TUBACOAT

POWERGEN APPLICATIONS

JUNE 2016

- TUBACOAT concept
- Product characterization
- Powergen applications
  - Steam Reheater & TC
    - Experience CASE 1
  - Flue Gas Condenser
    - Experience CASE 2

- TUBACOAT concept
- Product characterization
- Powergen applications
  - Steam Reheater & TC
    - Experience CASE 1
  - Flue Gas Condenser
    - Experience CASE 2

General outline

ADVANCED COATING SOLUTIONS





Introduction

1. Start-up Company

2. 100% subsidiary of TUBACEX

3. Development and commercialization of tubular solutions based on advanced coatings

TUBACOAT
TUBACEX GROUP

Business model

Supply of ceramic coated steel long products:

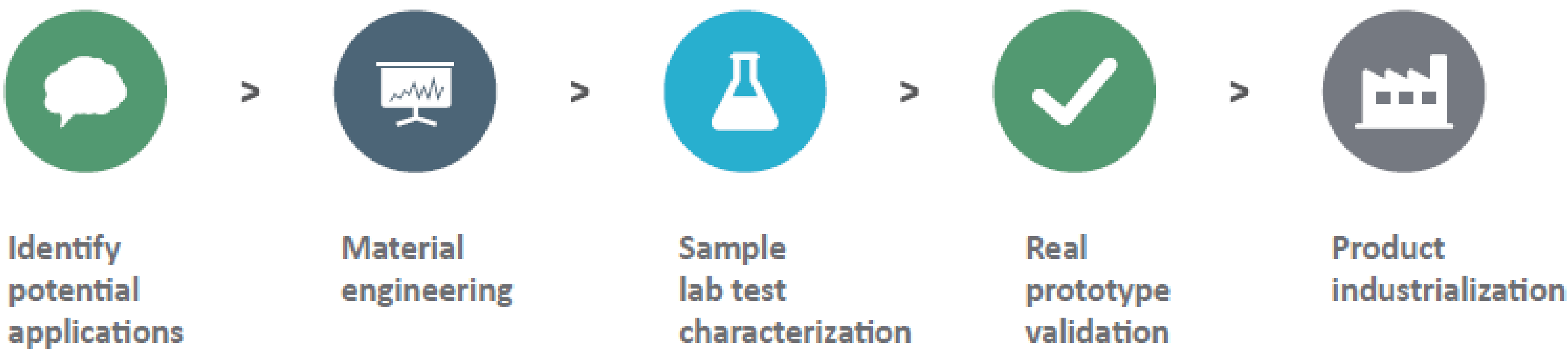
- Austenitic and carbon steel
- Pipes, tubes, profiles…

Product design for special needs:

- Customized special coating solutions

Business model

Tailor made approach



TUBACOAT
TUBACEX GROUP

Product properties

Value-added products with…

- ✓ Outstanding corrosion resistance in different media and thermal conditions
- ✓ High abrasion resistance
- ✓ Anti-adherent and anti-fouling properties
- ✓ Improved mechanical hardness

Potential applications

> Oil & Gas

> Fertilizers

> Chemical & petrochemical

> Industrial processes

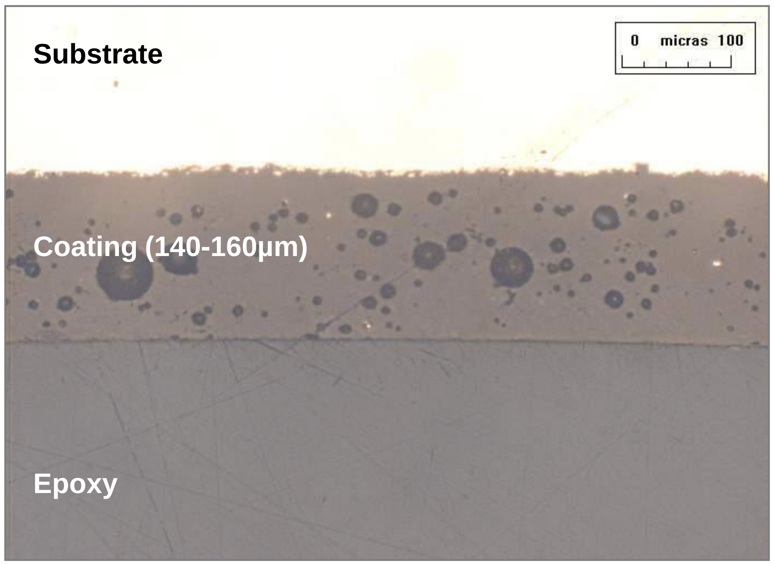
> Powergen

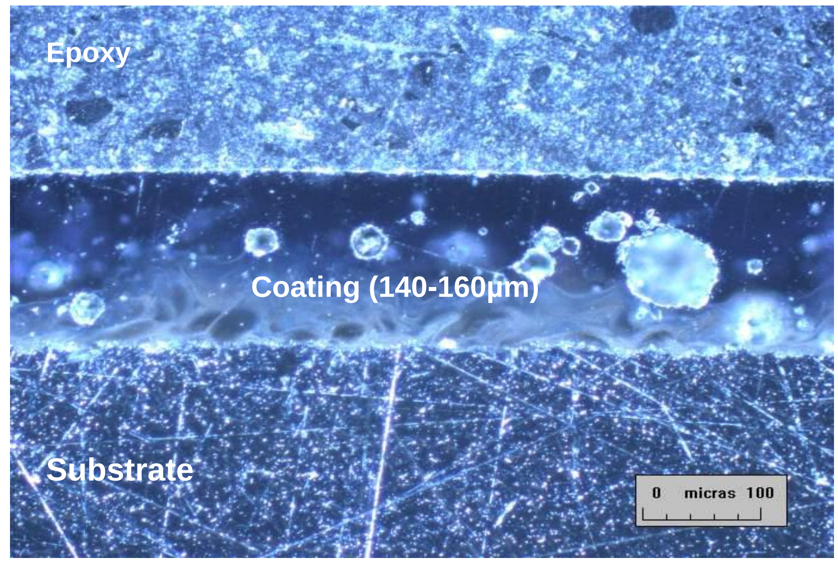
- Furnace chambers
- Pulp & paper boilers
- Biomass and waste boilers
- Waste to energy boilers
- Heat exchangers
- Reactors
- Flue gas condensers
- Nitric acid cooler condensers

- TUBACOAT concept
- Product characterization
- Powergen applications
  - Steam Reheater & TC
    - Experience CASE 1
  - Flue Gas Condenser
    - Experience CASE 2

Morphologycal

Continuous coating layer
Thickness control based on suspension parameters & rheological properties



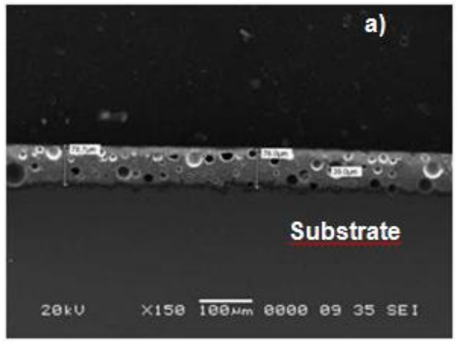


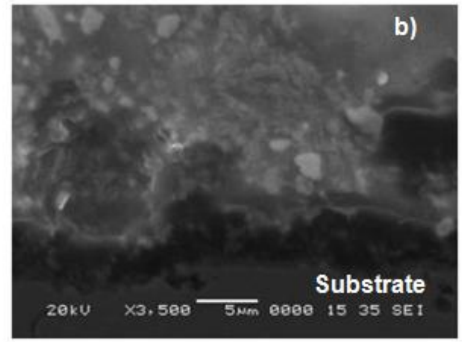
Typical coating thickness range: 100-200 µm

Morphologycal

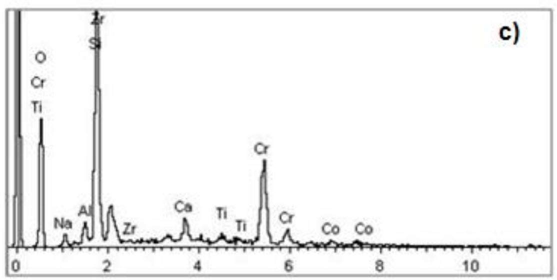
Good **chemical bonding** between
metal substrate and ceramic coating

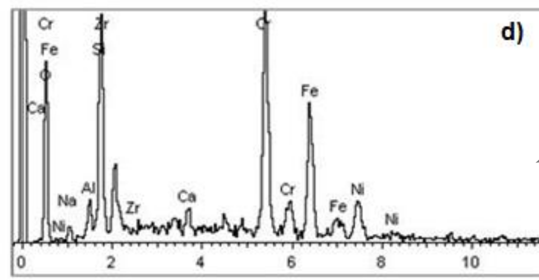
Ceramic coating micrograph





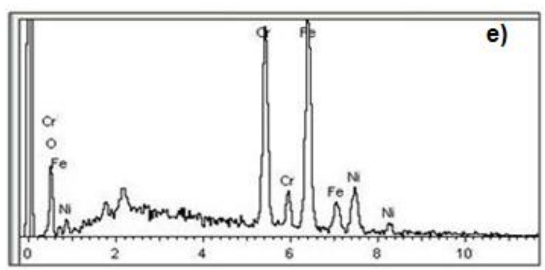
Interface. Diffusion area





Interface EDX results

Ceramic coating EDX results

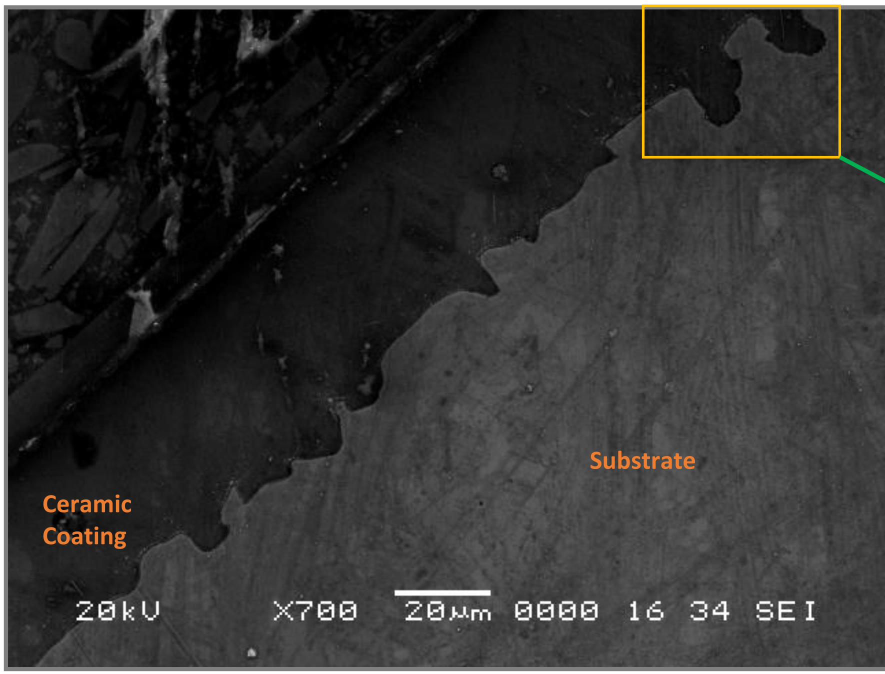


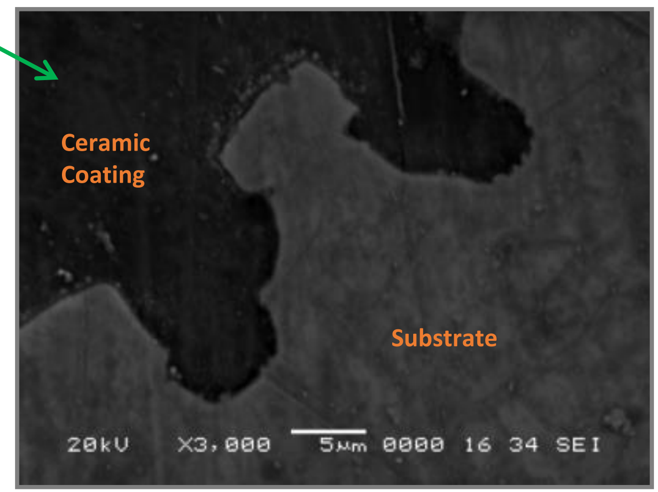
Metal substrate EDX results

TUBACOAT
TUBACEX GROUP

Morphologycal

Good chemical bonding between metal substrate and ceramic coating





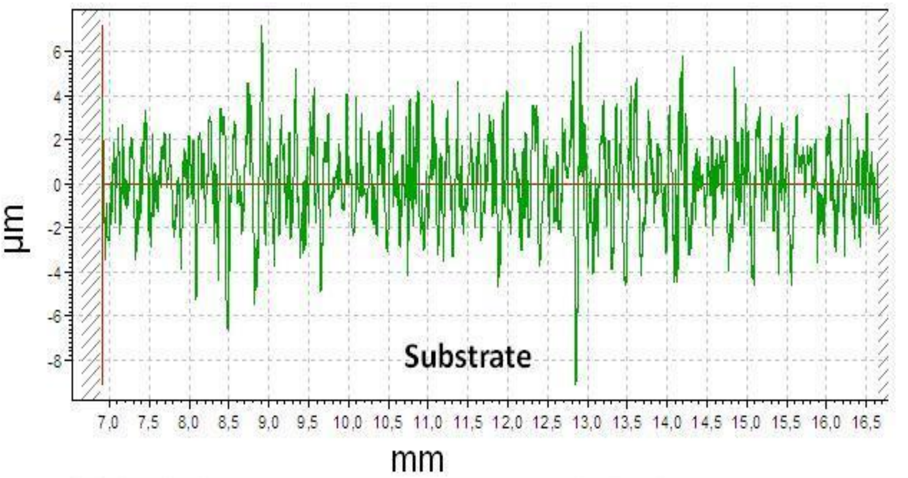
Metal-ceramic interface. Migration of compounds (Fe, Cr, Ni) takes place in **5 µm**

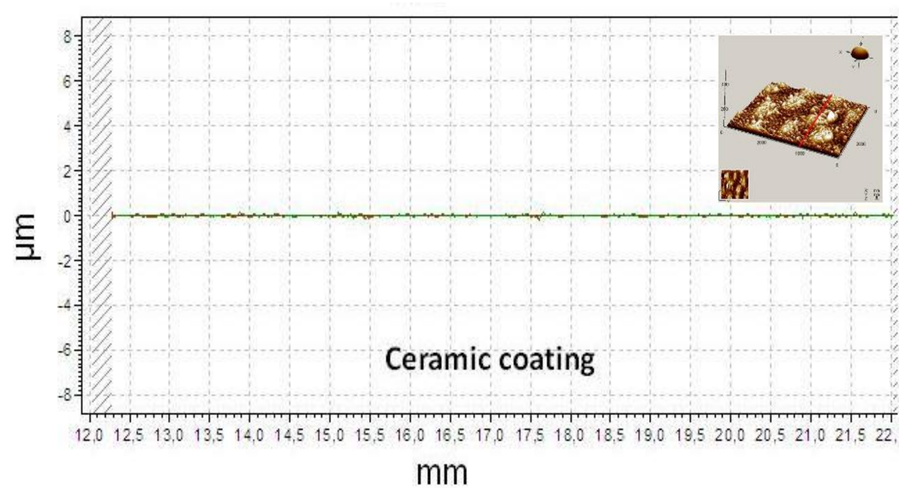
TUBACOAT

TUBACEX GROUP

Morphologycal

Roughness. Ra and Rz decrease ≈ 97% minimizing particle adhesion





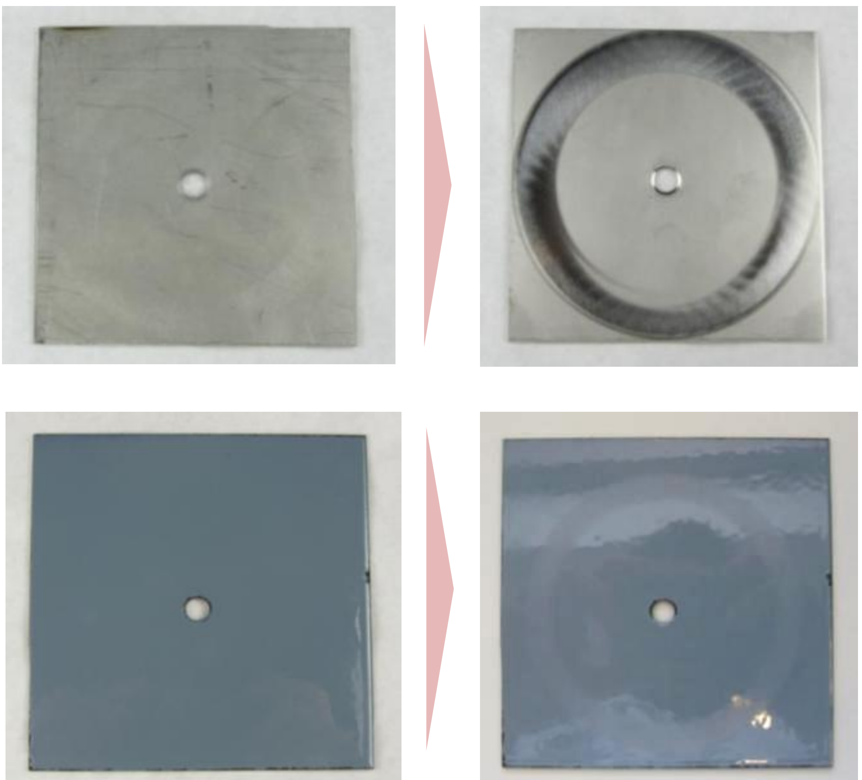
Substrate	Ceramic coating
Ra ≈ 1,5 µm and Rz ≈ 7,8 µm	Ra < 0,04 µm and Rz ≈ 0,2 µm

Product characterization

Mechanical

Abrasion resistance
≈ 94% decrease in mass loss

0 cycles | 10000 cycles



Mass loss for 10.000 cycles

$$\Delta w_n = \langle w_0 \rangle - \langle w_n \rangle$$

- Substrate

$$\Delta w_{10000} = 94.783 - 94.725$$

$$\Delta w_{10000} = 58\ mg$$

- Ceramic coating (T153)

$$\Delta w_{10000} = 119.377 - 119.373$$

$$\Delta w_{10000} = 4\ mg$$

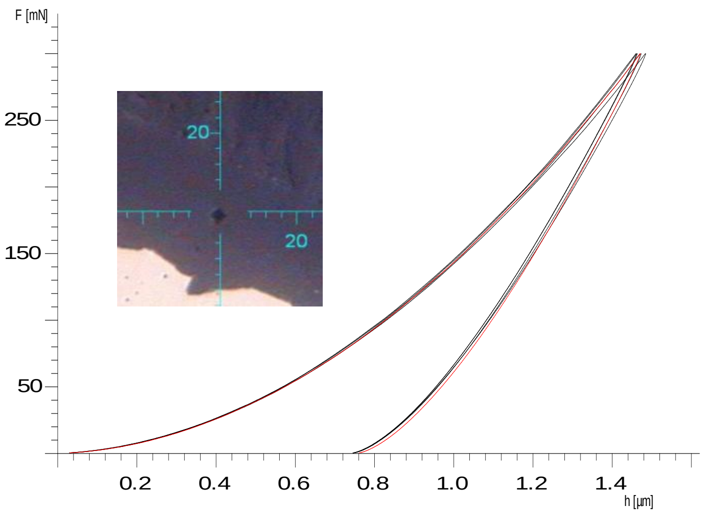
TUBACOAT

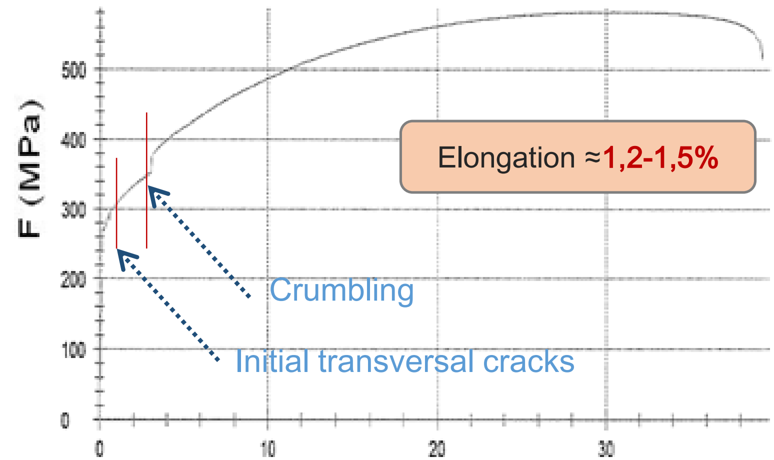
TUBACEX GROUP

Mechanical

Hardness & Elasticity

Coating is harder than substrate but less elastic





	Base Material	Ceramic coating
Hardness (HV)	220	840
Elastic Modulus EIT (GPa)	140	87

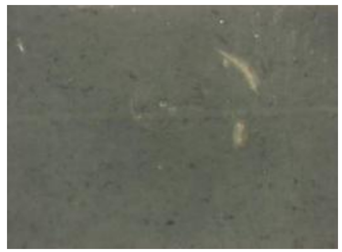
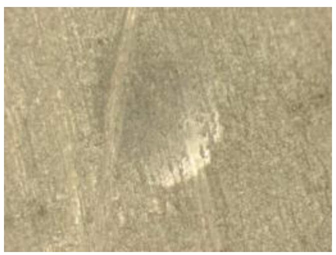
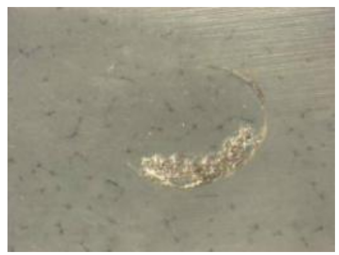
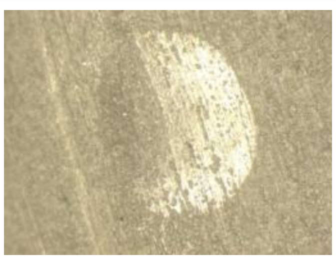
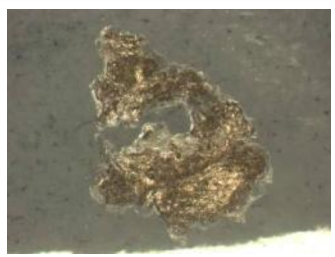
Tensile results			
$R_{p0.2}$ MPa	R_{p1} MPa	$R_{p0.5}$ MPa	R_{m} MPa
288	323	301	582

Hardness and elasticity properties can be improved by modifying structure and composition of ceramic compounds and process conditions

Product characterization

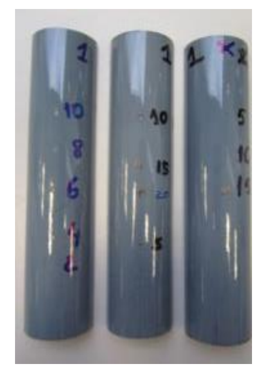
Mechanical

Good adherence. Impact test:
No coating detachments at medium loads

Height	Stainless Steel	Ceramic coating
5 cm		
10 cm		
15 cm		

BEFORE

AFTER

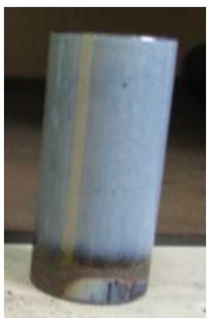


Product characterization

Mechanical

Good performance under **thermal cycling**
High **temperature resistance**

Thermal cycling (450ºC / 10min)

n Cycles	0	1	2	3	4	5	6
Air cooled							

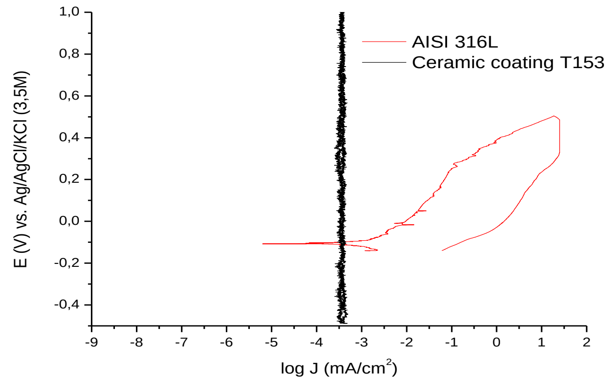
Different working temperature and thermal cycling resistance can be achieved by modifying structure and composition of ceramic compounds

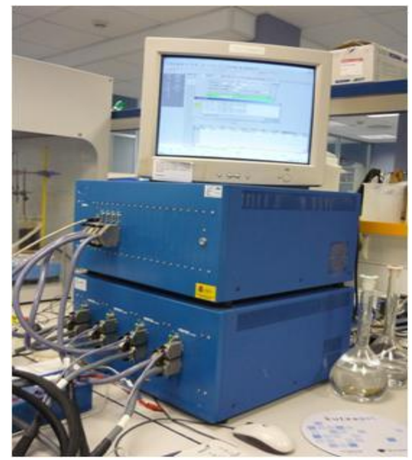
Product characterization

Chemical

High corrosion resistance
compared to base material

Pitting Corrosion Resistance





- JIS G-0577:2005
  - *Conditions:*
    - Solution: 5% NaCl, 25 ºC
    - Counter electrode: Platinum
    - Reference electrode: Ag/AgCl
    - The tested surface was fully immersed in test solution for 2 h
    - The test was conducted by potentiokinetic method from natural electrode potential to 1 mA/cm2 of anodic current density
    - Potential sweeping velocity: 1mV/s

	Ecorr (mV vs Ag/AgCl)	Log Jcorr (mA/cm^2)
Stainless Steel	**-106**	**-2.54**
Ceramic coating	**UNALTERED**	

TUBACOAT

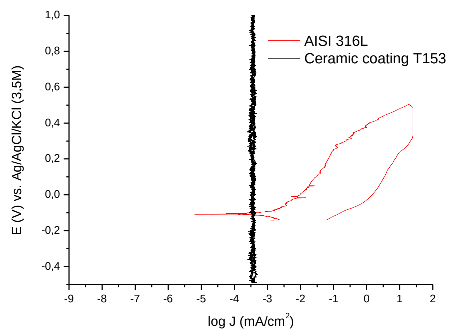
TUBACEX GROUP

Chemical

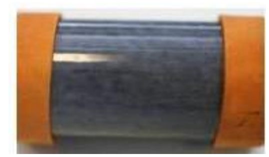
High corrosion resistance
compared to base material

Pitting Corrosion Resistance

- ASTM G48A
- Method A-Ferric Chloride



- *Conditions:*
  - Solution: 10% $FeCl_3$
  - Steps:
    1. 24 hours in 10% $FeCl_3$ at room temperature
    2. 72 hours in 10% $FeCl_3$ at 50 ºC
- *Determination of weight loss:*
  - Maximum 4 g/m^2 (Norsok)

10% $FeCl_3$	Stainless steel	Ceramic coating
0 h (25 ºC)		
72 h (50 ºC)		
Weight Loss (g/m2)	>700	≈0

TUBACOAT

TUBACEX GROUP

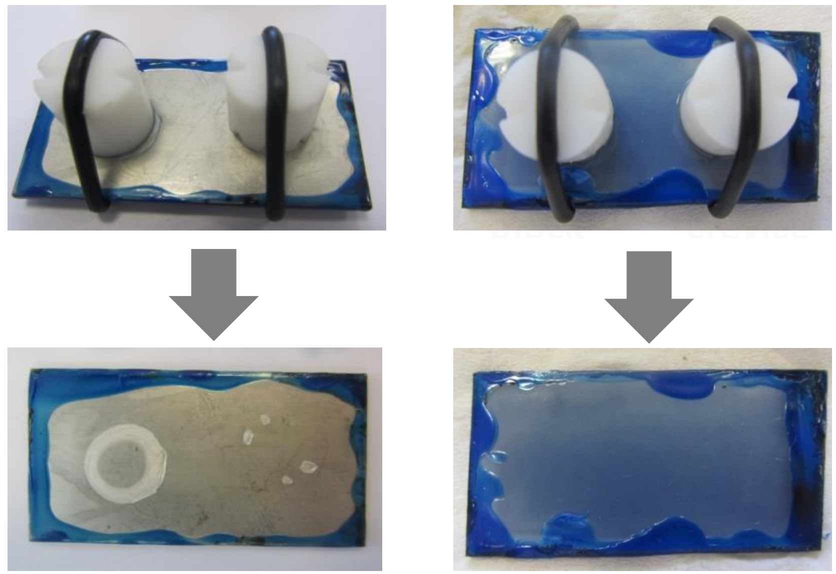
Chemical

High corrosion resistance
compared to base material

Crevice Corrosion Resistance

- ASTM G48A
- Method B-Ferric Chloride Crevice Corrosion Test
  - *Conditions:*
    - Solution: 10% $FeCl_3$ at 22ºC
    - Steps:
      1. Fasten TFE-fluorocarbon block and crevice to test specimen with rubber band 24 hours in 10% $FeCl_3$ at room temperature
      2. 72 hours in 10% $FeCl_3$ at 50 ºC
      3. Visual inspection

Stainless Steel | Ceramic coating



Product characterization

TUBACOAT

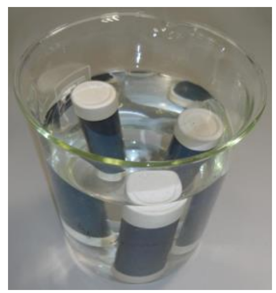
TUBACEX GROUP

Chemical

High corrosion resistance
compared to base material

Seawater corrosion test

- *Conditions:*
  - Solution: 3,5% NaCl at 22ºC
  - Visual inspection



Seawater Corrosion Test	
0 h	
1000 h	
2000 h	

High corrosion resistance for offshore applications

TUBACOAT

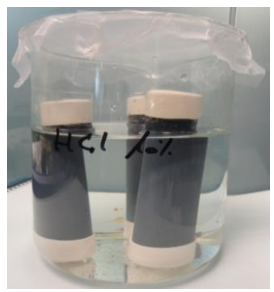
TUBACEX GROUP

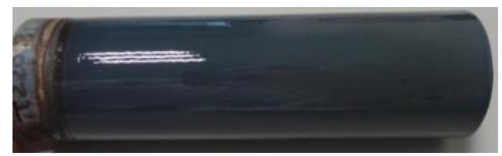
Chemical

High corrosion resistance
compared to base material

Acid corrosion test

- *Conditions:*
  - Solution: 10% HCl at 22ºC
  - Visual inspection



Acid Corrosion Test	
0 h	
1000 h	
2000 h	

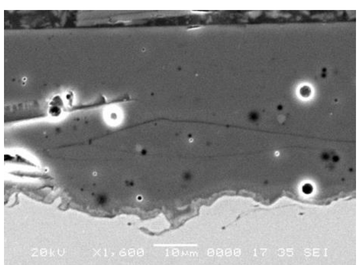
Loss of brightness during timing test, but ceramic coating continues to protect the metal substrate

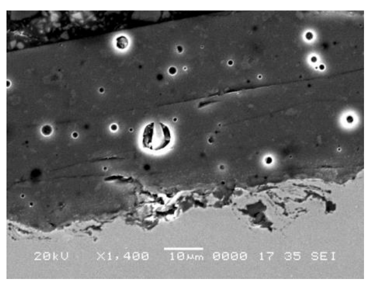
Chemical

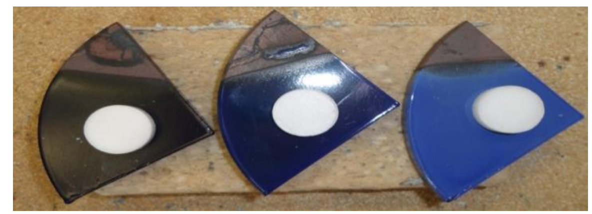
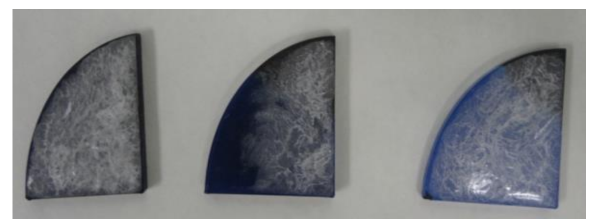
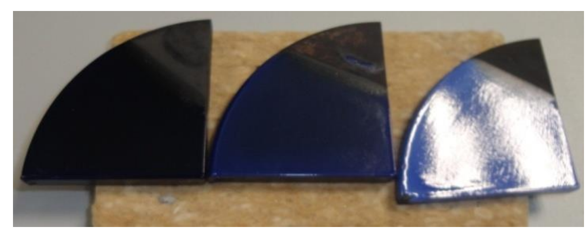
High corrosion resistance
compared to base material

Molten salt corrosion test

- *Conditions:*
  - Molten salt composition: NaNO3 + KNO3 (60/40)
  - Blocks of molten salts positioned over the ceramic coating
  - 46 cycles HEATING (8 h at 400ºC)/COOLING (air cooled)
  - Visual and optical microscopy inspection





Molten salt Corrosion Test	
Initial (t0)	
46 cycles (before cleaning)	
46 cycles (after cleaning)	

- TUBACOAT concept
- Product characterization
- Powergen applications
  - Steam Reheater & TC
    - Experience CASE 1
  - Flue Gas Condenser
    - Experience CASE 2

TUBACOAT

TUBACEX GROUP

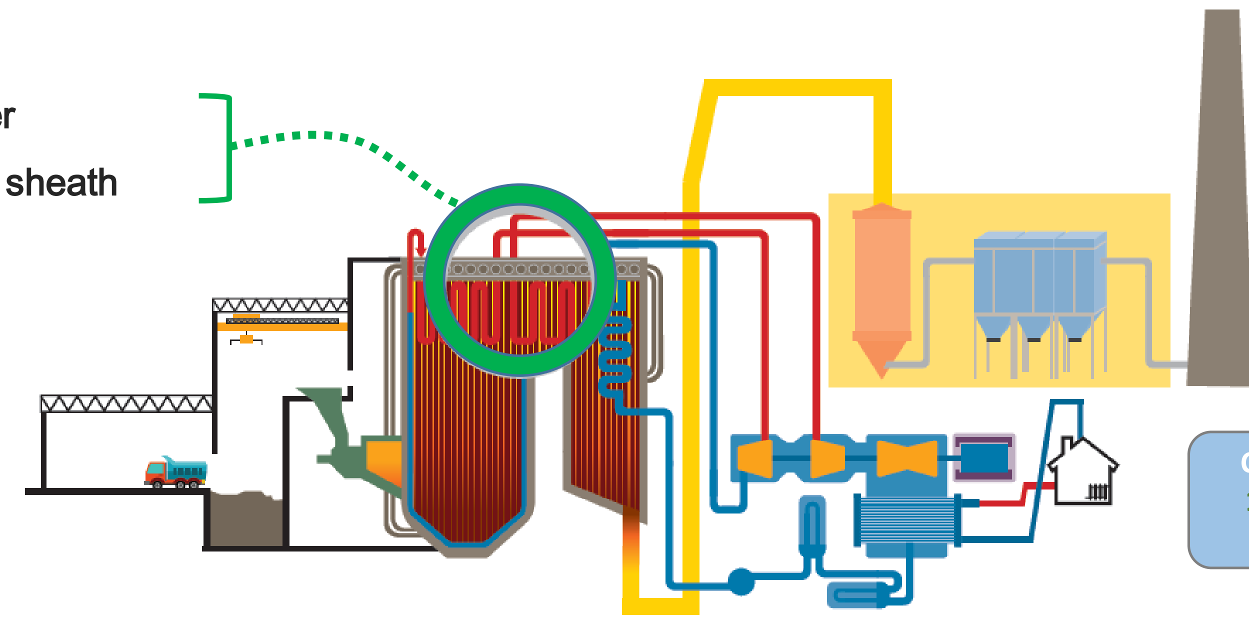
Steam reheater & Thermocouple sheath

Working conditions

Steam temperature	Pressure	Fumes temperature	Inner fluid media	Outter fluid media	Others
300 ºC	170 bar	850 ºC	Steam	W to E fumes	Alkaline ashes

Applications

- Steam reheater
- Thermocouple sheath



Current solution
16Mo3+Inconel cladding 4 mm

Chemical corrosion

Efficiency loss

High OPEX

Powergen application & Experience CASE 1

Steam reheater

TUBACOAT SOLUTION

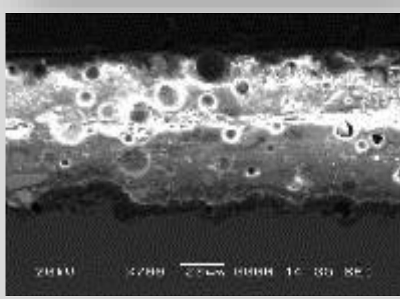
TP310H outer coated reheater tubes

On-site Weld coating

Powergen application & Experience CASE 1

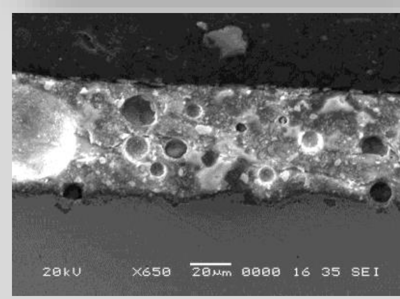
Steam reheater

March 2014



After one year of operation under real working conditions

February 2015



TUBACOAT

TUBACEX GROUP

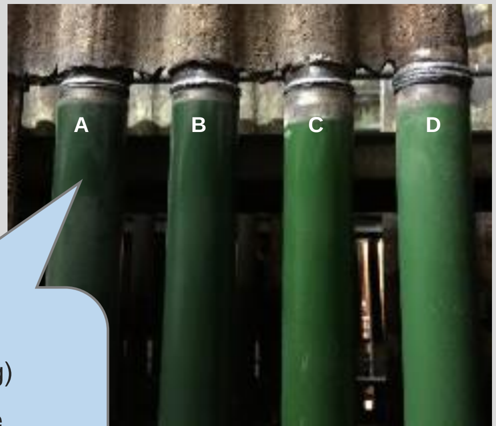
Steam reheater

TP310H outer coated tube before boiler cleaning (plant stoppage)

Powergen application & Experience CASE 1

Steam reheater

April 2015



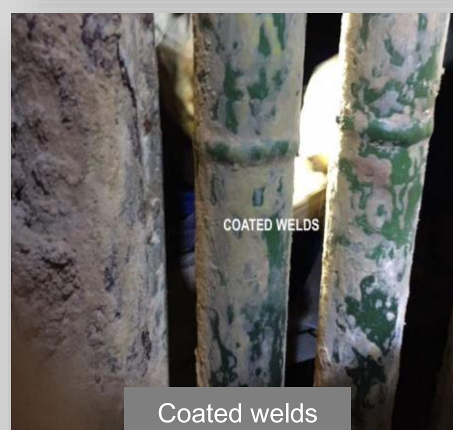
A. K100 2 year service (after hand sweeping)
B. K100: 1 year service
C. K100A: 2 year service
D. K.100A 1 year service

Coated welds

After one additional year of operation under real working conditions

April 2016

After 2 years of operation and cleaned by hand, rest of coated tubes are protected against shot blasting of the rest of the boiler



Coated welds

TUBACOAT

TUBACEX GROUP

Steam reheater

Results

- Low ash adherence
- Glossy surface after 1-2 years in operation
- Negligible loss of mass

Conclusions

- Excellent corrosion resistance
- Excellent coat bonding under thermal stress
- Homogeneous performance
- No ash adherence to outer surface

Major Improvements

- Longer tube life expectation
- Reduced cleaning and maintenance
- Improved thermal efficiency
- Possibility to increase thermal cycle temperature

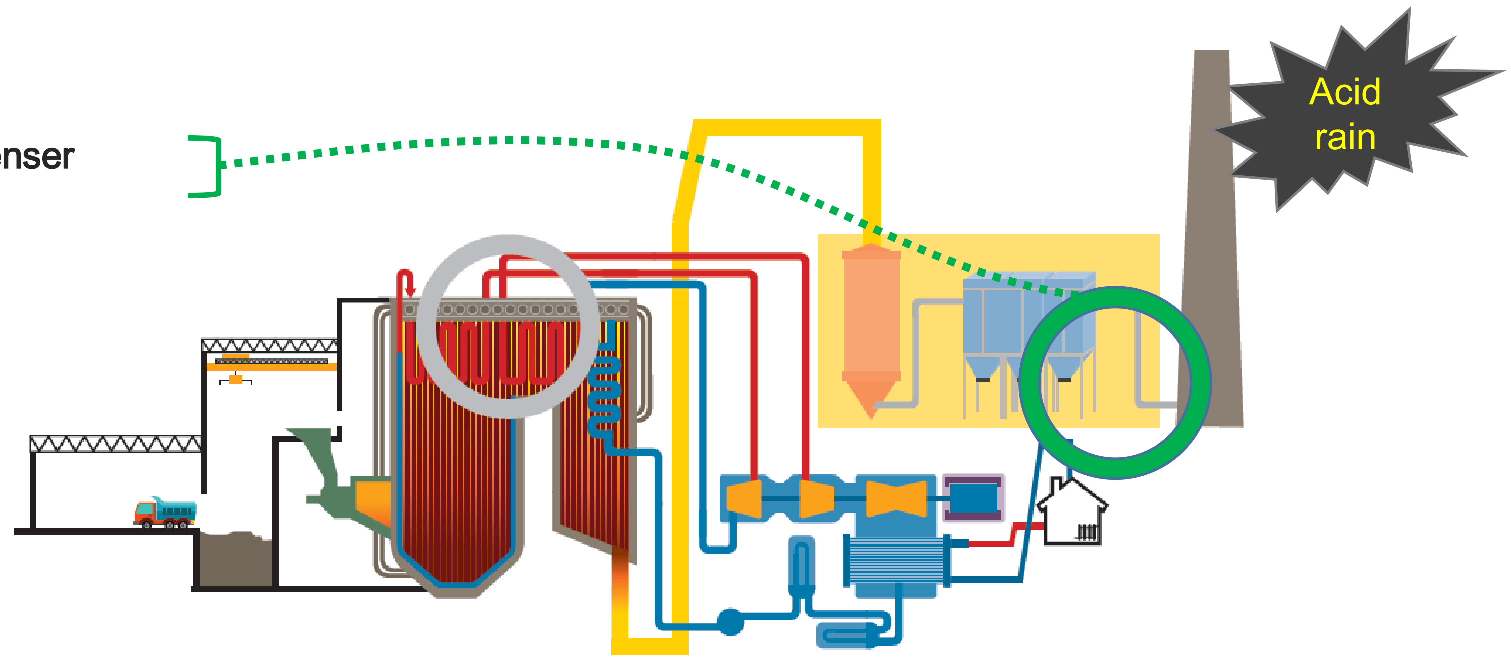
- TUBACOAT concept
- Product characterization
- Powergen applications
  - Steam Reheater & TC
    - Experience CASE 1
  - Flue Gas Condenser
    - Experience CASE 2

TUBACOAT
TUBACEX GROUP

Flue gas condenser

- **Working conditions**
  - Fume composition: NOx, COx…
  - Inlet fume temperature 120-150ºC

- **Applications**
  - Flue gas condenser



Chemical corrosion | NOx, COx emissions | Efficiency loss (*)

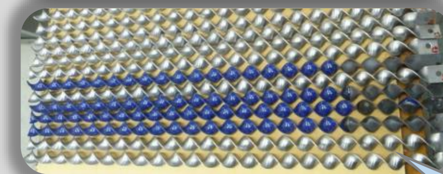
(*) Heat recovery potential

TUBACOAT

TUBACEX GROUP

Flue gas condenser

Fume passage



Turbulator

5KW Cold End Flue Gas Condenser prototype at a Waste to Energy Plant (SPAIN)

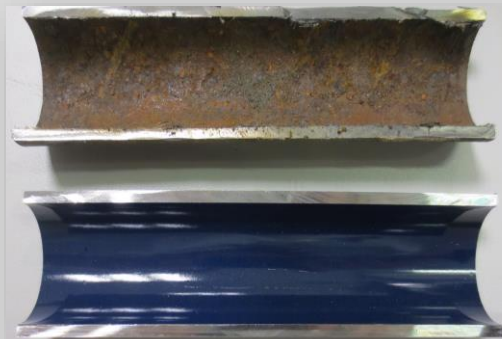
Carbon steel tubes coated with ceramic coating (inner surface)

TUBACOAT

TUBACEX GROUP

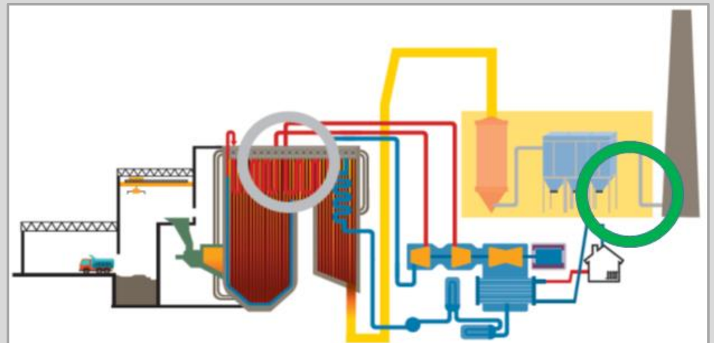
Flue gas condenser

Non-coated vs coated



Non-coated vs coated

Relevant process data

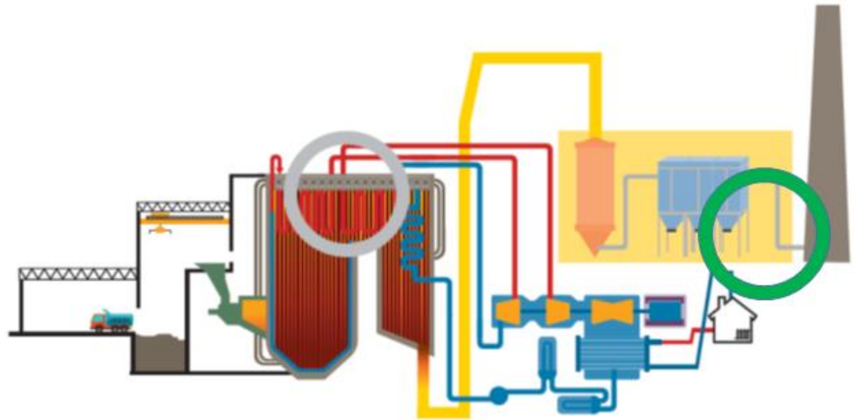


Recovered Heat (kWh)	5
Condensed water (l/h)	6
Condensed fluid PH (no neutralized)	3,65
Fume inlet temperature (ºC)	120
Fume outlet temperature (ºC)	40

TUBACOAT

TUBACEX GROUP

Flue gas condenser



CONCLUSIONS

- No damage to the inner tube Surface
- Full condensation of water vapour in the fumes
- Recovery of sensible and latent heat by fume condensation

MAJOR IMPROVEMENTS

- Increase in thermal plant efficiency
- Heat use for secondary applications (District Heating & Cooling)
- Neutralized condensed water for use in other applications
- Reduction in CO2 emissions

THANK YOU!