Materials For Industrial Heat Recovery Systems

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Materials For Industrial Heat Recovery Systems

Goal: Utilize improvements in materials to increase energy efficiency and process reliability in the Aluminum and Forest Products industries.

Challenges: Current designs and materials used in recuperators on melting furnaces in the Aluminum Industry do not permit operation for the required period of time. The Forest Products Industry would like to increase the capacity and operating pressures of recovery boilers. In both cases the industries are dealing with problems associated with severe tube distortions, material overheating, and localized corrosion.

Materials For Industrial Heat Recovery Systems

Benefits: For the Aluminum Industry waste heat recovery could save 3.6 trillion Btu/year; for the Forest Products Industry an improvement of overall recovery boiler efficiency could save 7 trillion Btu/year

Potential End-User Applications: In the Aluminum Industry fuel usage would be reduced and in the Forest Products Industry more low cost electricity would be generated on new boilers and more pulp produced at mills with retro-fit boilers

FY06 Activities: Complete characterization of recuperator and recovery boiler materials, design and construct corrosion probe, continue laboratory and field testing

Industrial Project Partners

	Recuperators	Superheaters	Mid-Furnace	Primary Air Ports
AB Sandvik	X	X	X	X
Andritz OY		X	X	X
Babcock & Wilcox		X	X	X
Domtar		X		X
E3M	X			
Eclipse	X			
Georgia-Pacific		X		X
Kvaerner Power		X	X	X
Logan Aluminum	X			
MeadWestvaco		X		X
Welding Services	X	X	X	X
Weyerhaeuser	X	X	X	X

Research Project Partners

	Recuperators	Superheaters	Mid-Furnace	Primary Air Ports
E3M	X			
IPST @ Ga Tech			X	X
ORNL	X	X	X	X
Paprican		X		X
PSL		X	X	X
Secat	X			
Weyerhaeuser		X	X	X

Materials For Industrial Heat Recovery Systems

Barriers	Pathways	Critical Metrics
Aluminum Industry		
For **recuperators**, maintenance costs are greater than energy savings	Identify better materials, improved designs and SOPs	Install recuperators on all new furnaces for savings of 3 trillion Btu/yr
Pulp and Paper Industry		
For **superheaters**, conditions associated with increased capacity and pressure exceed limits of current materials	Identify better materials, improved designs and SOPs	Use better materials to improve new recovery boiler efficiency by 1.5% and increase capacity of existing boilers by 20% for total savings of 7 trillion Btu/yr
For **mid-furnace** corrosion, don't understand how conditions impact local environments	Develop validated CFD model to predict operating temperatures and compositions at wall	
For **primary air port** tube cracking, don't know what parameters influence failures	Identify cause of cracking and crack-resistant materials	

Materials For Industrial Heat Recovery Systems

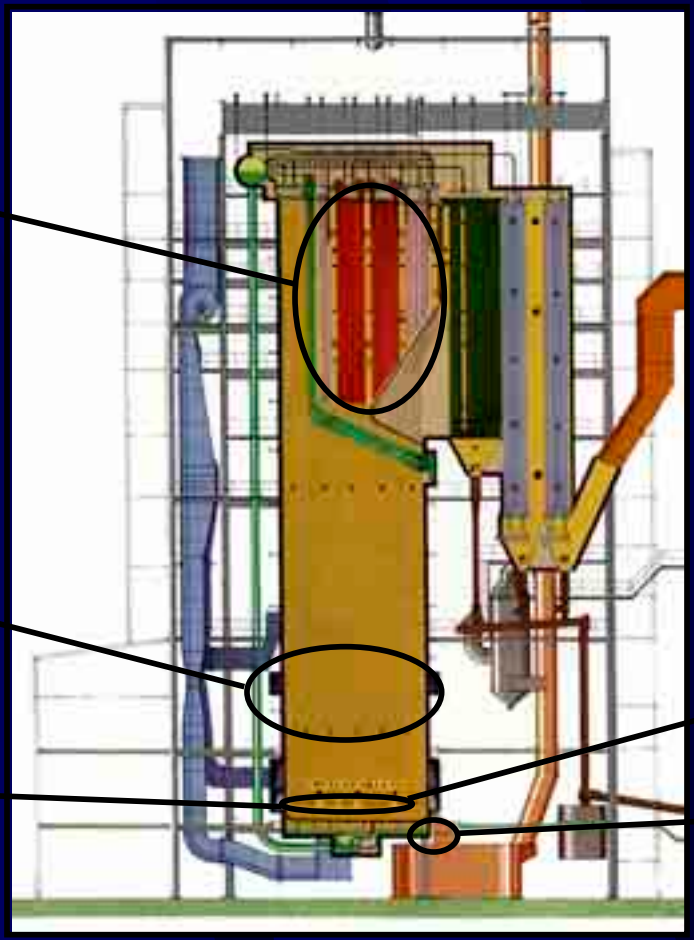
Number	Milestone	Target Date	Percent completed
1	Complete final report on primary air port cracks	6/30/05	85%
2	Complete characterization of materials	9/30/06	40%
3	Complete modeling studies	3/31/07	20%
4	Complete laboratory testing	3/31/07	0%
5	Complete field testing	9/30/07	0%
6	Complete final reports on recuperators, mid-furnace corrosion and superheaters	12/31/07	0%

Three Of The Project Tasks Address Paper Mill Recovery Boiler Issues; One Concerns Primary Air Port Tube Cracking

Superheaters

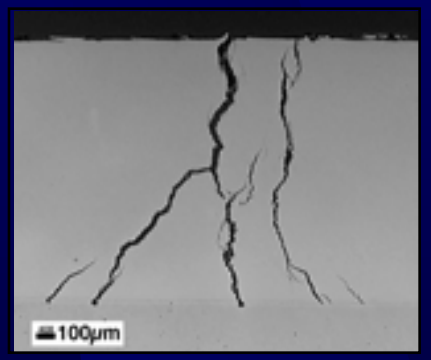
Mid-furnace

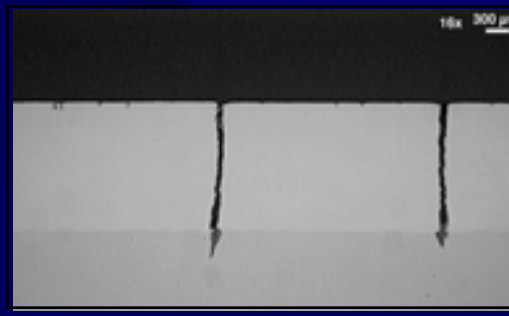
Primary air ports

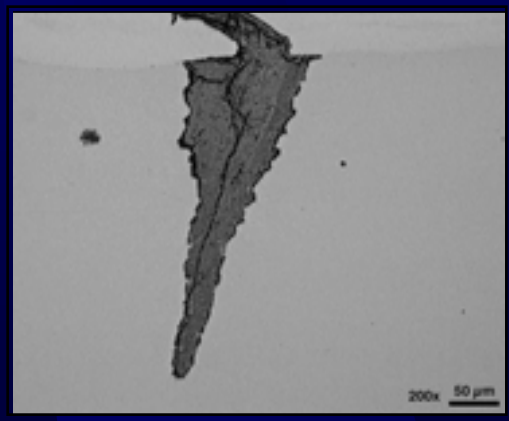


Smelt spouts

Cracks In Co-Extruded Primary Air Port Tubes Have A Potential To Rupture And Lead To A Boiler Explosion

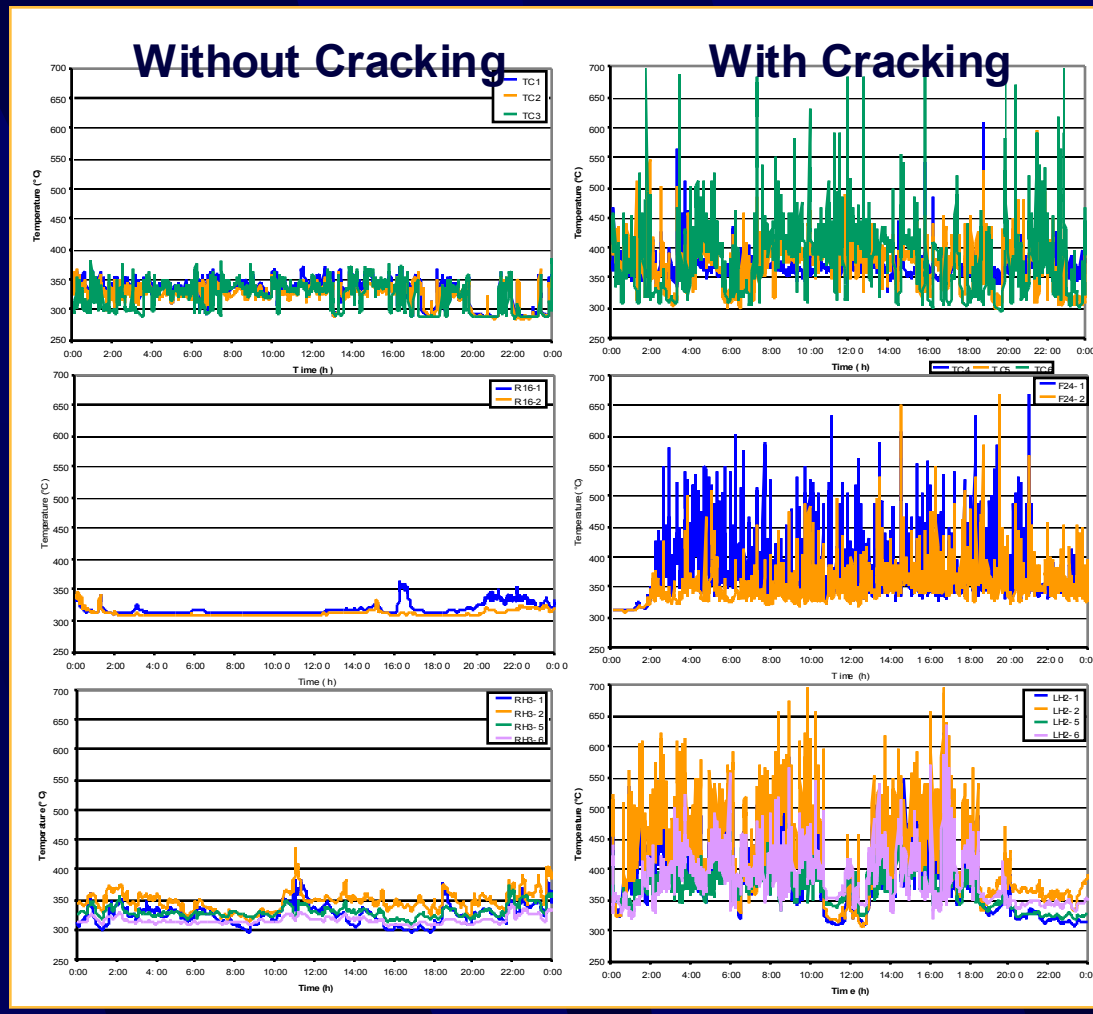






Cross-sections show that some cracks advance through the stainless steel cladding and into the carbon steel

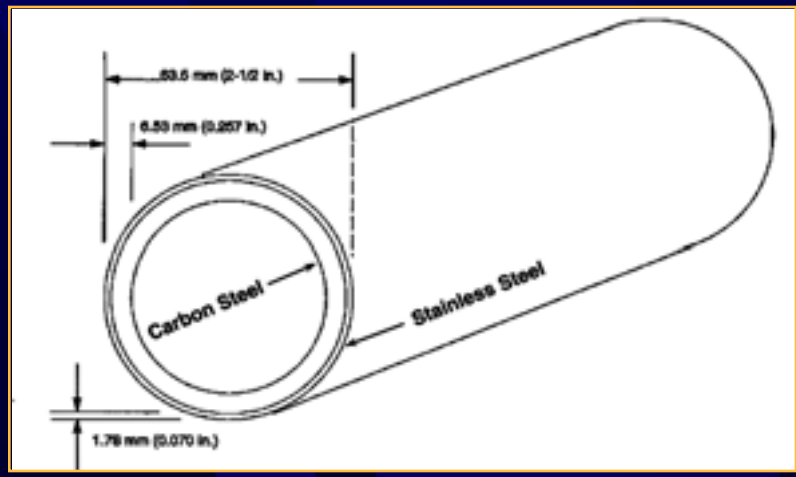
Measurements Have Shown An Association Between Temperature Variations And Cracking



Thermocouples mounted on the tubes forming primary air ports provide valuable information on the likelihood of tube cracking

One Approach To Prevent Cracking Is To Use An Alternate, More Crack-Resistant Material For Tube Cladding

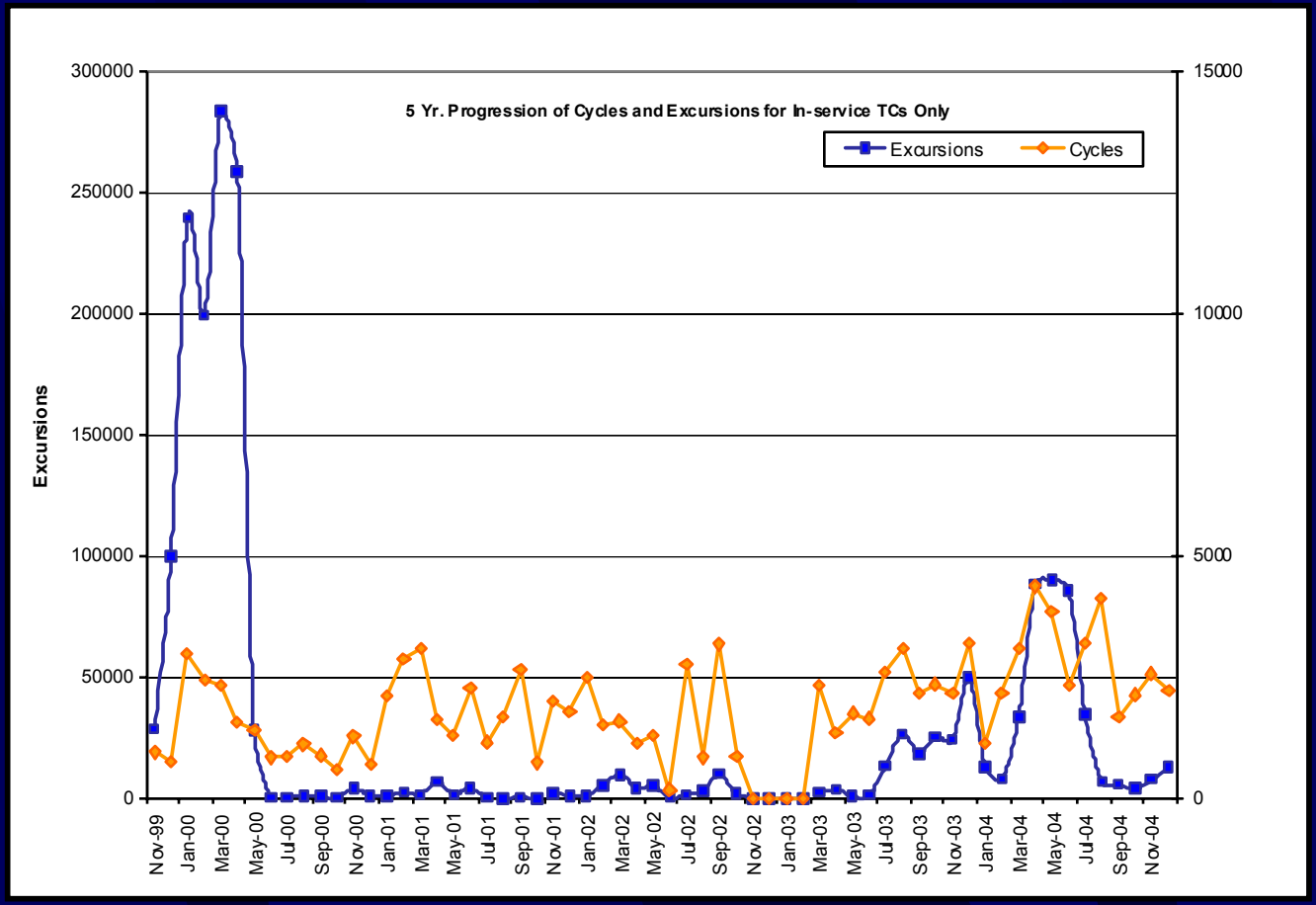
- Studies have considered the current material and three alternates
  - Co-extruded 304L stainless steel/SA210 carbon steel (current)
  - Co-extruded modified alloy 825/SA210 carbon steel
  - Co-extruded alloy 625/SA210 CS
  - Weld overlaid alloy 625 on CS



Studies Have Also Been Directed Toward Finding The Cause Of The Temperature Fluctuations

- A camera was designed and built to permit viewing the fireside surface of air port tubes during boiler operation
- Field tests were conducted to determine the role of bed height, liquor spray pattern, liquor temperature, etc. on temperature fluctuations
- CFD modeling was used to predict temperatures, gas velocities, liquor trajectories, etc. for various operating conditions
- Studies also addressed the effects of temperature fluctuations on the microstructure and the residual stresses in the tubes and the role of these stresses on crack propagation

Long-Term Studies In A Boiler With Severe Cracking Showed Certain Operational Changes Significantly Reduced Temperature Fluctuations

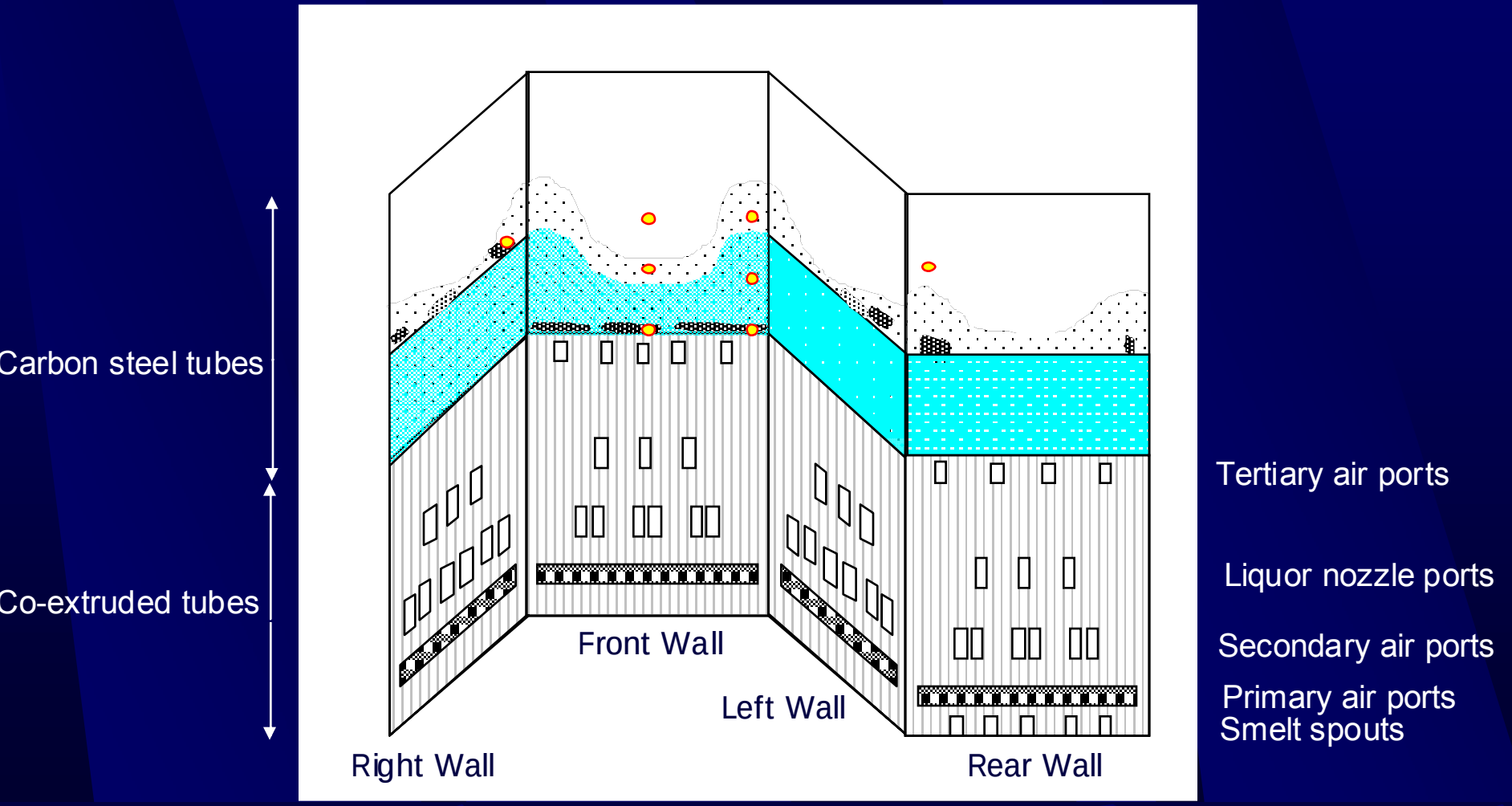


Plot showing the cumulative totals of cycles and excursions for six thermocouples in continuous service in a recovery boiler that has experienced extensive primary air port tube cracking. In April 2000, the liquor temperature, the liquor gun type and the air distribution patterns were changed.

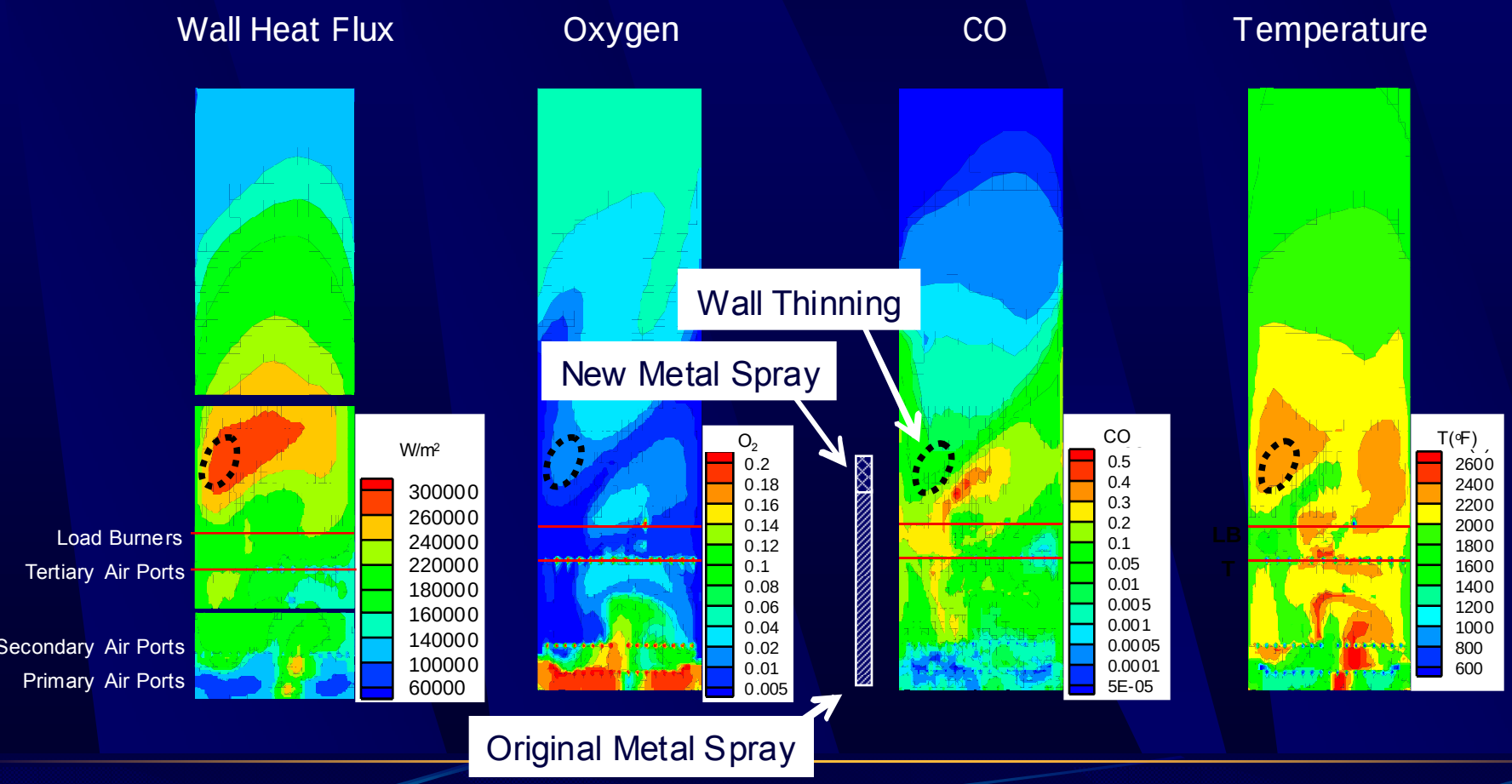
Conclusions From Primary Air Port Studies

- The relationship of severe temperature fluctuations with cracking of primary air port tubes has been well documented
- A combination of thermocouple measurements, in-bed camera observations, and process modification trials shows that a combination of parameters control generation of temperature fluctuations
- Critical parameters for minimizing fluctuations include maintaining sufficient primary air jet momentum to keep the bed away from the walls, switching from wedge to splashplate nozzles to minimize spraying on the walls, and modifying black liquor properties to promote burning in suspension
- Cycling a 304L composite tube to 600°C can change the stress state in the carbon steel so that stresses at the interface are tensile allowing cracks to advance into the carbon steel
- With a cycle to 600°C, the stresses in an alloy 825 composite tube remain compressive thus preventing crack advance into the carbon steel

Mid-Furnace Corrosion Typically Occurs In The Tubes Just Above The Transition From Co-extruded Tubes To Carbon Steel Tubes



CFD Model Is Predicting Conditions In Recovery Boilers Experiencing Mid-Furnace Corrosion



Current Activities Around Mid-Furnace Corrosion

- CFD modeling appears to be capable of predicting locations where mid-furnace corrosion will occur
- Process Simulations Limited is improving the CFD model to predict near wall conditions
- IPST/Ga Tech is completing field measurements of gas compositions and temperatures in a recovery boiler in a southeastern U.S. mill
- Plans call for validating the CFD model

For The Other Tasks, Work On Characterization Of Materials And Environments Is Underway

Degraded aluminum furnace recuperator tubes after 6+ months exposure

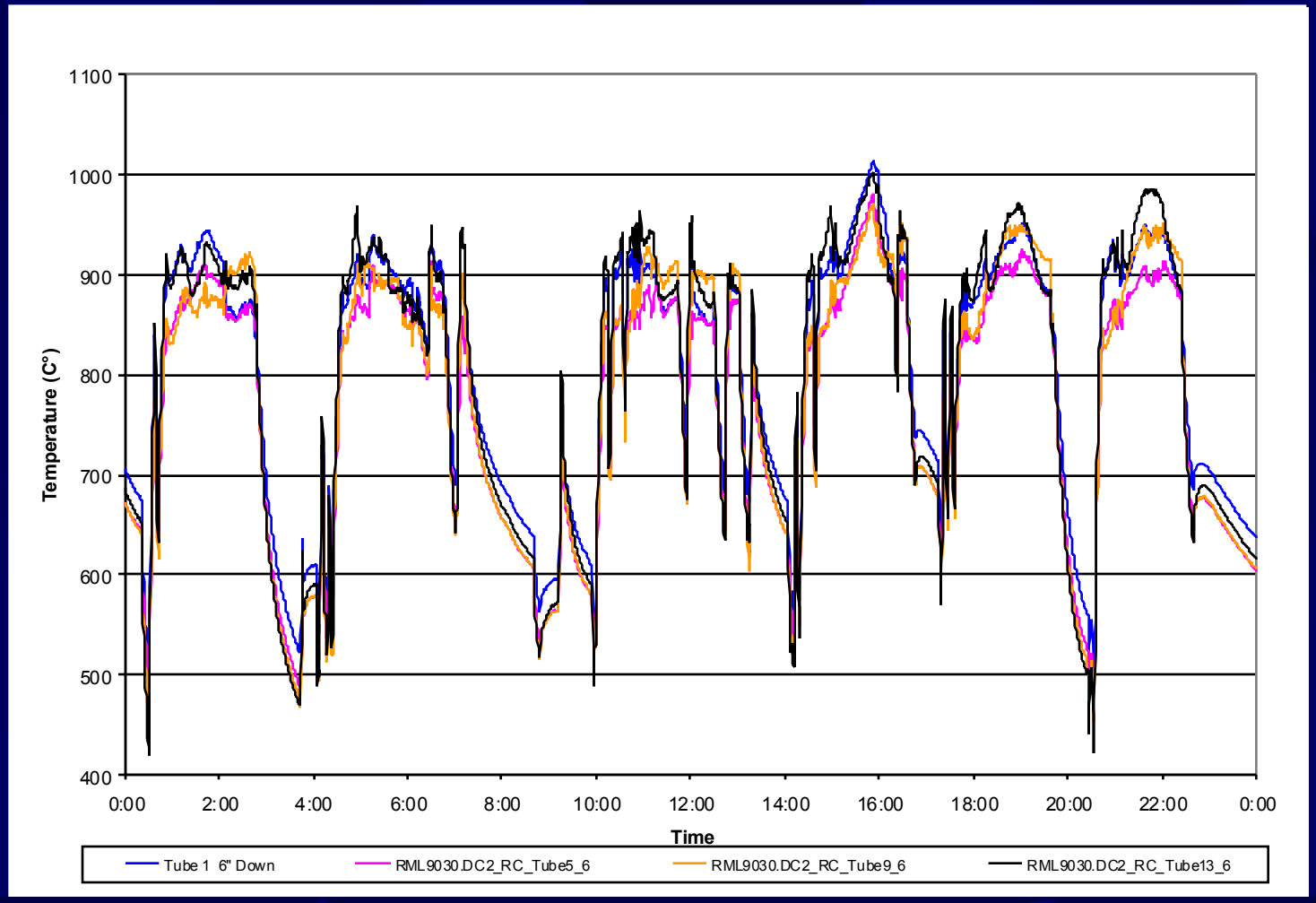
The leading tubes experienced warping, thinning and cracking, and refractory protecting the headers was lost

Examination of degraded tubes and refractory is underway

In Addition To Examination Of Degraded Recuperator Tubes, Characterization Of The Environment Is Underway

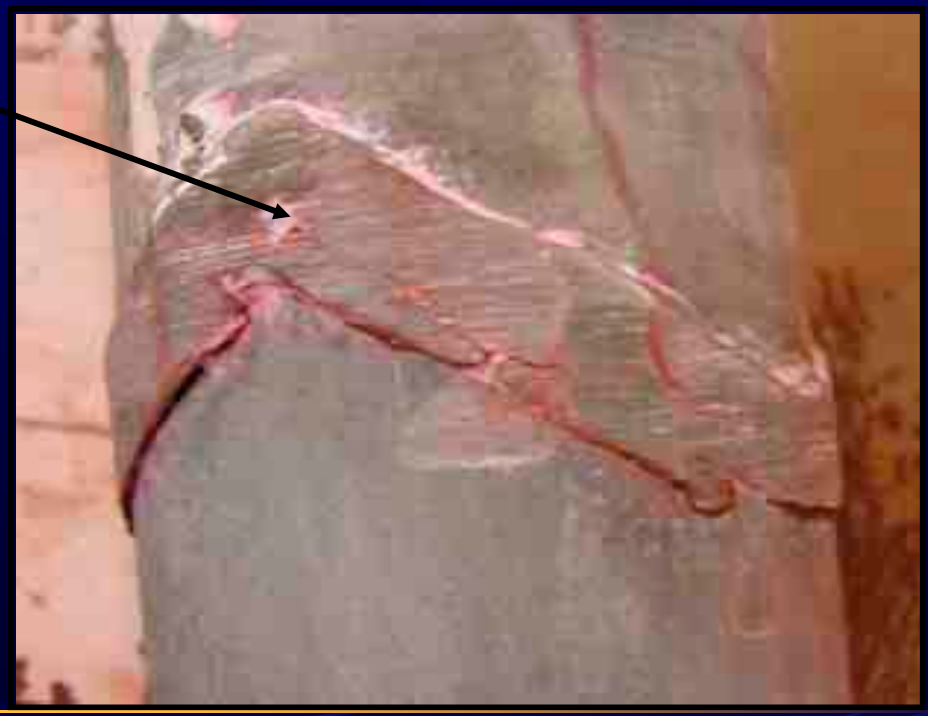
Sixteen specially fabricated thermocouples were installed on uncooled tubes hanging in front of the recuperator tubes in order to measure gas temperatures

Temperature Measurements On Recuperator Tubes Show Cyclic Pattern That Could Accelerate Degradation

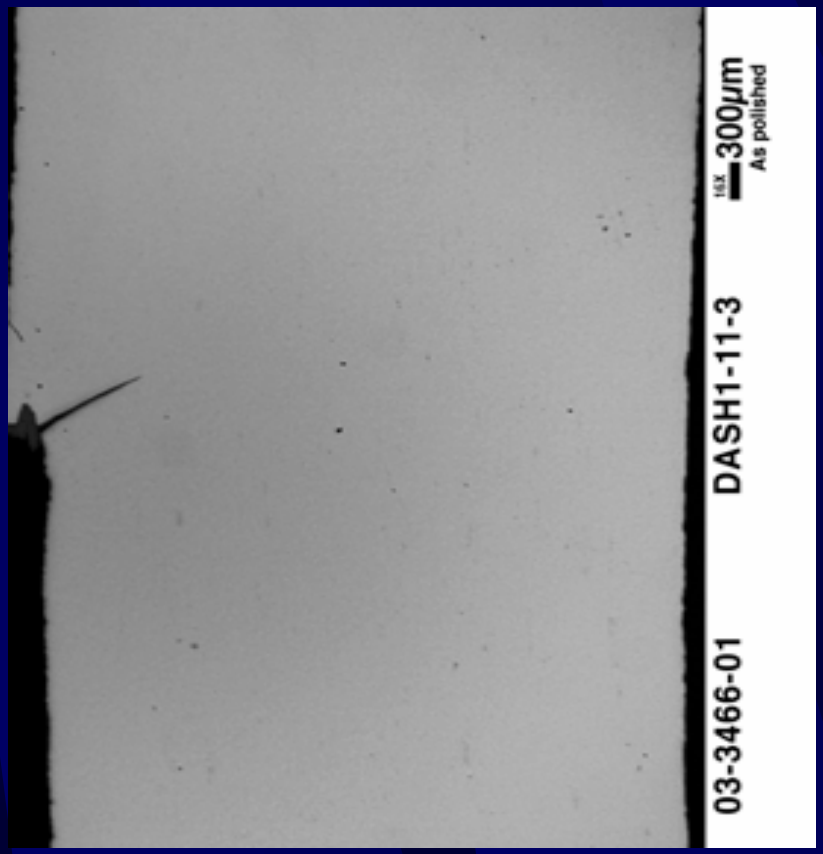


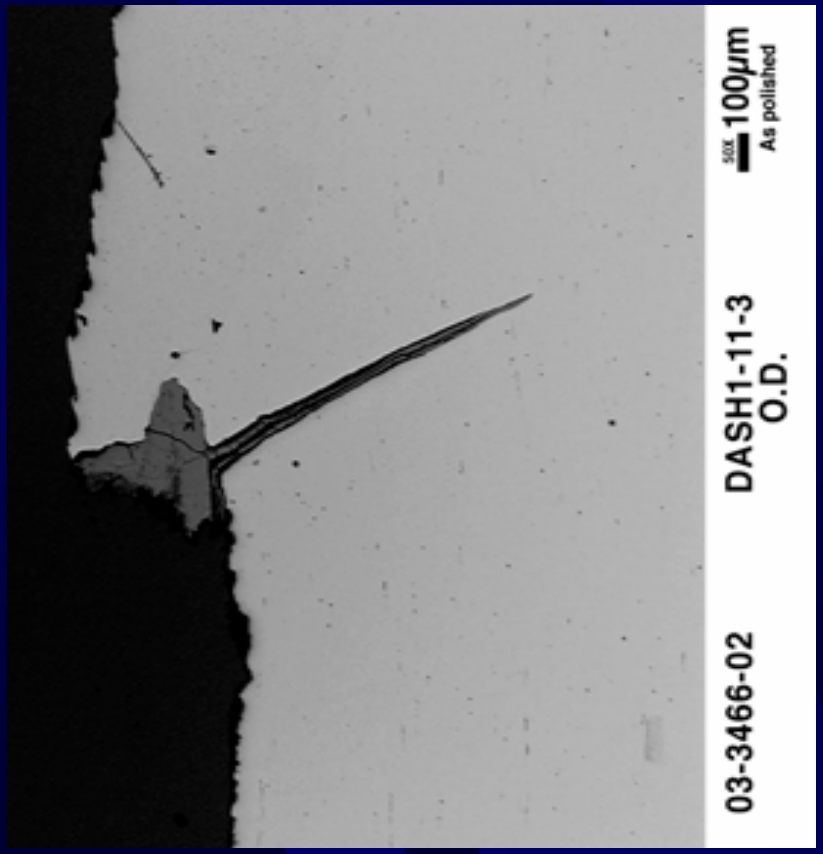
One Mill With A Superheater Tube Cracking Problem Provided Tubes For Examination

Most of the framework supporting the tubes was removed from the tubes to permit dye penetrant inspection and subsequent metallographic examination



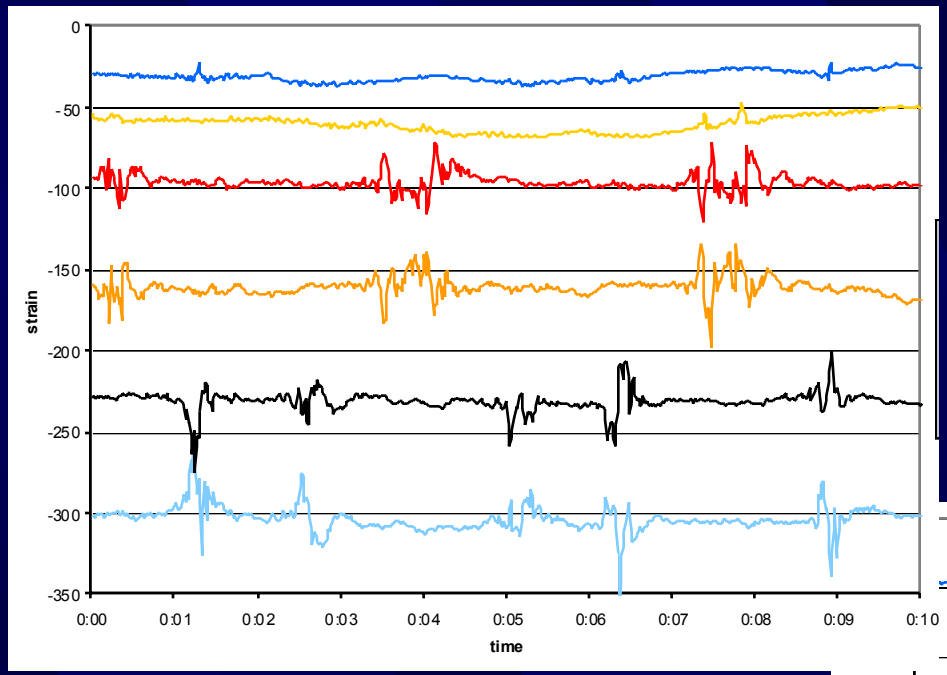
On Four Tubes A Crack Was Found Just Below The Support Structure Weld



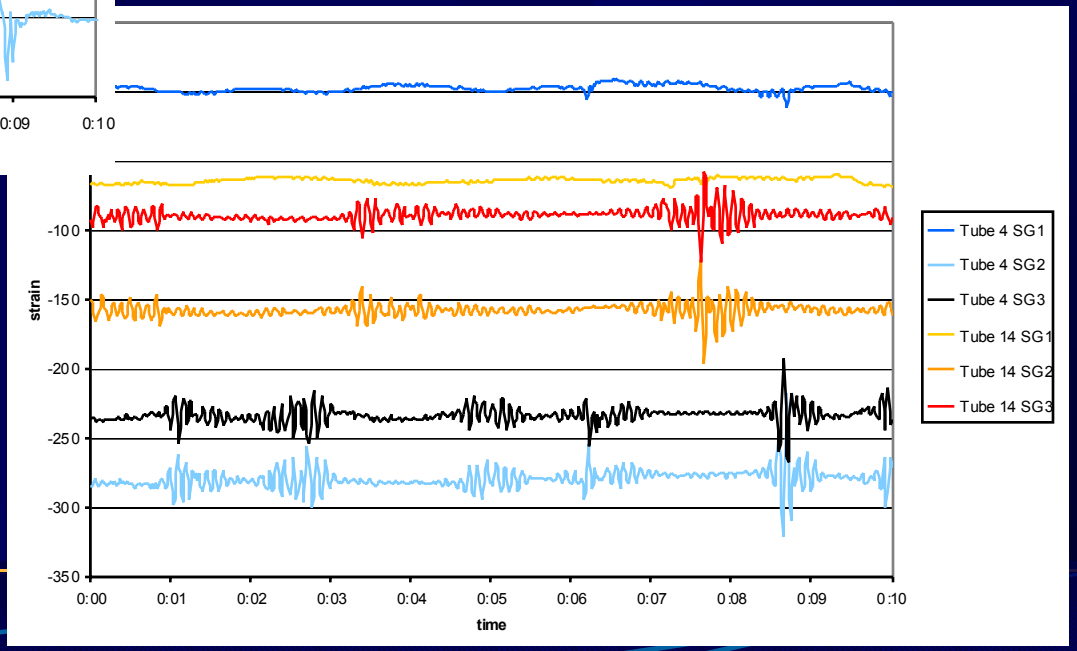


Example of a crack that had advanced through about 20% of the superheater tube wall

Strain Gauges Were Mounted On Two Superheater Tubes To Characterize The Swinging Motion

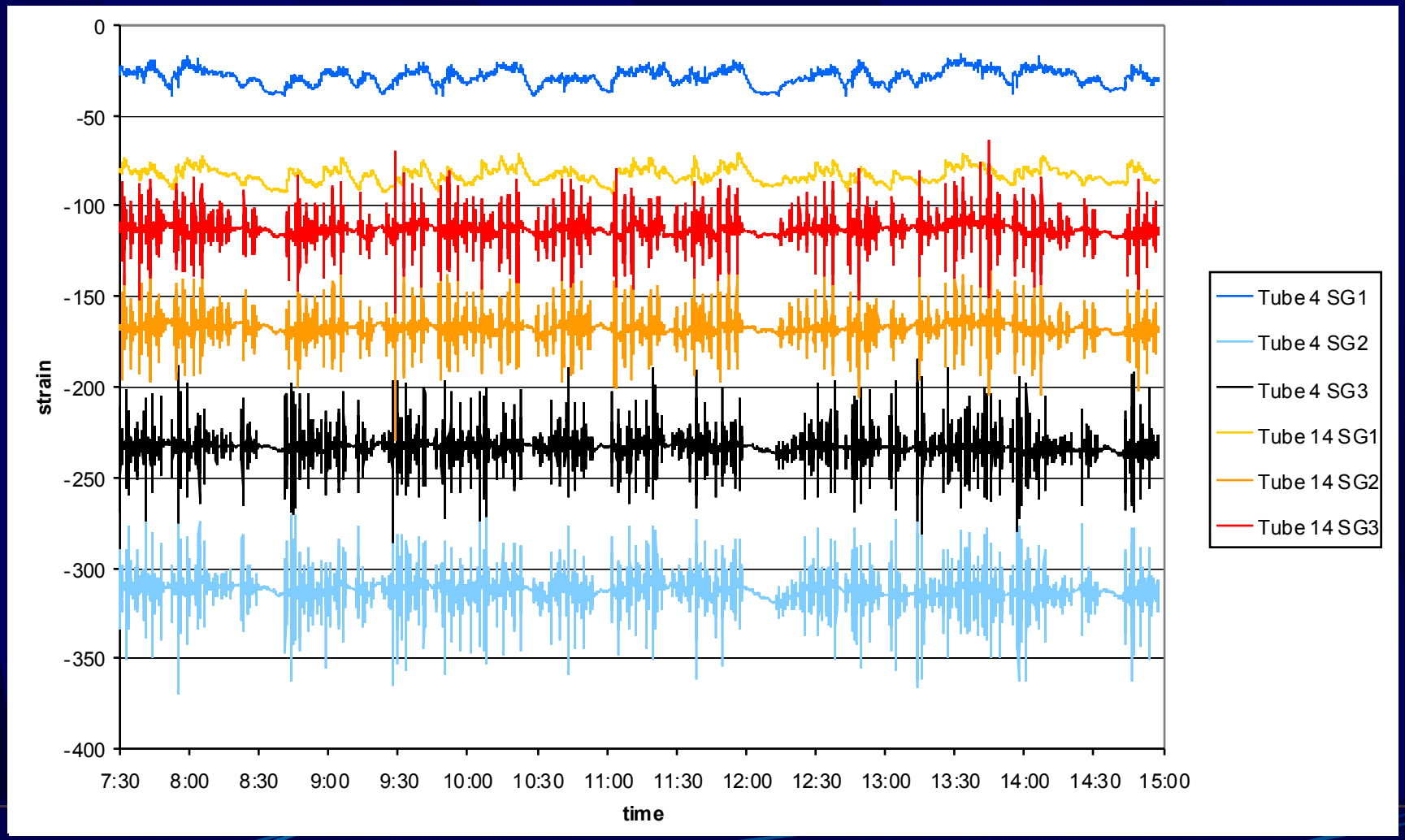


Strain gauges



Short-term data show tubes/platens experience a predominately side to side swinging, and strains are not sufficient to cause failure by a mechanical fatigue mechanism

Longer Term Data Show Tube/Platen Motion Corresponds To Sootblower Operations



Future Plans

- For the aluminum furnace recuperator task, more extensive characterization of the tube environment is planned and the flow of flue gas will be modeled
- For the recovery boiler primary air port task, the summary report will be completed and issued
- For the superheater tube studies, vendors will be visited to document material selection and experience, a corrosion probe will be designed and constructed, CFD modeling will be continued, mill inspection visits will be continued, and laboratory testing will be initiated. Collaboration with the SOTU project in Finland will be pursued.
- For the mid-furnace corrosion task, mill inspection visits will continue, gas analyses will be conducted on an additional boiler, CFD modeling will continue and laboratory testing will be initiated
- Quarterly reports will be provided, review meetings will be held, and presentations made for association conferences and industry groups

Commercialization Plans, Pathways And Risks

- For prevention of primary air port tube cracking, alternate materials have been identified and operational changes recommended. These have been communicated through presentations, publications and direct conversations and have been implemented by many mills.
- For aluminum furnace recuperators, once the environment has been well defined, alternate materials will be suggested, and, hopefully, installed in a recuperator.
- For recovery boiler superheater tubes, considerable effort is needed to define the environment and the influence of boiler operating conditions. Once the environment is better characterized, alternate materials will be identified for testing in a boiler.
- For mid-furnace corrosion, a better understanding is needed of the effect of operating conditions on the environment of mid-furnace tubes. This will enable identification of alternate materials or changes in operating conditions to avoid developing a corrosive environment.
- For the latter three tasks, commercialization will depend on successful characterization of the environment and effect of operating conditions.

Conclusions

- Although the mechanism of primary air port tube cracking is not completely defined, alternate materials and changes in operating parameters have been identified that should prevent or, at least, minimize cracking
- Studies of recuperator tube degradation have been initiated, but considerably more information on the tube environment is needed
- Superheater tube studies have been initiated, but the large variety of superheater designs and materials will require considerable documentation and characterization. Collaboration with the SOTU project in Finland provides an opportunity to leverage our studies
- Mid-furnace corrosion studies at IPST/Ga Tech provide a “running start” for this task, but studies need to be extended to additional mills and more information collected on the performance of alternate materials