Evaporative Metal Bonding of APMT to Nickel Superalloys

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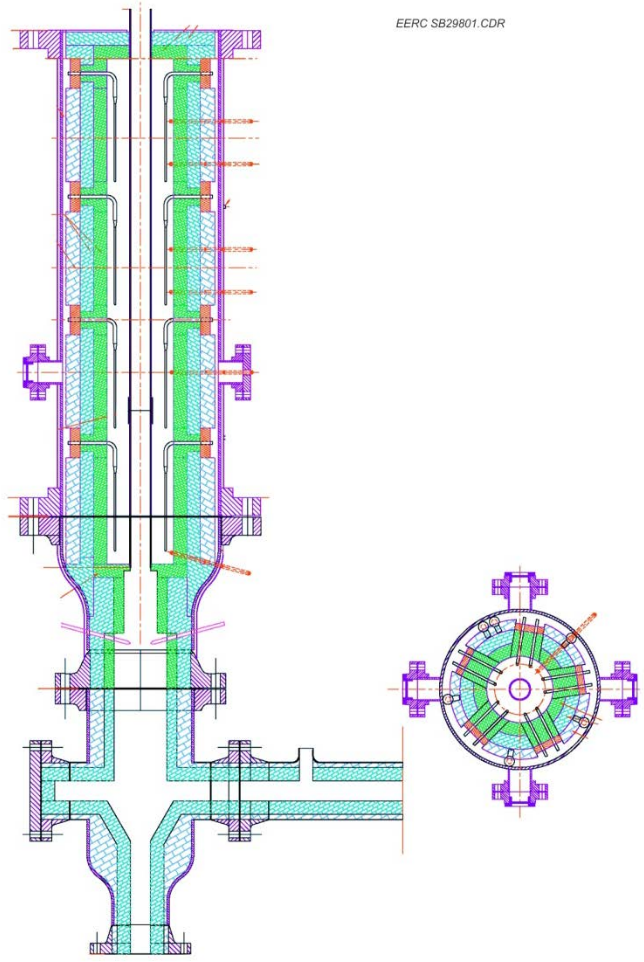
Energy & Environmental Research Center (EERC)

Project Overview

- The University of North Dakota (UND) Energy & Environmental Research Center (EERC) and Department of Mechanical Engineering are working with Siemens Energy to test a new method for joining high-temperature alloys for use in advanced high-hydrogen-gas-burning turbines.
- Developed models for designing clamping fixtures and zinc diffusion.
- Thin plates of oxidation- and spallation-resistant Kanthal APMT™ have been bonded 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 at Siemens Energy.
- Gasifier sampling to determine appropriate corrosion conditions.

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 two pilot-scale gasifiers.
- Analysis of captured microcontaminants by SEM.



EERC Pilot-Scale Gasifiers

Entrained-Flow Gasifier (EFG)
1800°C, 300 psi

Fluid-Bed Gasifier (FBG)
800°C, 600 psi

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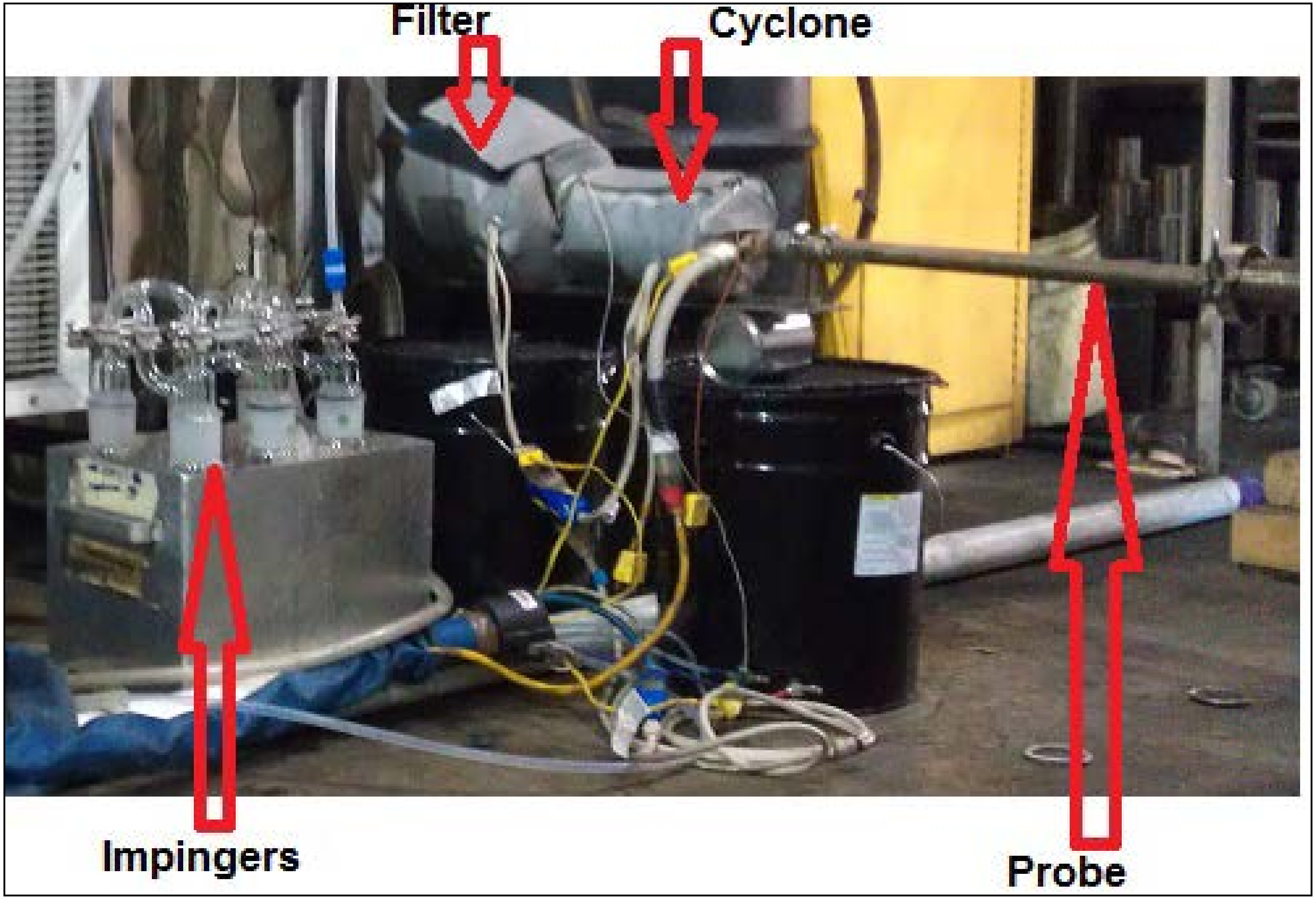
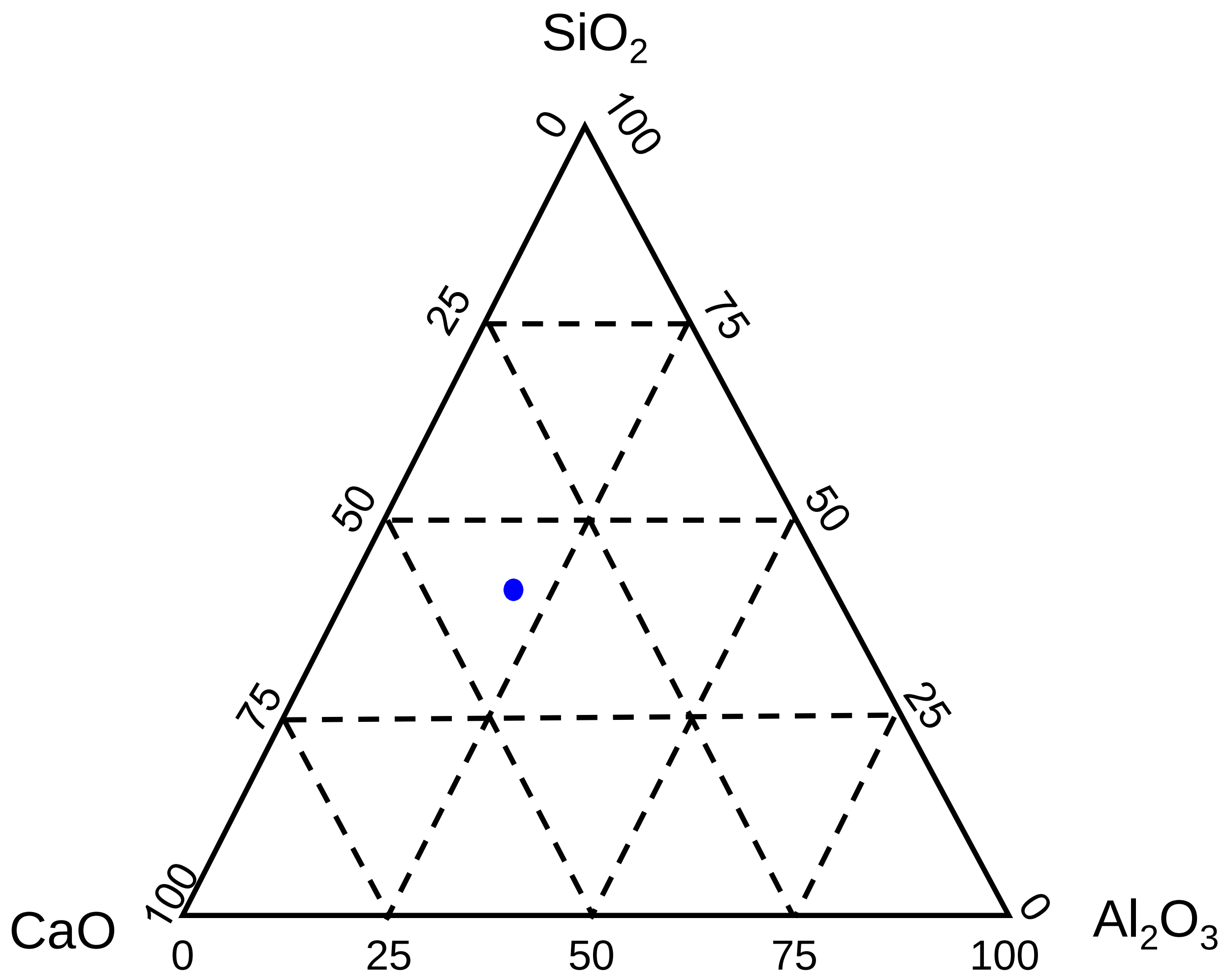
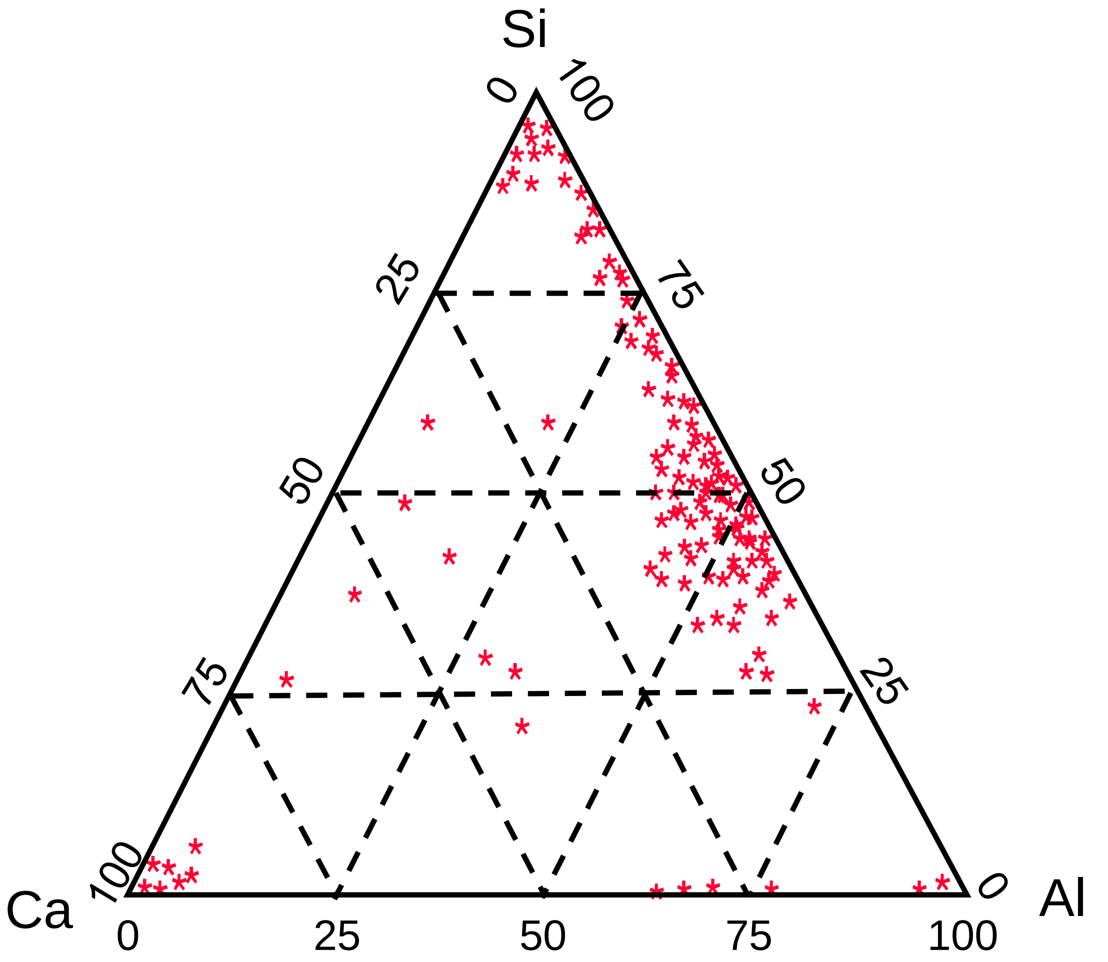
Method 29
Sampling System



Eagle Butte Coal Ash Composition

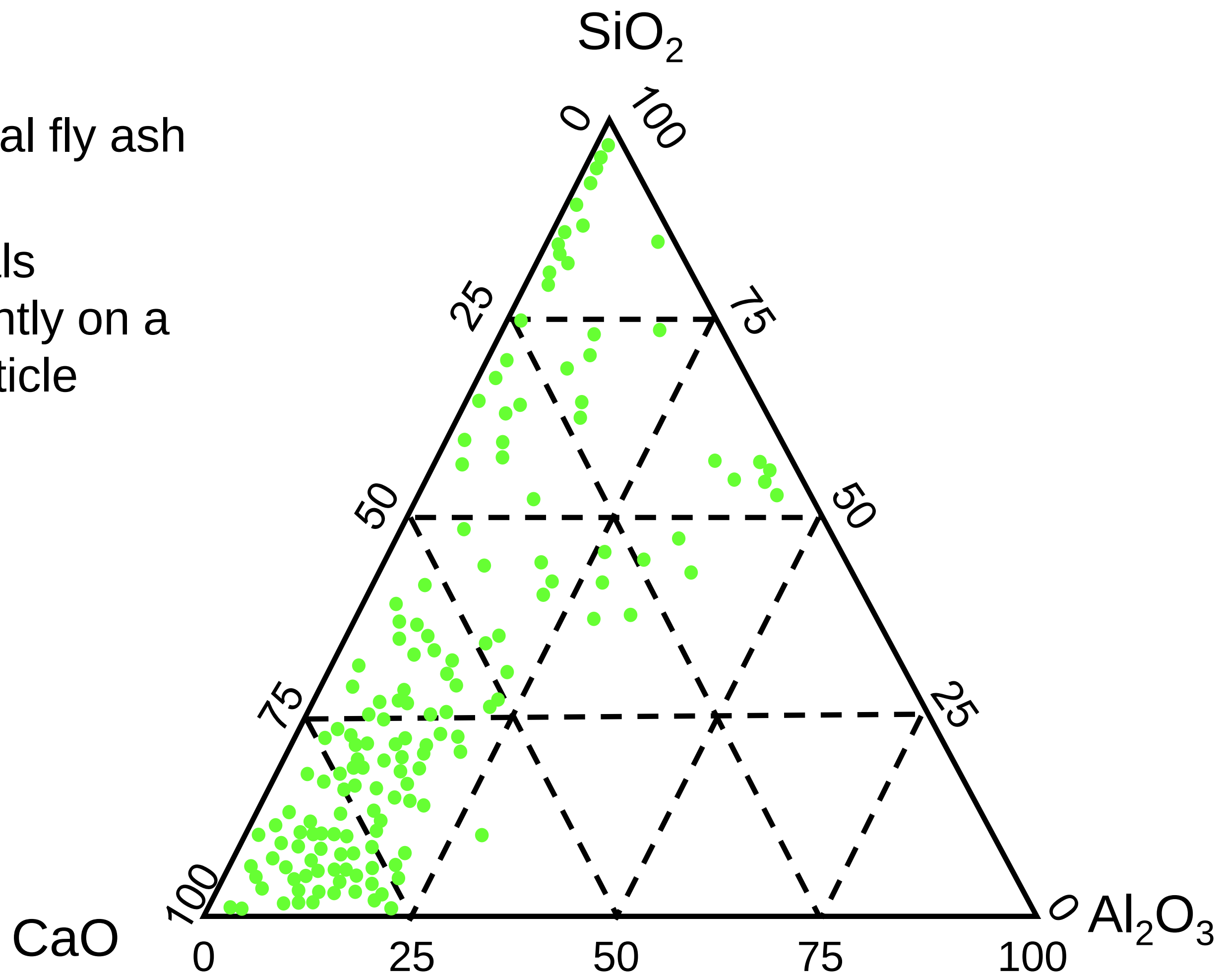


Eagle Butte Coal Mineral Compositions



Advanced Technique Analysis for Eagle Butte Fly Ash

- Plot of individual fly ash minerals.
- Fly ash minerals behave differently on a particle-by-particle basis.



Results of FBG Particulate Analyses

- In the quenched syngas, the particulates are predominantly 0.1–0.5 μm in diameter.
- We were not able to get good energy-dispersive x-ray analyses of the small predominant particles.
- XPS shows that the average composition of the syngas particles is very close to that of the polycarbonate filter and is most likely carbonaceous soot.
- In the combusted syngas, the carbonaceous particles are more spherical than in the syngas and slightly larger, typically 0.2–2 μm.
- The combusted particles show more O, N, and S than the noncombusted particles.
- Ion etching shows that the increased O, N, and S were confined to the surface of the particles.

Results of EFG Particulate Analyses

- No submicron particulates were seen on the syngas filter either because the filter had softened or there is just less soot formed due to the lower tar formation in an EFG.
- Flakes of iron oxide were collected from the syngas that came from system surfaces. They contained some C, Na, Cl, S, and Zn.
- Combusted syngas contained 0.1 to 0.3 micron soot particles.
- Some soot is collected even when burning only natural gas, but particles are smaller and fewer than when burning syngas.

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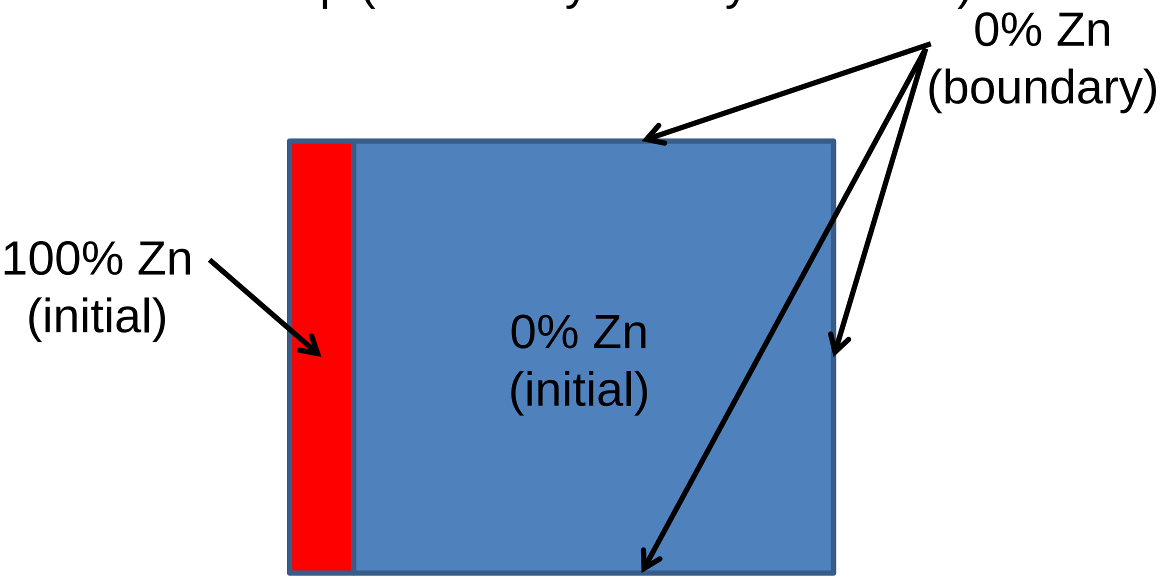
Diffusion Modeling

$$\frac{\partial C}{\partial t} = D\left[\frac{\partial^2 C}{\partial x^2} + \frac{\partial^2 C}{\partial y^2} + \frac{\partial^2 C}{\partial z^2}\right]$$

3-D Diffusion with Constant Diffusivity

No analytical solution exists for the combination of initial and boundary conditions present in the experimental setup (midline symmetry assumed):



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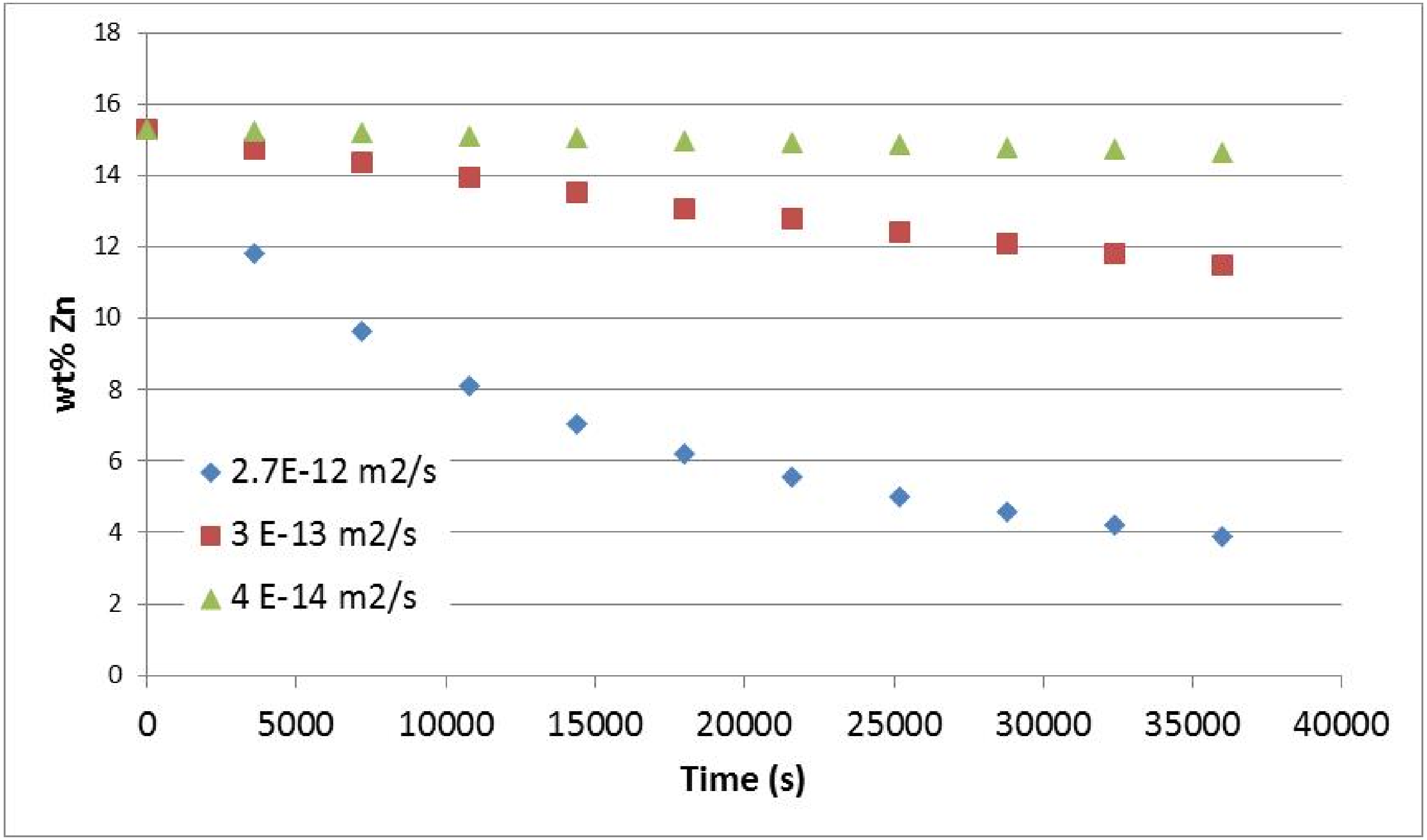
Diffusion Modeling

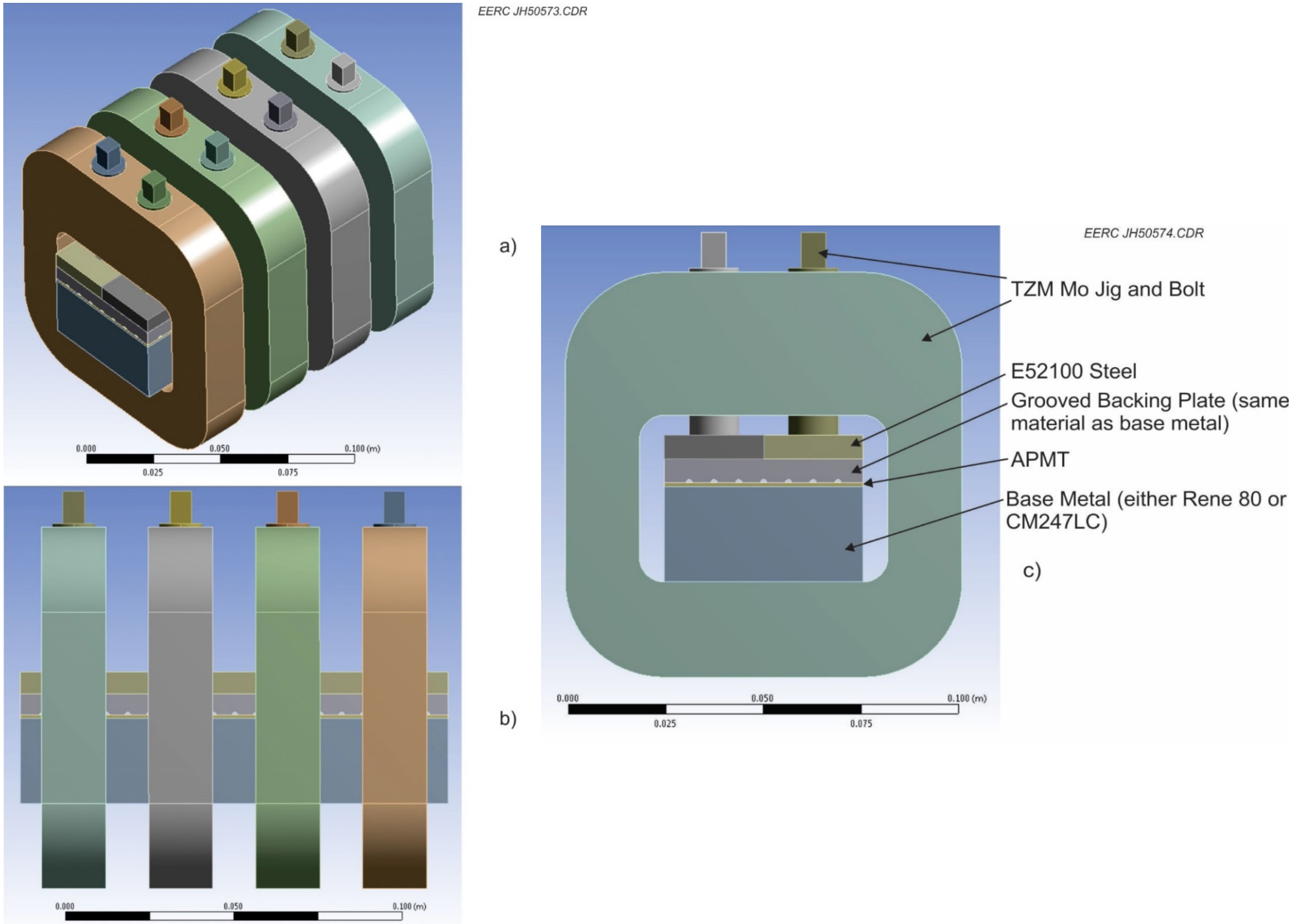
- A finite difference algorithm was implemented within MATLAB to solve the diffusion equation.
- The ‘hopscotch’ iterative solver was implemented to improve accuracy and computational efficiency.
- Algorithm assumes initial midline concentration of Zn, assumes constant diffusivity, uses a rectangular geometry and allows for different mesh size in each direction (x, y, z).

Diffusion Modeling



- ~15 wt% initial centerline composition for model
- D for Zn in APMT ~2.7 E-12 m^2/s
- D for Zn in Rene 80/CM 247 ~4 E-14 m^2/s

Jig Assembly for Fabrication of Samples



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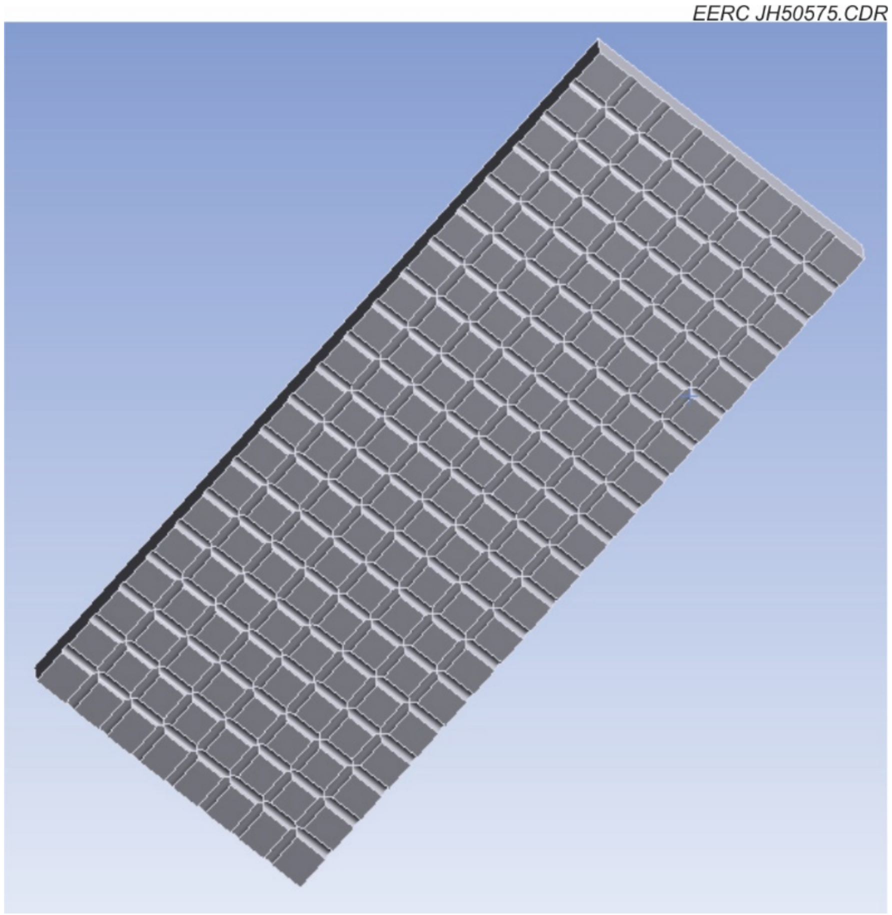
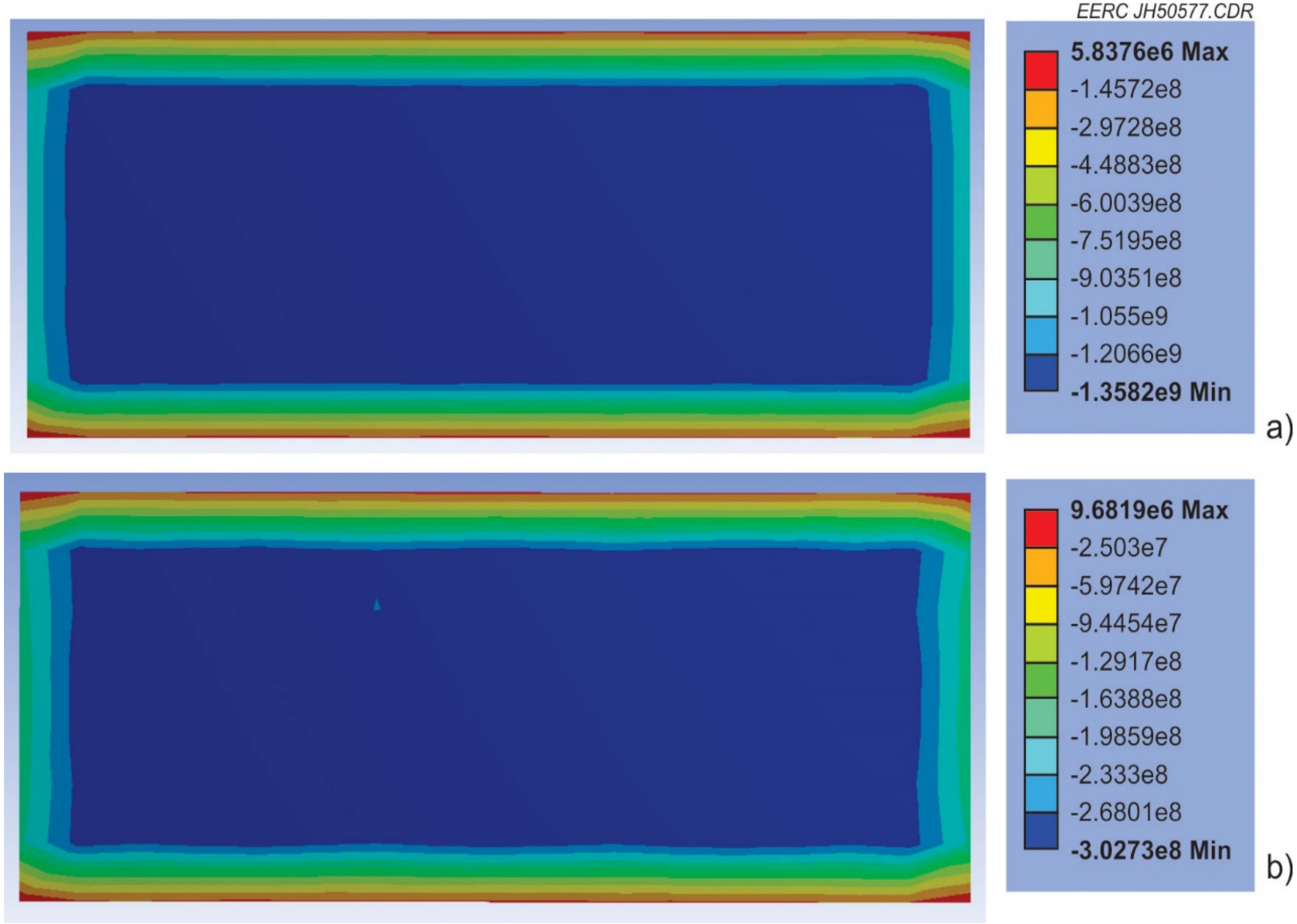
Grooved Backing Plate



Normal Stresses in the Plane for the APMT for CM247LC and Rene 80 at 1200°C



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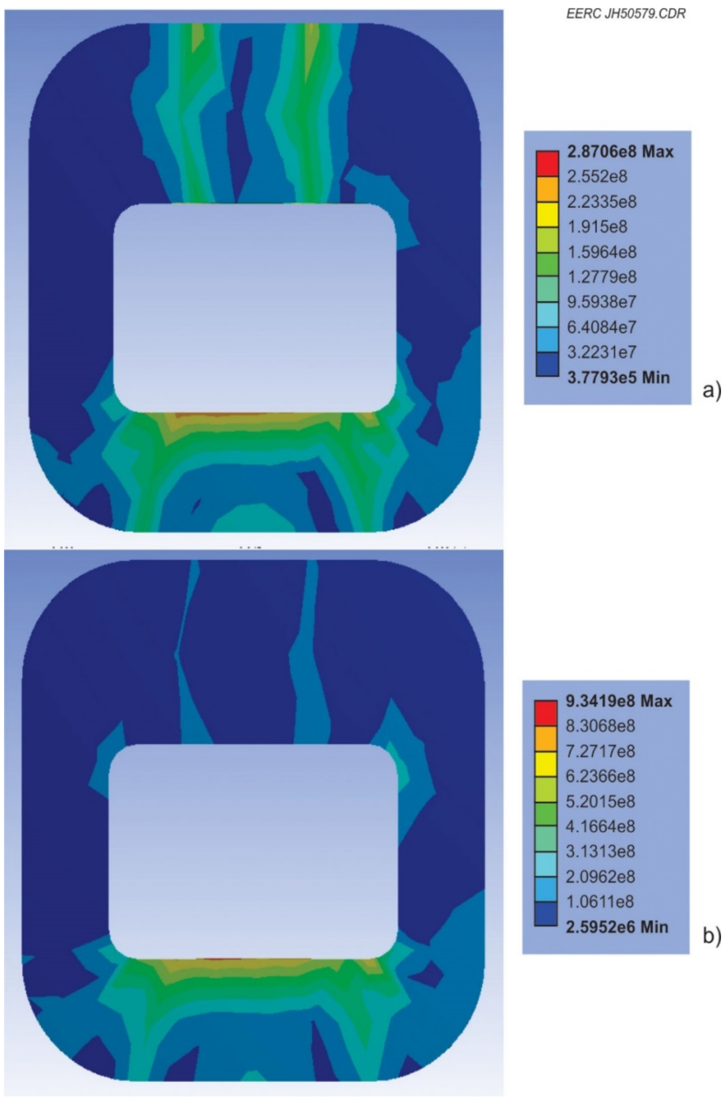
TZM Mo Jig Equivalent Stresses for CM247LC and Rene 80 at 1200°C



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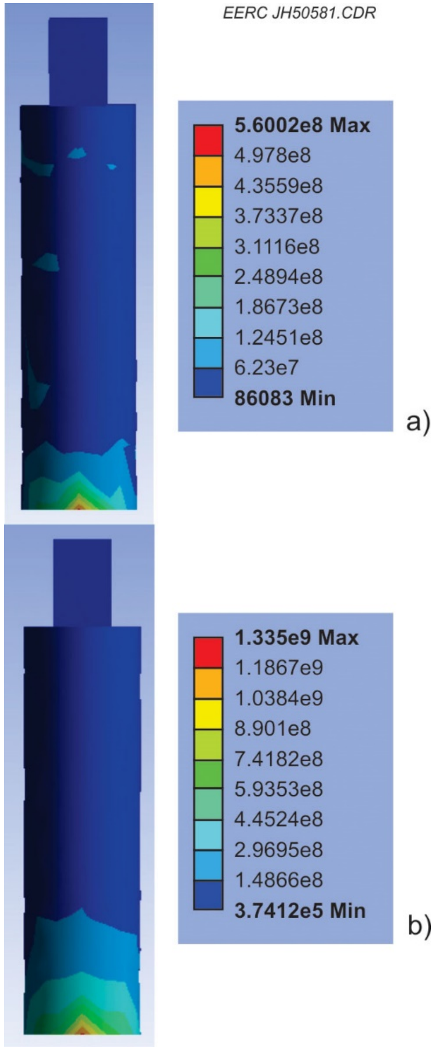
Base Metal–TZM Mo Jig Normal Stresses for CM247LC and Rene 80 at 1200°C



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Assembled Jib in Preparation to Bond the APMT Plate to the Superalloy Block

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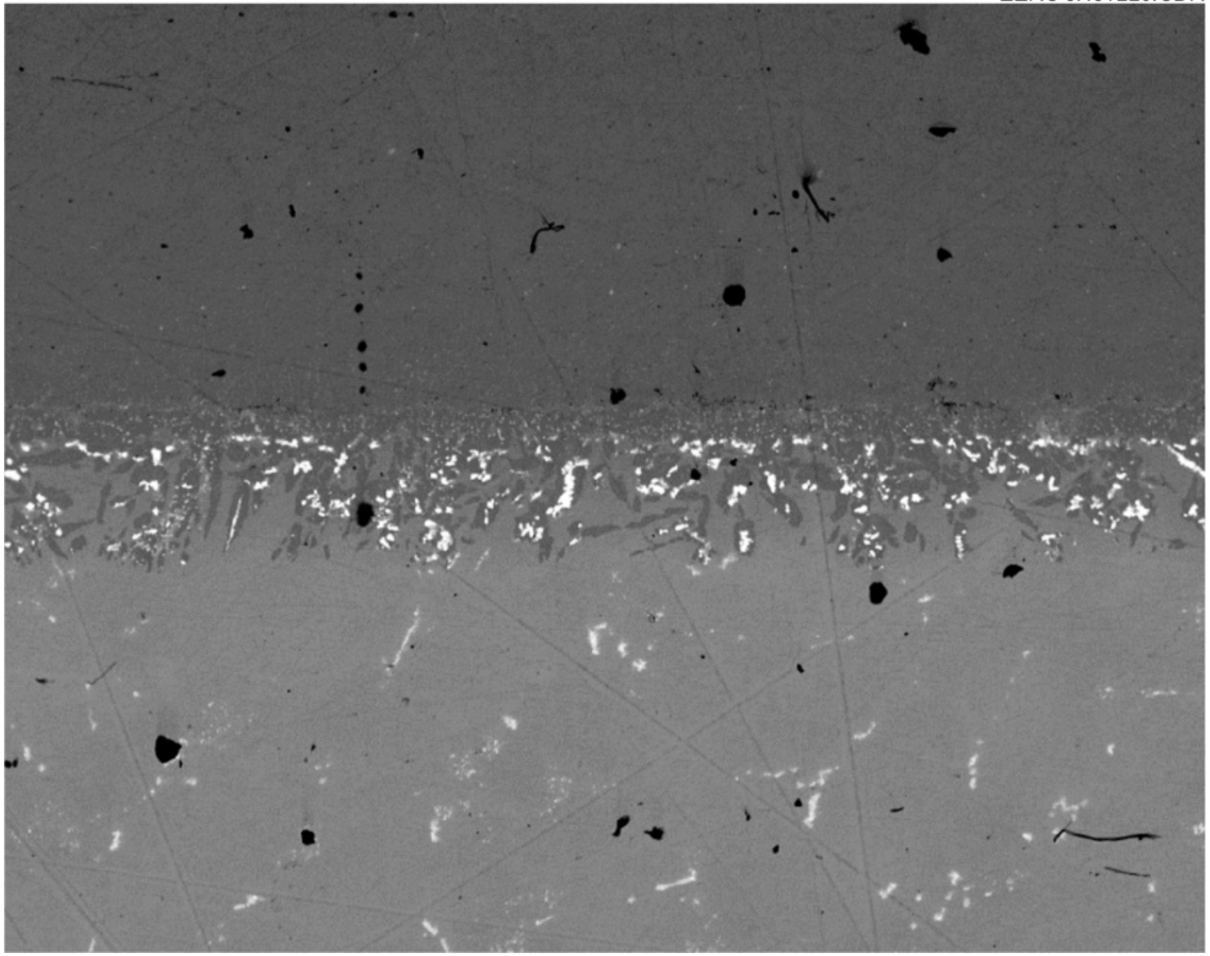
Alloy Compositions

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

Composition of CM247 LC, wt% – Gamma Prime-Strengthened													
	Fe	Ni	Cr	Al	Ti	Co	Mo	Ta	W	Nb	Hf	Mn	Si
CM247LC	–	Balance	8.1	5.6	0.7	9.5	0.5	3.2	9.5	0.1	1.4	–	–

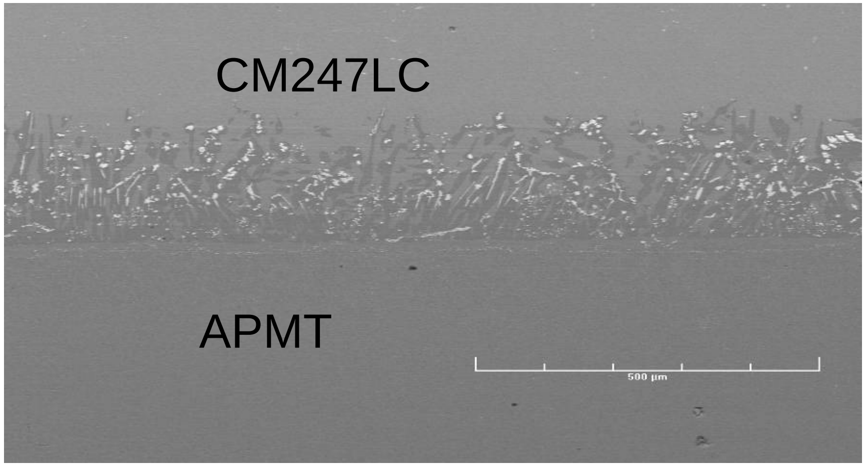
Composition of Rene 80, wt% – Gamma Prime-Strengthened												
	Cr	C	Mo	W	Ti	Nb	Co	Al	B	Fe	Zr	Ni
Rene 80	14.2	0.16	4.0	4.1	5.1	0.03	9.4	3.0	0.02	0.10	0.04	Balance

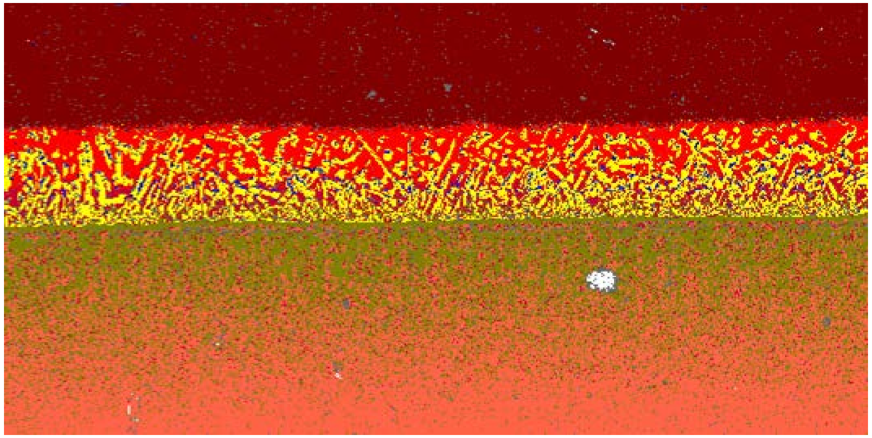
Bond Line Between CM247LC (bottom) and APMT (top) at 100× Magnification



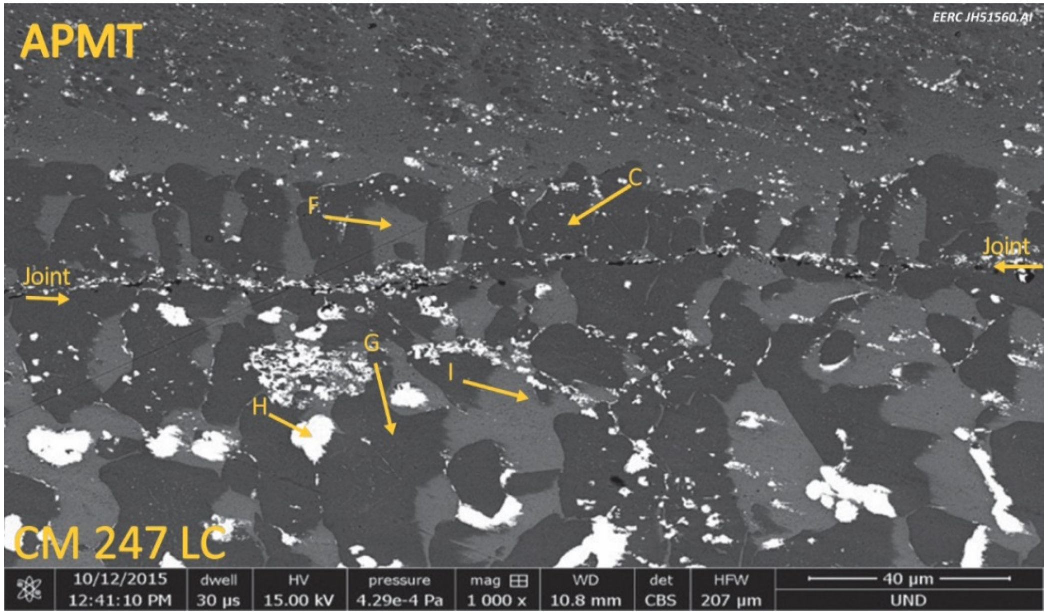
Microstructure of EM Joints

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





Morphologies and Compositions in the APMT and the CM247LC Near the Bond Line at 1000×



	Element, wt%												
	Fe	**Ni**	**Cr**	**O**	**Al**	**Mo**	**Hf**	**Ta**	**Ti**	**Mn**	**Zr**	**Co**	**W**
C: Large, dark gray areas in APMT; from 0 to 30 µm into APMT	18.8	57.8	4.4	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	4.8	0.0
F: Large, light gray regions in APMT; present from 0 to 40 µm	41.2	29.1	13.7	0.0	2.6	1.1	1.0	1.5	0.0	0.0	0.0	5.3	4.5
G: Large, dark gray regions in CM247LC; present from 0 to 225 µm into CM247LC	15.1	58.7	2.8	0.0	12.8	0.0	1.8	3.1	0.4	0.3	0.0	5.0	0.0
H: Large, white regions in CM247LC; present from 40 to 260 µm	14.5	7.0	8.8	0.0	0.9	2.6	3.5	57.0	0.7	0.7	0.0	4.3	0.0
I: Large, light gray regions between precipitates in CM247LC	31.5	34.8	13.5	0.0	3.4	1.5	2.5	3.6	0.9	0.8	0.0	7.5	0.0

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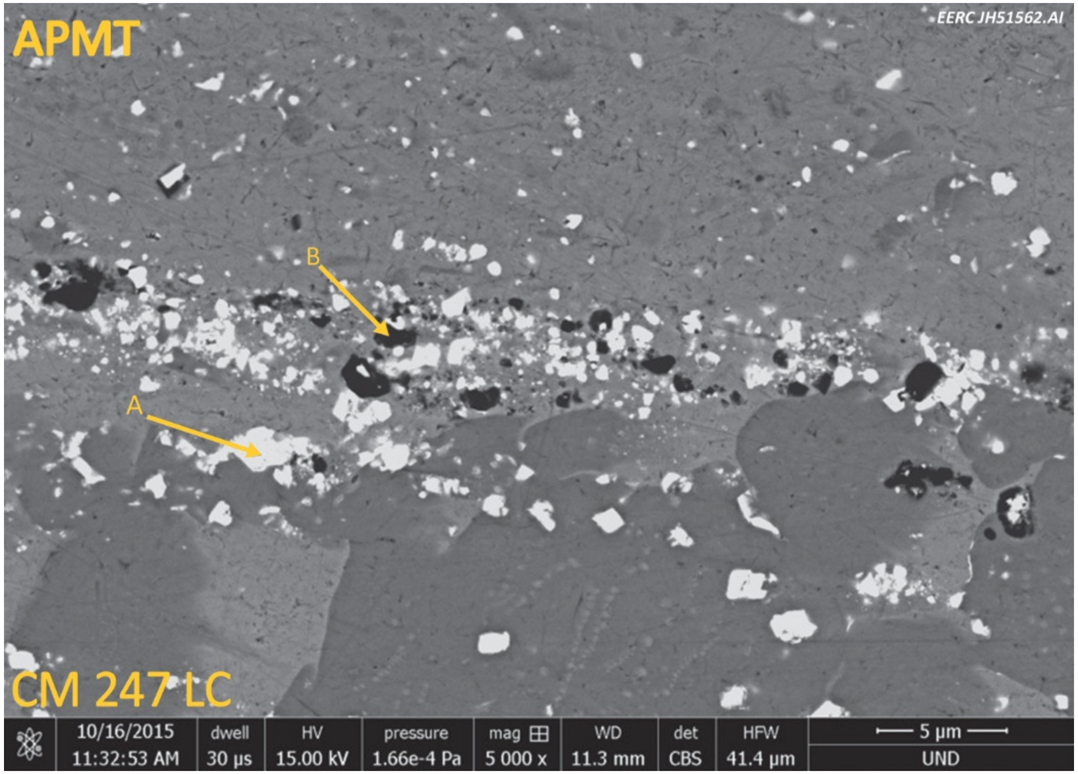
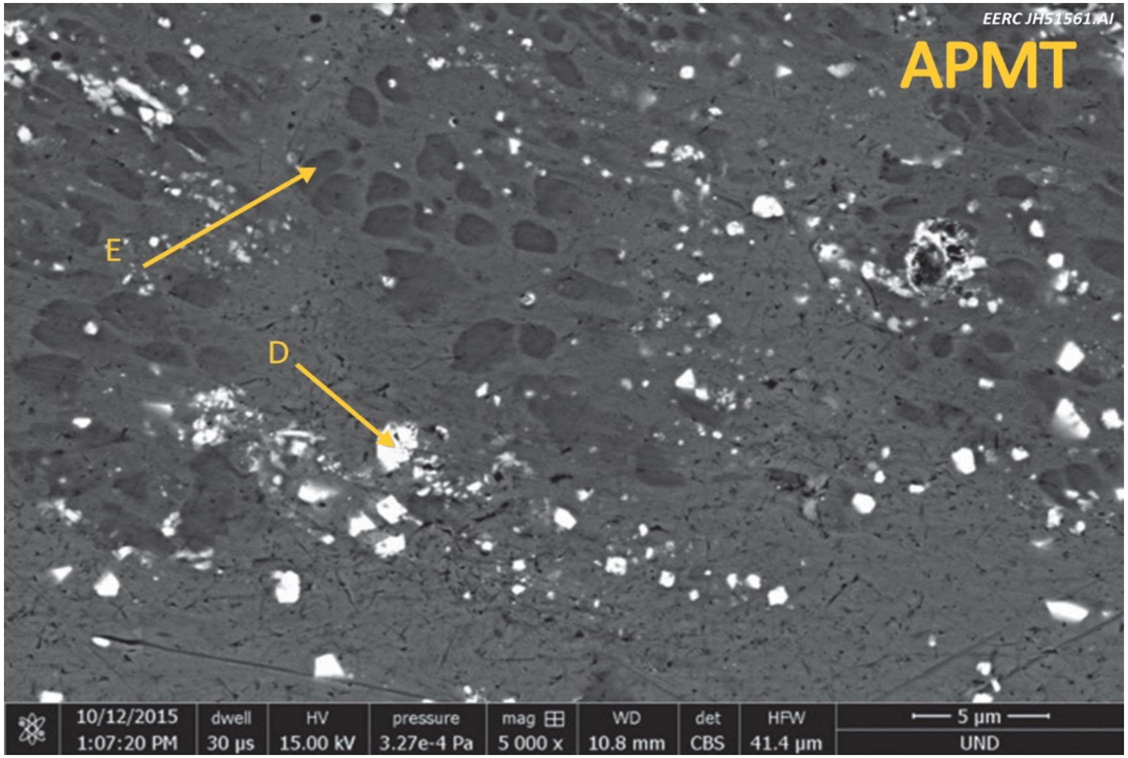
Precipitates at the Bond Line of a CM247LC–APMT Joint at 5000×



	Element, wt%												
	Fe	**Ni**	**Cr**	**O**	**Al**	**Mo**	**Hf**	**Ta**	**Ti**	**Mn**	**Zr**	**Co**	**W**
A: Small white specks found along bond line	7.1	12.8	4.9	0.0	2.7	0.0	27.8	25.0	4.3	0.0	0.0	2.2	13.2
B: Black specks found along bond line	6.6	8.2	2.9	38.8	32.6	0.8	7.2	0.0	1.0	0.0	0.0	1.9	0.0

Precipitates Within the APMT Near a CM247LC–APMT Joint at 5000×



	Element, wt%												
	Fe	**Ni**	**Cr**	**O**	**Al**	**Mo**	**Hf**	**Ta**	**Ti**	**Mn**	**Zr**	**Co**	**W**
D: Small, white precipitates in APMT	8.3	3.3	3.0	0.0	0.6	0.2	23.8	42.8	14.5	0.1	2.7	0.7	0.0
E: Dark gray, small, and circular in APMT; present in APMT past 15 µm	22.7	49.5	6.5	0.0	13.4	0.3	1.0	2.8	0.2	0.2	0.0	3.4	0.0

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Bond Line Between Rene 80 (bottom) and APMT (top) at 100× Magnification

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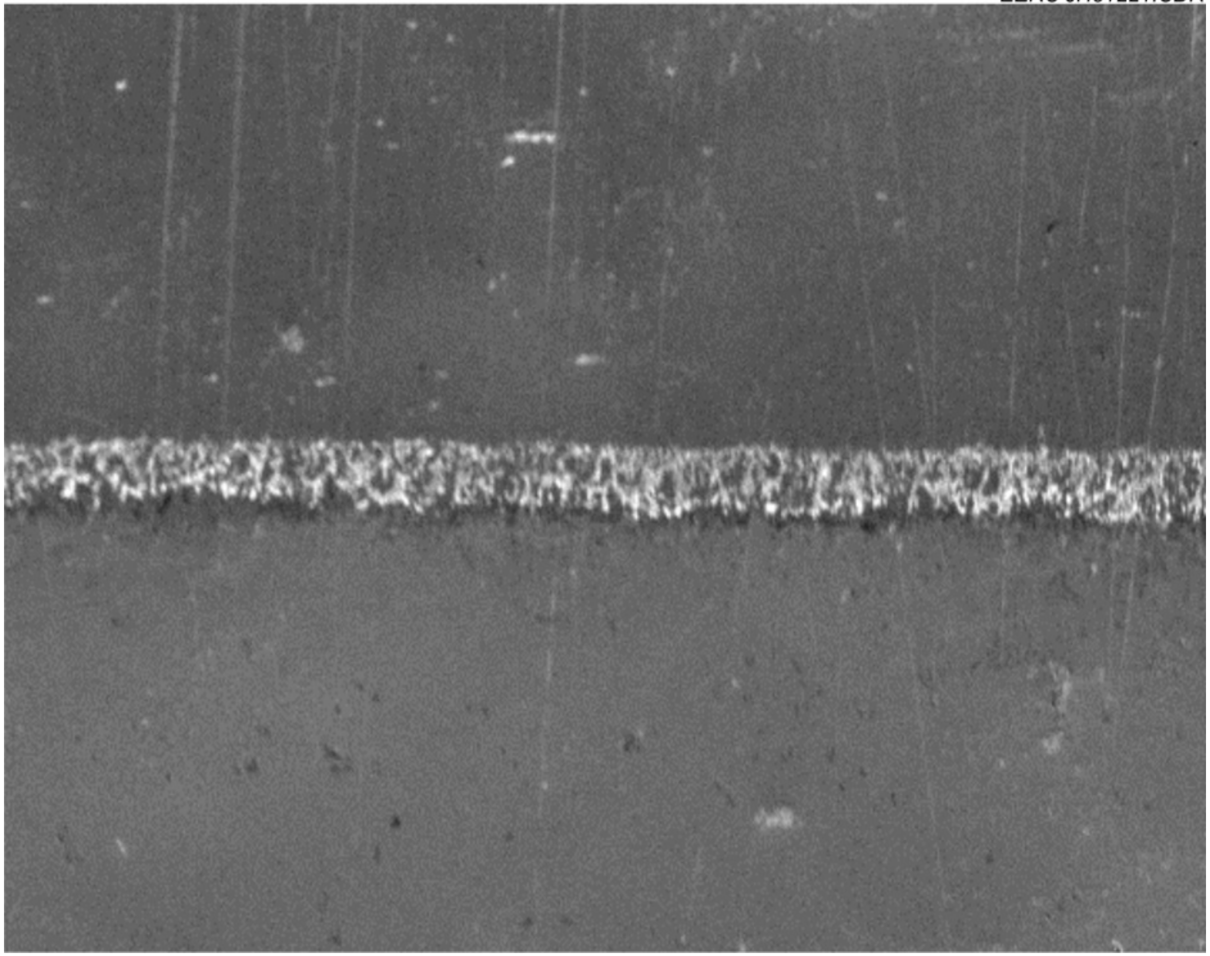
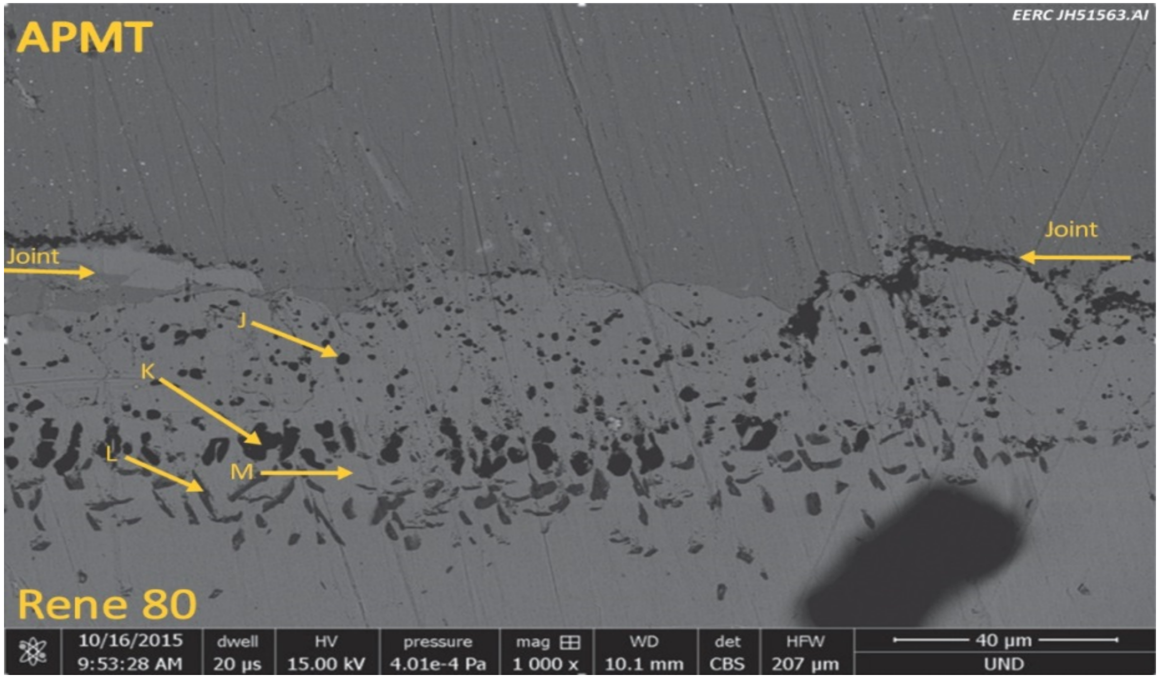
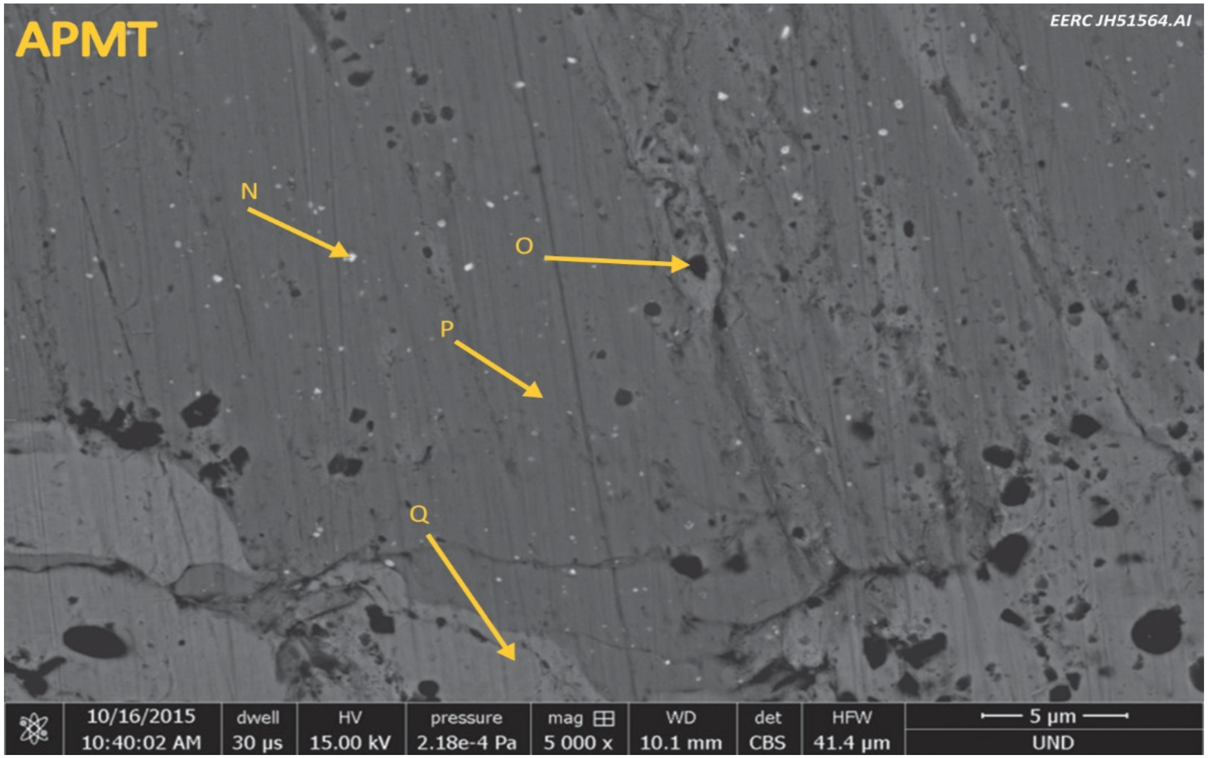


Morphologies Near the Bond Line in an APMT–Rene 80 Joint at 1000×



	Element, wt%												
	Fe	Ni	Cr	O	C	Al	Mo	Ti	Co	W	Zr	Y	Si
J: Black and round precipitates in bond line; diffused up to 30 µm into base metal	2.7	12.3	4.0	37.9	6.1	33.6	0.0	0.8	2.6	0.0	0.0	0.0	0.0
K: Black precipitates in Rene 80; formed approx. 30–45 µm below bond line	0.0	2.0	0.7	47.0	3.1	47.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
L: Light gray, skinny, and long precipitates in Rene 80; formed approx. 45–60 µm below bond line	0.0	2.3	0.0	0.0	4.1	0.0	0.0	93.6	0.0	0.0	0.0	0.0	0.0
M: Gray regions in between other ppt.	3.7	64.0	8.9	0.0	3.8	3.4	3.2	3.4	9.6	0.0	0.0	0.0	0.0

Precipitates in the APMT Near an APMT–Rene 80 Joint at 5000×



	Element, wt%												
	Fe	**Ni**	**Cr**	**O**	**C**	**Al**	**Mo**	**Ti**	**Co**	**W**	**Zr**	**Y**	**Si**
N: White specks in APMT	50.7	3.6	11.4	0.8	13.0	2.5	0.0	2.0	0.0	0.0	7.7	0.0	8.3
O: Black specks in APMT; from 0 to 30 µm	44.4	2.7	10.6	15.0	5.7	12.6	1.3	0.0	0.0	0.0	0.0	7.7	0.0
P: Gray region in APMT	68.3	3.8	15.5	0.0	5.2	4.4	2.8	0.0	0.0	0.0	0.0	0.0	0.0
Q: Gray region	69.7	4.8	15.3	0.5	3.0	3.9	2.6	0.0	0.0	0.0	0.0	0.0	0.2

EM Bonding Initial Observations

- One bond for each superalloy was weak, likely due to oxidation during a month long period between sandblasting and bonding.
- Previous tests with CM247LC show bond is stronger than the APMT.
- The procedure allows all of the zinc to diffuse out down to the detection limit (0.1%) and evaporate from the surface.
- Most zinc diffusion occurs through the APMT.
- There is significant interdiffusion between the alloys, especially iron, nickel, tantalum, and hafnium, more with CM247LC than with Rene80.
- The interdiffusion causes precipitation of different phases near the bond line.

Future Work

- Siemens Energy will perform precipitation hardening procedure on bonded superalloys.
- TBC will be applied to the APMT layer on a portion of the samples.
- They will then perform their standard oxidation, spallation resistance, and hot corrosion tests on the samples and compare to previous results for unbonded samples.
- EERC will perform hardness tests and SEM analyses on nonhardened and hardened crosssections.
- EERC will perform SEM analyses on oxidized and corroded samples. Will aluminum cross from the superalloy (source) to the APMT (sink)?

Acknowledgments

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