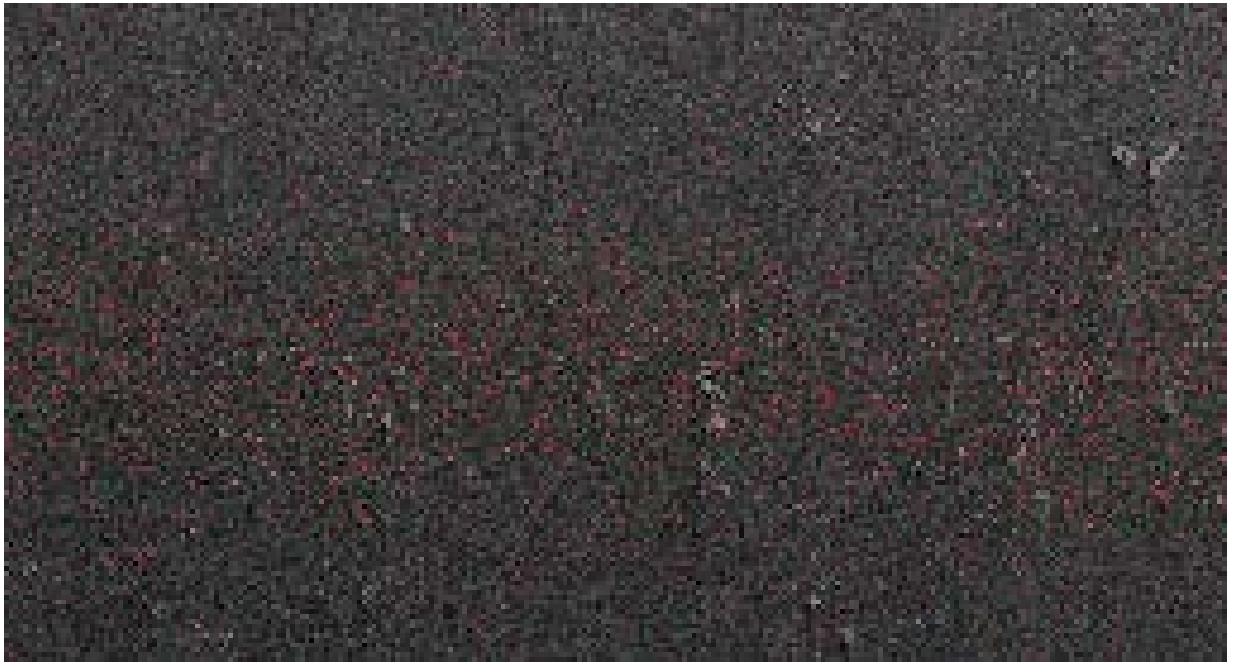
Elemental Map of Zn – CM 247 bonded at 1214°C for 1 hour (joint edge)

UTSR 2011 Award – Task 1



Elemental Map of Zn – CM 247 bonded at 1214°C for 1 hour (joint center)

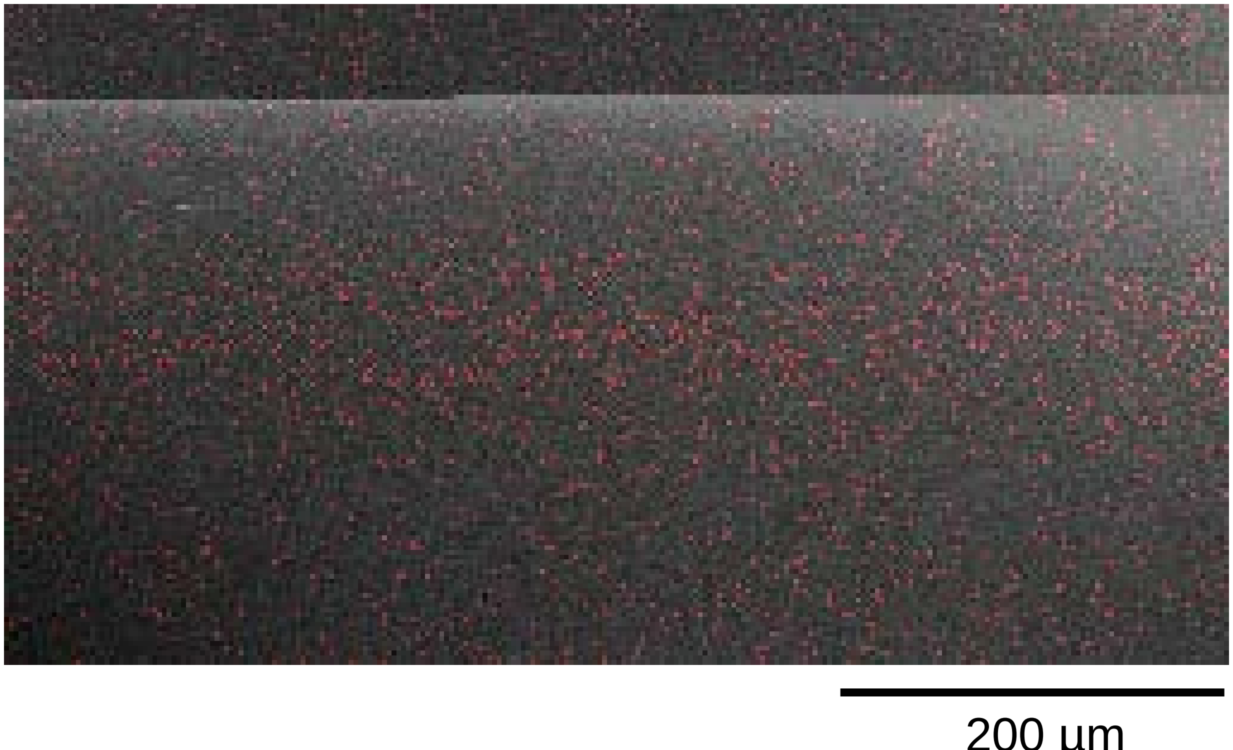
UTSR 2011 Award – Task 1



200 µm

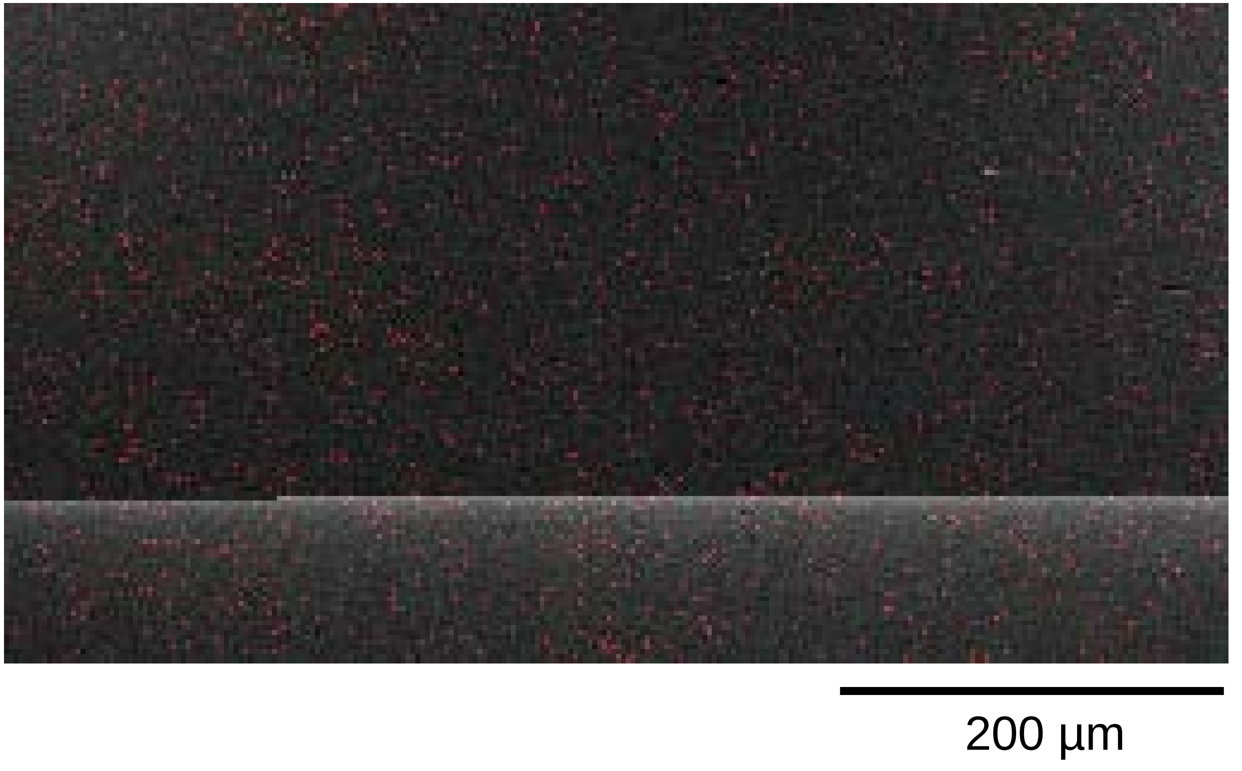
Elemental Map of Zn – CM 247 bonded at 1214°C for 3 hours (joint center)

UTSR 2011 Award – Task 1



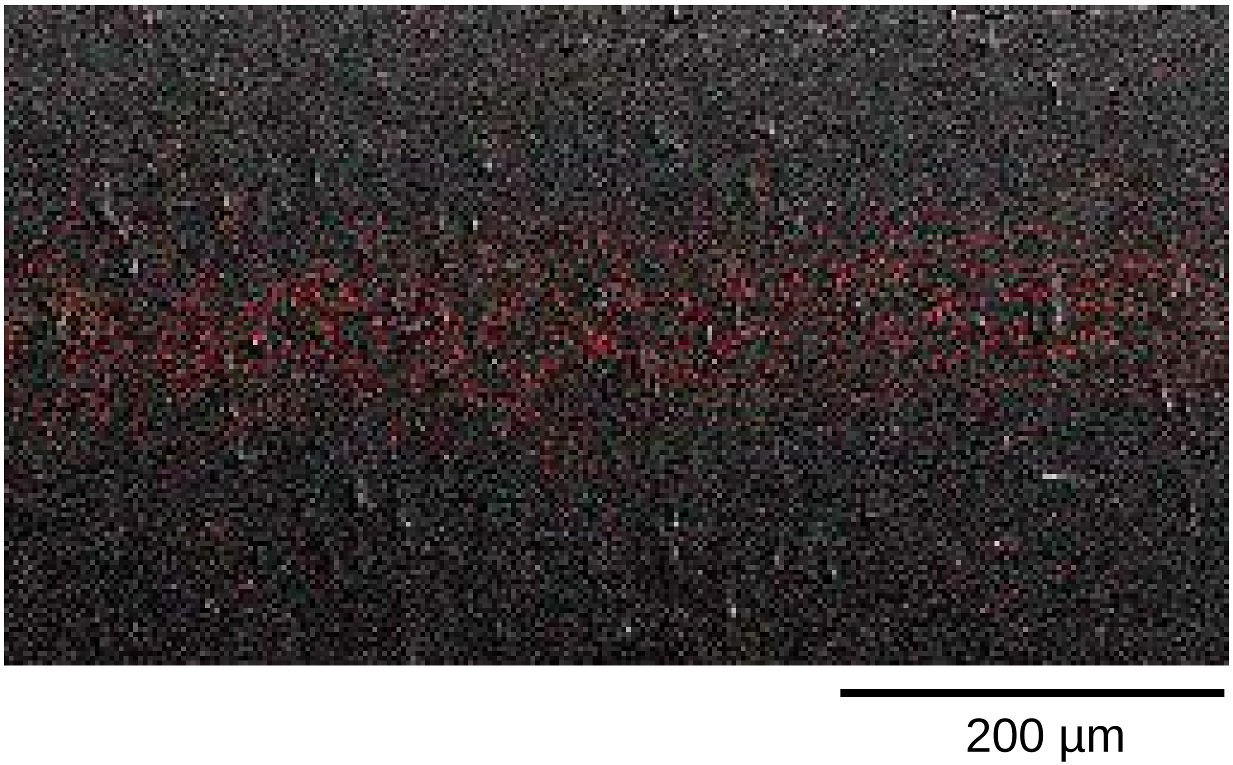
Elemental Map of Zn – APMT bonded at 1214°C for 1 hour (joint center)

UTSR 2011 Award – Task 1



Elemental Map of Zn – APMT bonded at 1214°C for 3 hours (joint center)

UTSR 2011 Award – Task 1



Elemental Map of Zn – Rene 80 bonded at 1214°C for 1 hour (joint center)

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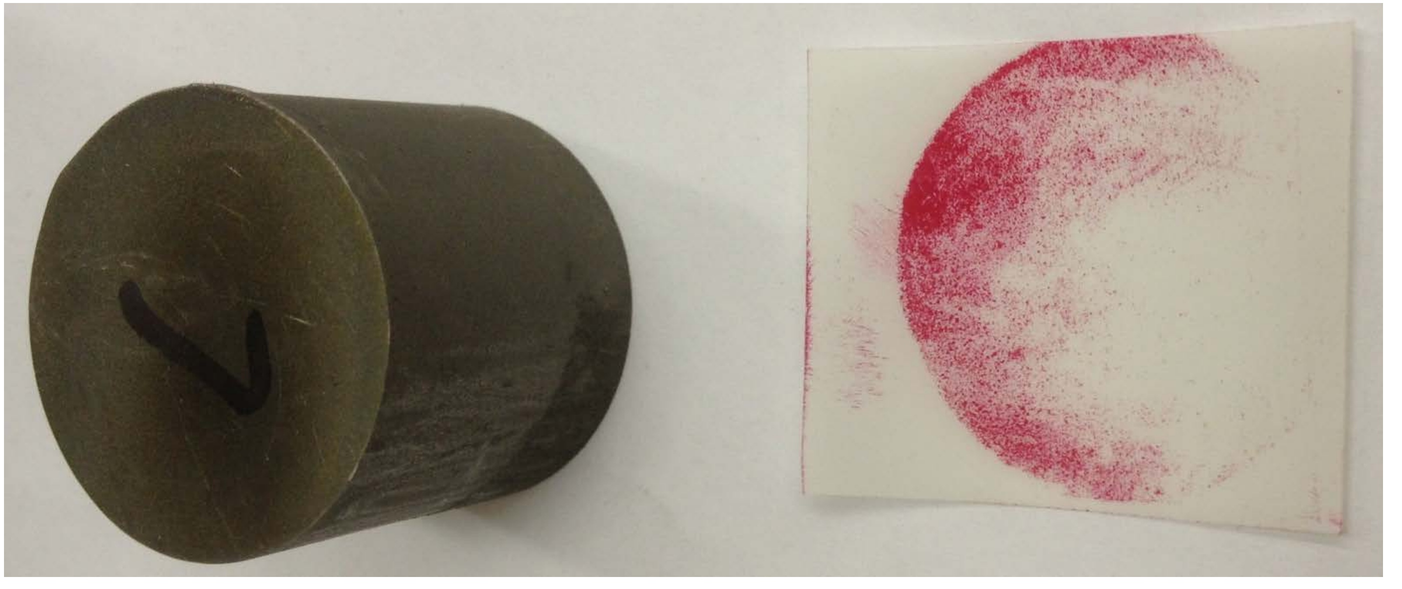
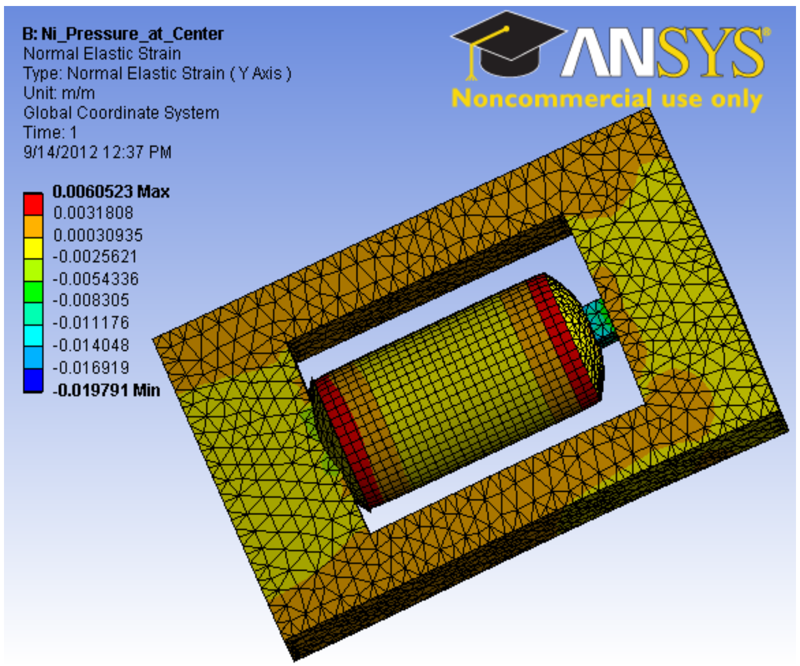
UTSR 2011 Award – Task 2

- Task 2 – Model bonding pressure distributions in complex joints.
  - Measure bonding pressures in actual joints.
  - Measure high temperature properties of substrate metals (E, α)
  - Model pressures at the bond line at temperature.
  - Design clamping system.
  - October 2011 - March 2013

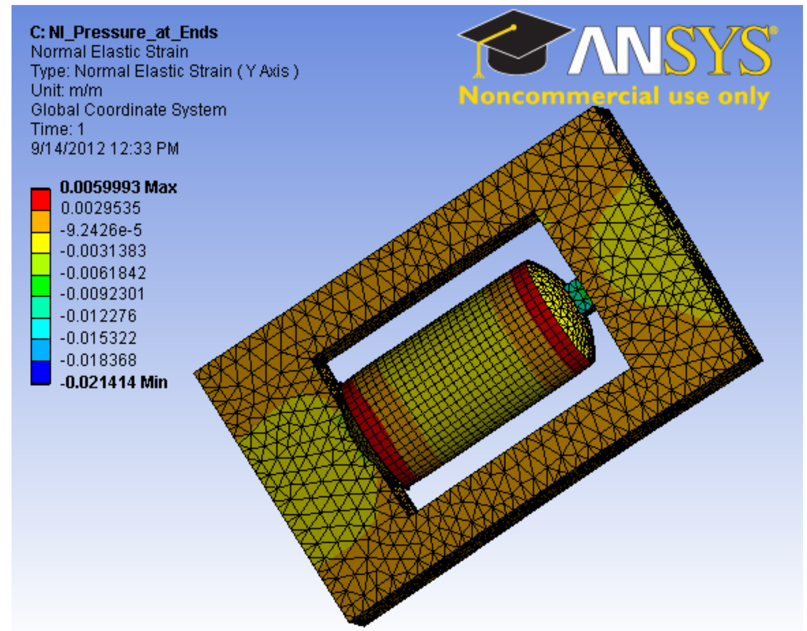
UTSR 2011 Award – Task 2



UTSR 2011 Award – Task 2



(a)



(b)

Comparison of strains in the bonding assembly when loads applied at a) joint center or b) joint ends.

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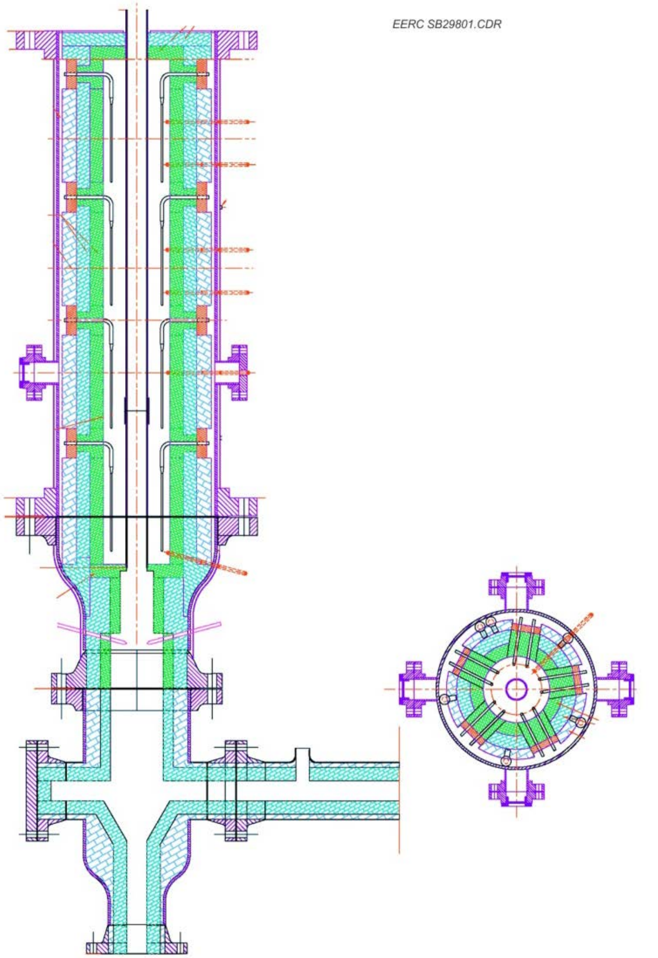
UTSR 2011 Award – Task 3

Task 3 – Characterization of combusted syngas contaminants.

- Information to be used in designing later corrosion testing – contaminants will not be similar to gasifier fly ash.
- Collection of microcontaminants in combusted syngas created in a pilot-scale gasifier.
- Analysis of captured microcontaminants by SEM.
- Data will be made available to other researchers.



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UTSR 2011 Award – Task 3

EERC entrained flow gasifier test rig

EERC fluidized bed gasifier test rig

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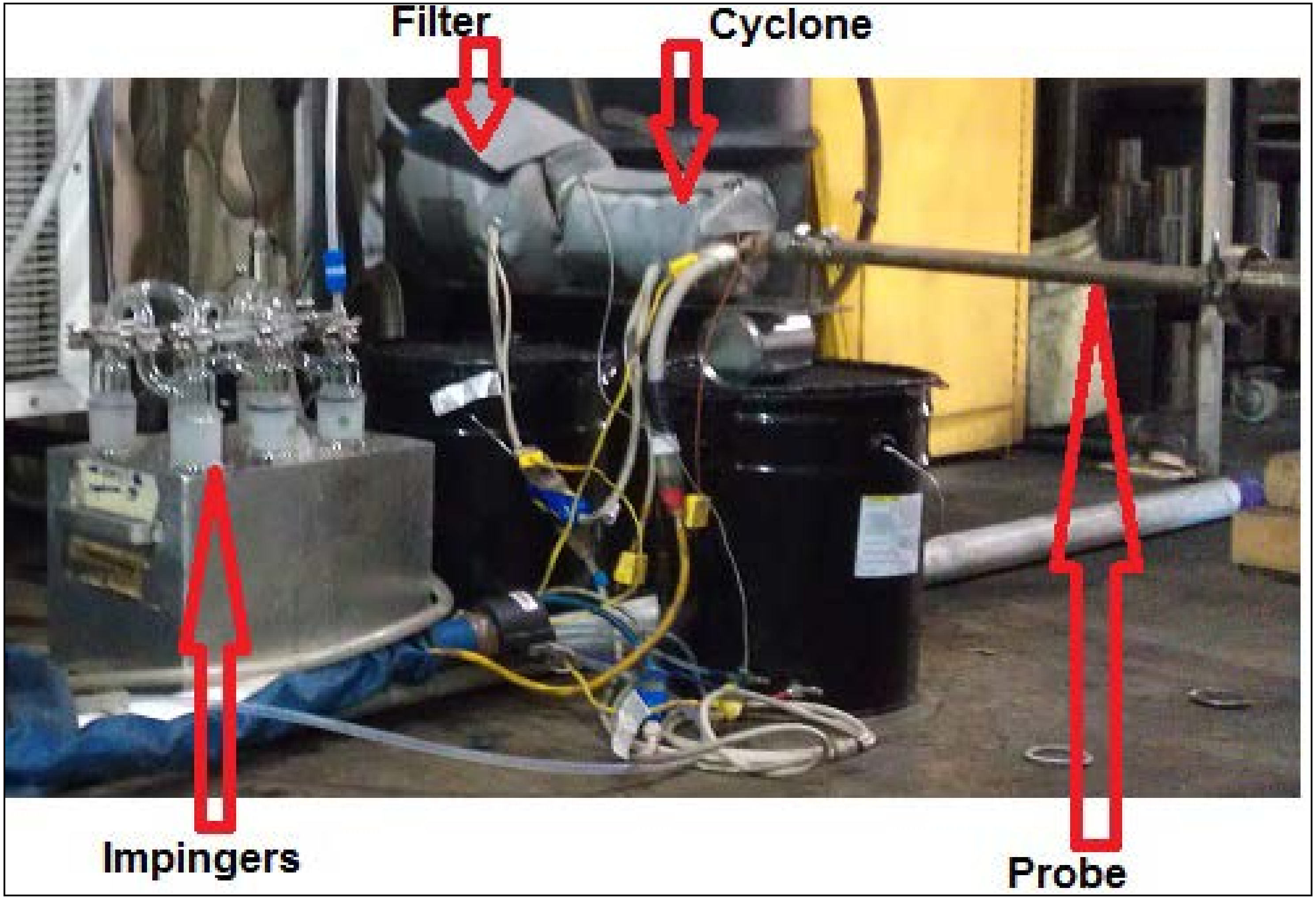

UTSR 2011 Award – Task 3

- Sampling method follows EPA methods 26A and 29
- Flow enters probe at about 750°C and cools to 100°C
- Flow passes through a polycarbonate filter (0.1 micron diameter holes)
- Flow enters water-filled impingers

Trace Metal	As	Be	Cd	Co	Cr	Mn	Ni	Pb	Sb	Se	Hg
LLQ (µg/L)	0.5	0.1	0.1	0.5	0.1	0.1	0.2	0.1	0.1	1.0	0.02
Conc.(µg/L)	0.4	0.2	0.2	0.4	8.2	63.80	7.53	0.76	0	1.1	0.99
Conc.(µg/m^3)	0.12	0.06	0.06	0.12	2.39	18.58	2.19	0.22	0	0.32	0.29

Trace Metal	K	Mg	Ca	Na	Fe	Ti	V	Mo	Zn	Ge
LLQ (µg/L)	20	20	20	20	20	20	20	20	20	20
Conc.(µg/L)	140	128.8	670.4	243.5	354.6	15.84	0.777	3.959	13.42	1.881

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UTSR 2011 Award – Task 3

Spectrum	O	Si	S	Cr	Fe	Ni	Total
Spectrum 1	63.83	3.74	18.98	2.06	11.40		100.00
Spectrum 2	62.65	2.68	19.45	2.01	12.15	1.06	100.00
Spectrum 3	70.25		17.28		12.47		100.00
Spectrum 4	65.51	3.26	18.11	2.54	10.58		100.00
Spectrum 5	72.48		17.11		10.41		100.00
Max.	72.48	3.74	19.45	2.54	12.47	1.06	
Min.	62.65	2.68	17.11	2.01	10.41	1.06	

Composition of 316L Stainless Steel in wt % (max)								
C	P	S	Cr	Al	Mo	Mn	Si	Fe
0.03	0.045	0.03	16-18	10-14	2-3	2	0.75	Bal.

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UTSR 2011 Award – Tasks 4-6

- Task 4 – Preparation of APMT-plated superalloy turbine parts.
  - Use data from Tasks 1 and 2 to design clamping system and time–temperature heat treatment.
  - April 2013 – September 2014

- Task 5 – Environmental testing of plated turbine parts.
  - Oxidation and spallation testing at Siemens Energy.
  - Corrosion testing at the EERC.
  - October 2013 – September 2014

- Task 6 – Reporting (ongoing).

Acknowledgements

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- Joshua Braband

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