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Study on the Use of Metallic Coating Applied by Thermal Spray in Mineral Coal Acquatubular Boilers

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Objective

- The main purpose of this work is to evaluate the feasibility of using a metallic coating inside acquatubular boilers.

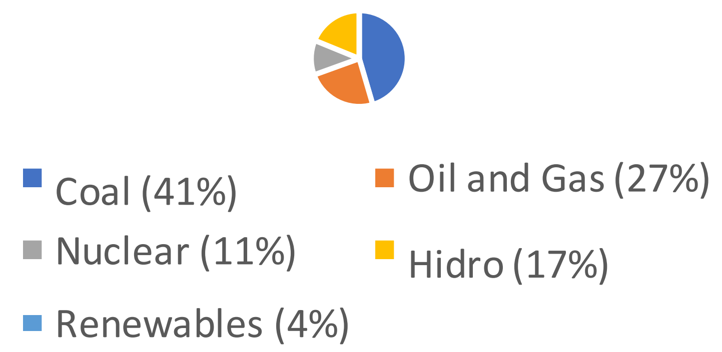
- The process of metalization by thermal spraying of pipes, subjected to high pressure, temperatures and impact of solid microparticles, shall be tested.

- An overview about the importance of mineral coal for the generation of electric energy is part of the feasibility of this process.

Thermoelectric Energy Overview

Electric energy generation source in the World (IEA, 2015)

Participation in Electric Energy Generation



Brazilian Reserves (millions of oil equivalent tons) – BEN 2015

	Coal	Oil	Nuclear	Gas
Total	7.027	2.289	1.254	467

Thermoelectric Energy Overview

Mineral Coal Thermoelectric Production in Brasil

Power Plant	Rated Power (MW)
Total	3.388

New Mineral Coal Thermoelectric Projected and Contracted in Brasil

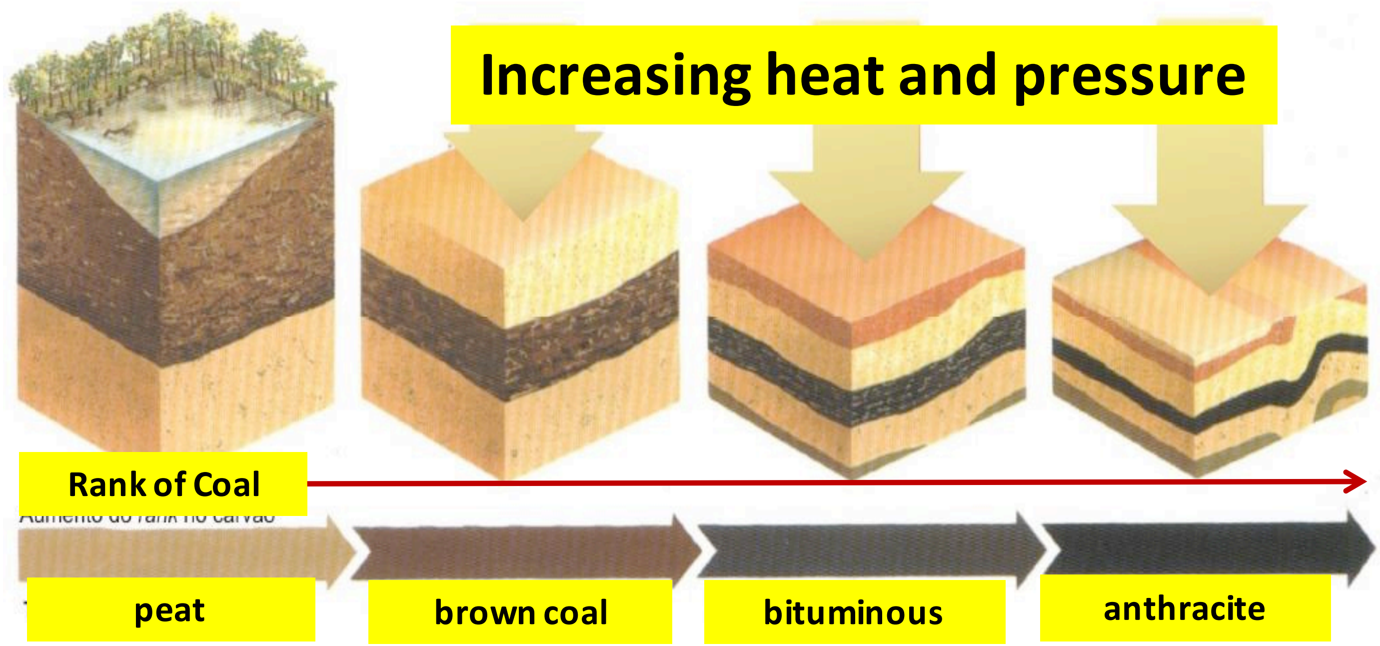
Power Plant	Rated Power (MW)
Total	1.785

Reserves of Brazilian Mineral Coal

Brazil	Reserves (million ton)	Participation (%)
Total	6.630	0,7

Thermoelectric Energy Overview

The Quality of Mineral Coal



Thermoelectric Energy Overview

Brazilian Mineral Coal Properties

Brazilian Coal	Calorific Value	Carbon (%)	Sulfur (%)	Ashes (%)
Total	3.307 kcal/kg	25,8	1,7	51,7

Brazilian Suppliers Mineral Coal Properties

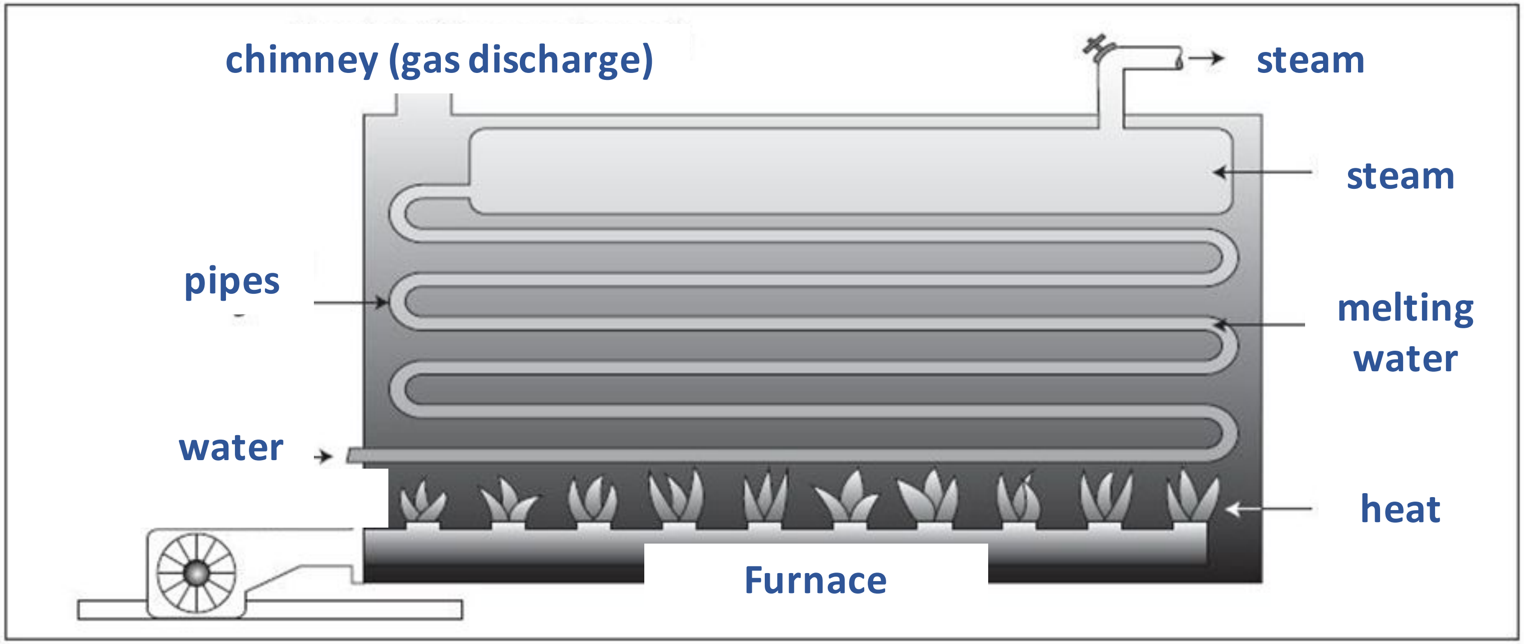
Imported Coal	Calorific Value	Carbon (%)	Sulfur (%)	Ashes (%)
Total	6.394 kcal/kg	55,1	0,8	15,9

World Productors Average Coals

World Coal	Anthracite and Bituminous (Mt)	Sub-bituminous and Linhito (Mt)	Total (Mt)
Total	403.199	488.332	891.531

Aquatubular boiler

Scheme of an Aquatubular Boiler



Mineral Coal

Chemical Composition of Coal Ashes from Southern Santa Catarina Minerals and its Correlation with Melting Point

Table 1 - Results obtained for the average of 20 (twenty) Ash samples analyzed with different methodologies

Oxides (%)	By Atomic Absorption	By X-ray Fluorescence
SiO_2	60,79	60,54
Al_2O_3	15,04	23,81
Fe_2O_3	3,74	3,72
CaO	1,18	2,38
K_2O	3,70	3,00
Outros óxidos	3,99	4,65

However, silicon oxide is highly preponderant over aluminum and iron oxides. There was a small variation in the deformation temperatures, beginning of fusibility, where the minimum temperature obtained was 1378°C and the maximum was 1421°C.

Mineral Coal

Characterization of Coal Ashes from Thermal Electric Plants

Table 2 - Percentages of the CNHS group in ashes

Elements	BRASKEM	CMPC	TRACTEBEL
Carbon	18,32	4,93	0,92
Nitrogen	0,19	0,10	0,05
Hidrogen	0,30	0,05	0,02
Sulfur	0,27	0,17	0,09

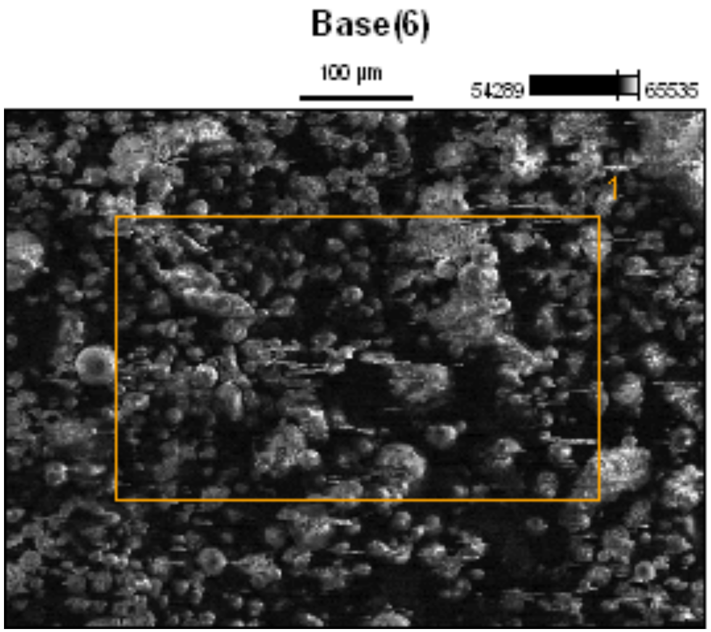
Table 3 - Percentages of oxides present in the ashes

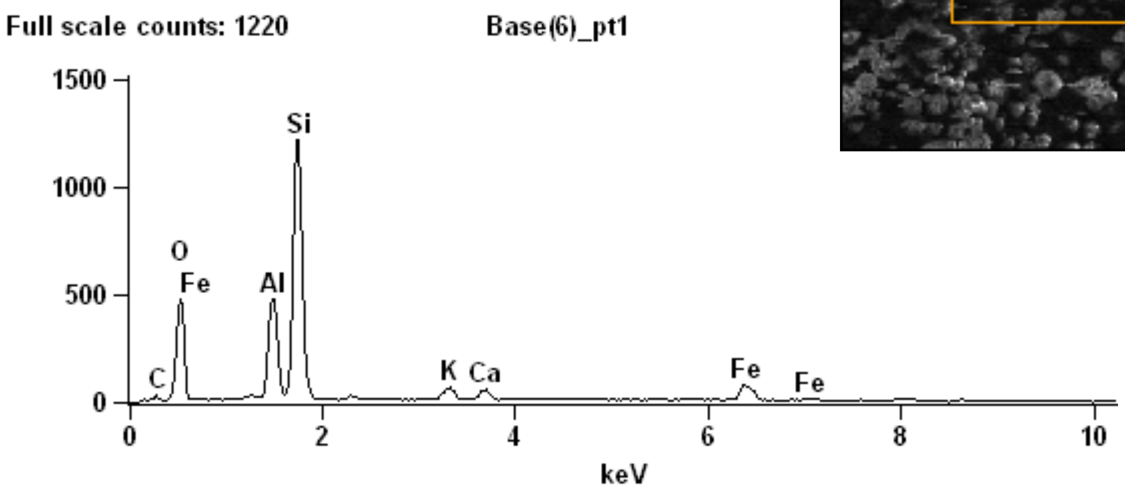
Elements	BRASKEM	CMPC	TRACTEBEL
SiO2	51,83	52,57	60,45
Al2O3	23,48	23,45	26,20
Fe2O3	3,83	5,42	5,18
CaO	2,70	4,81	2,17
K2O	1,47	1,38	1,65

Mineral Coal

PDI of 87 Particles of Ashes:

- EDS – 20kV – 200x
- Average of All Particles = 20.19 micrometers
- Highest Particle = 56.94 micrometers
- Minor Particle = 3.82 micrometers



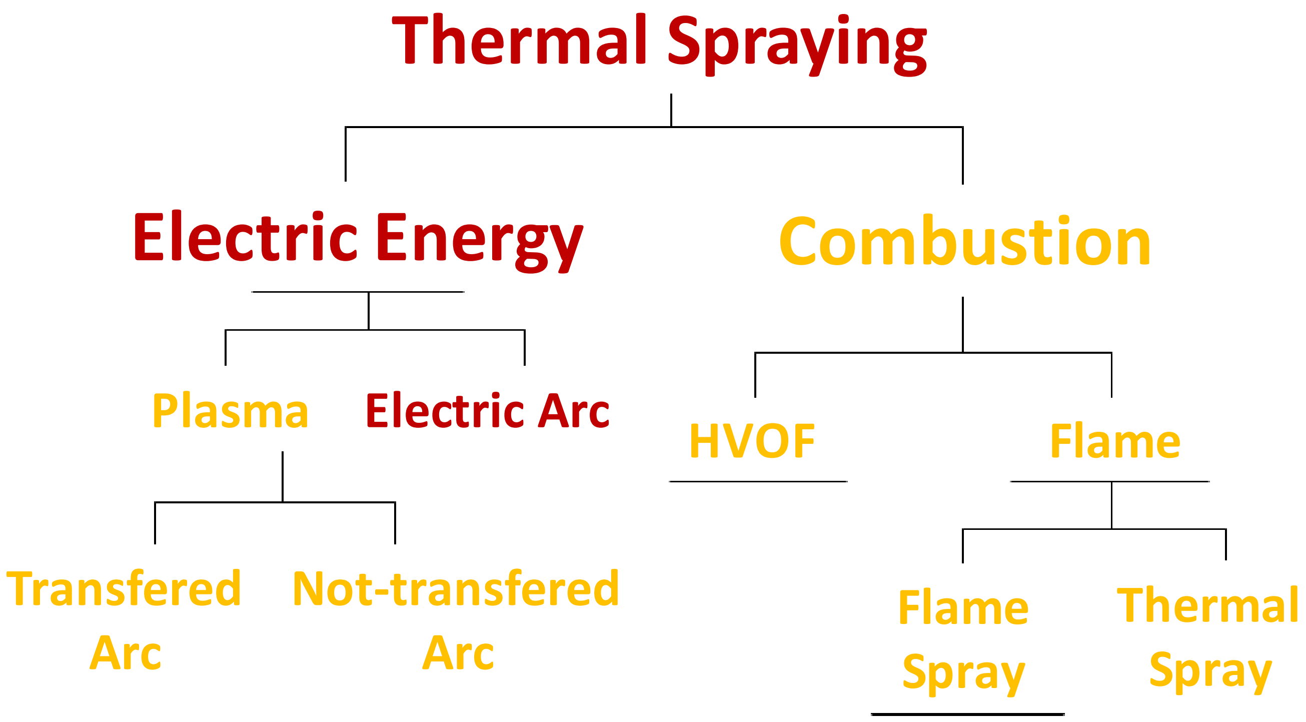


Mechanism of Deterioration

Pipes in Aquatubular Boilers after long time impact of Mineral Coal Ashes

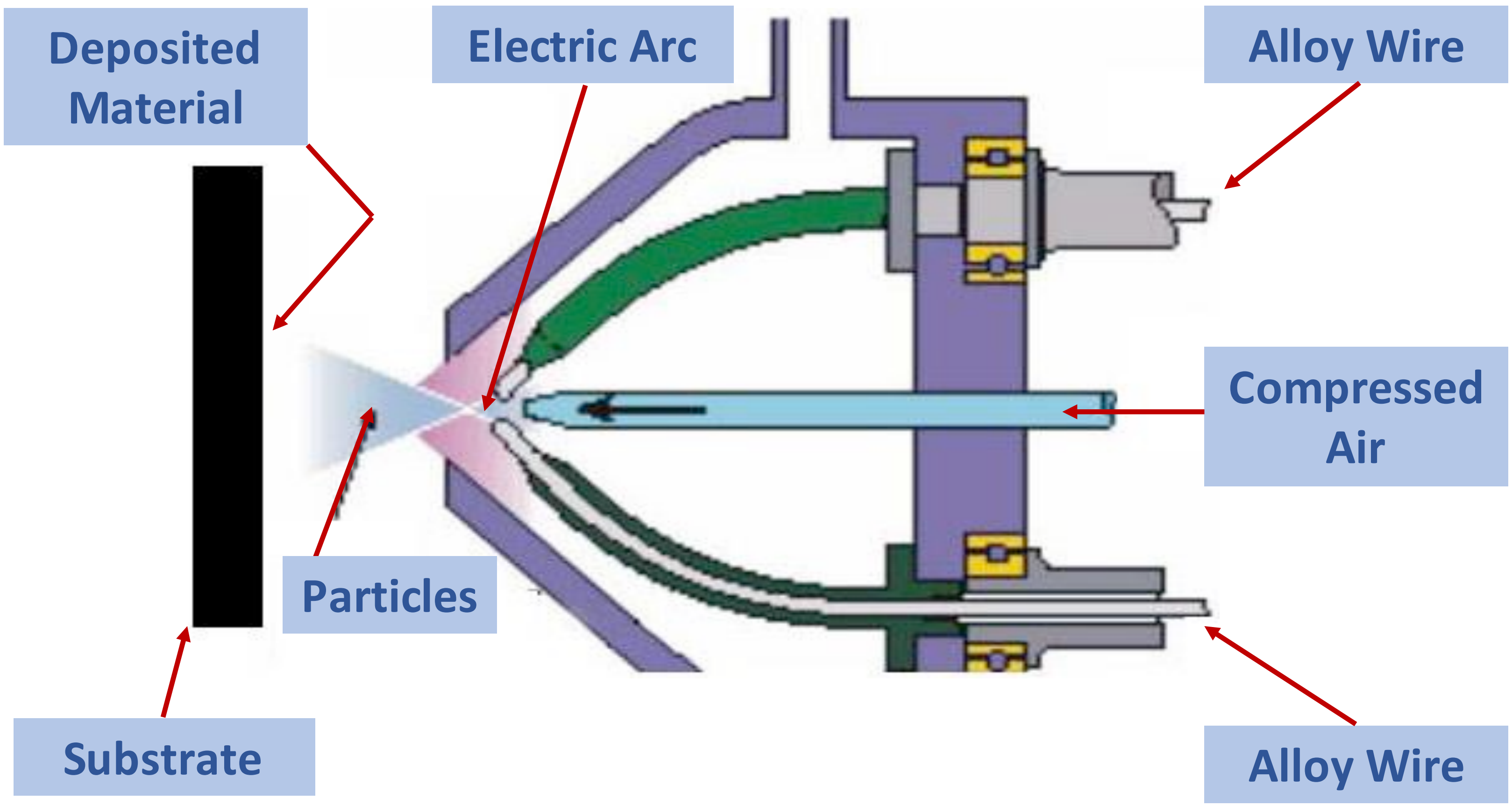
Mechanism of Protection

Various Types of Thermal Spray Methods



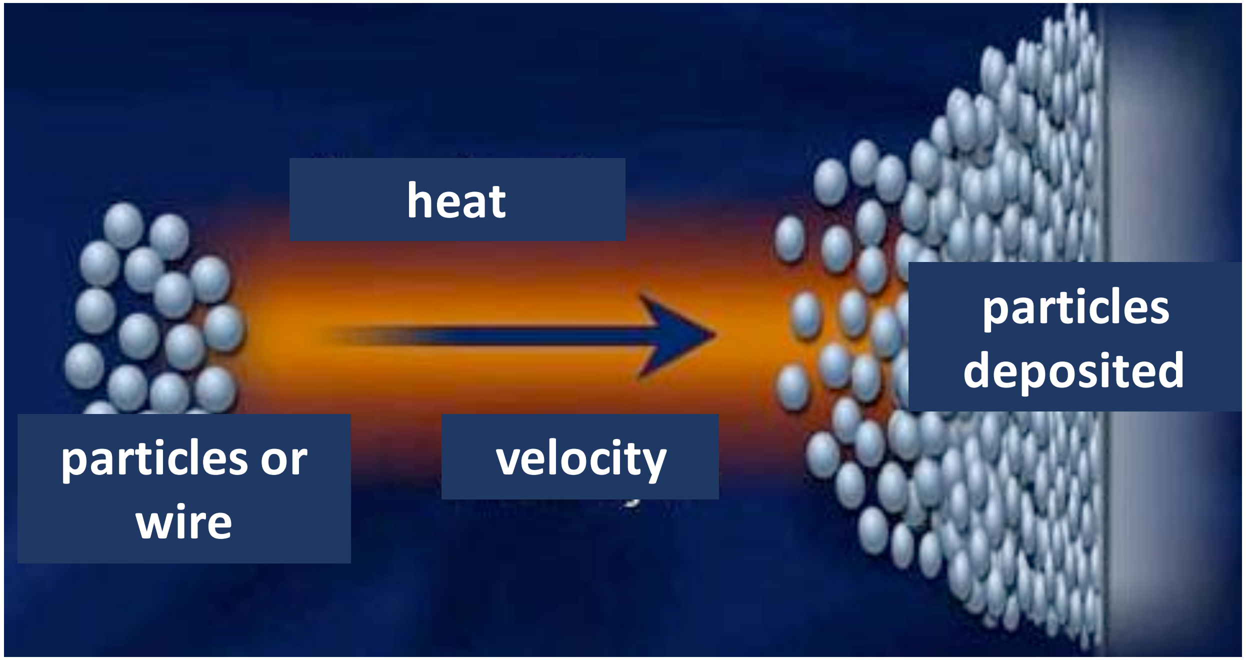
Thermal Spraying

Scheme of a Thermal Spray Gun for Aplication by Electric Arc



Thermal Spraying

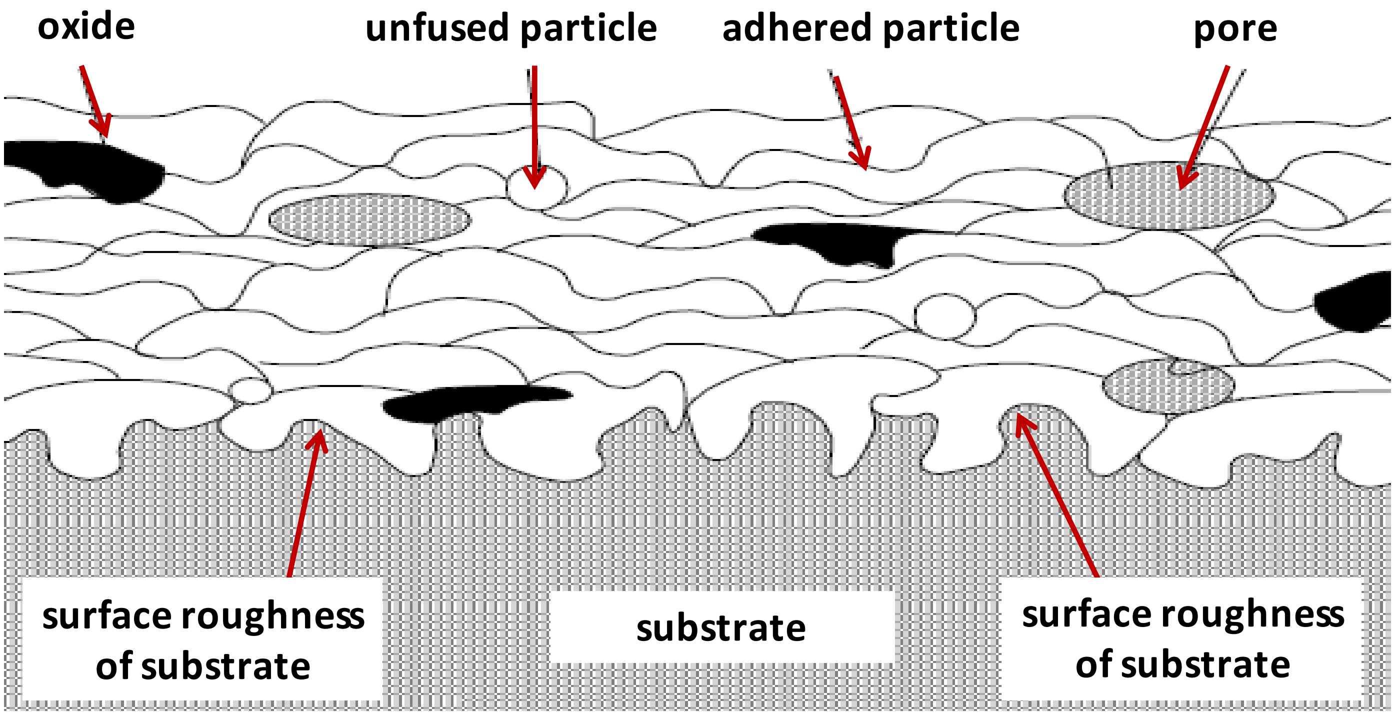
Mechanism of Deposition by Thermal Spray



Process	Temp (°C)	Speed (m/s)	% of Porosity
Electric Arc	4.000 – 6.000	250	2 - 10

Thermal Spraying

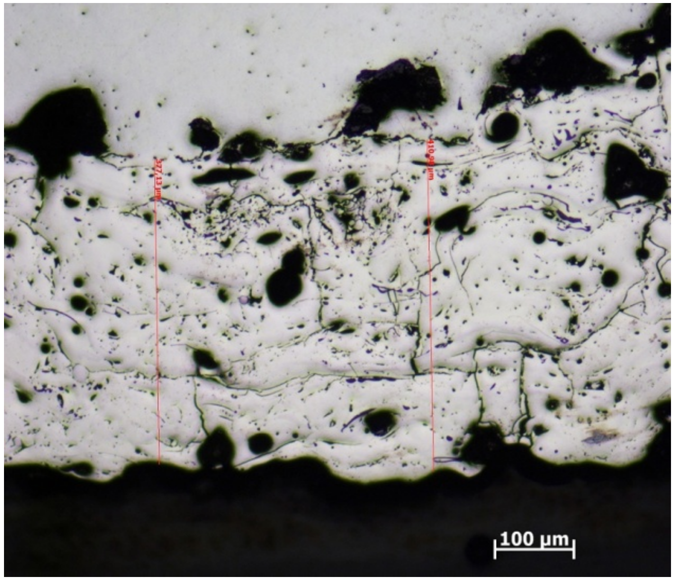
Characteristics of a Coating by Thermal Spray

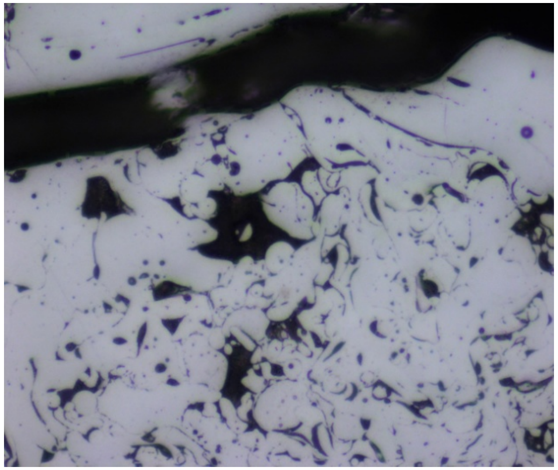


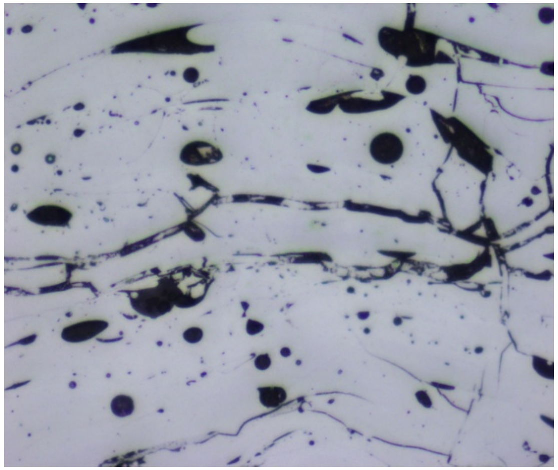
Optical Microscope

Images made in Optical Microscope

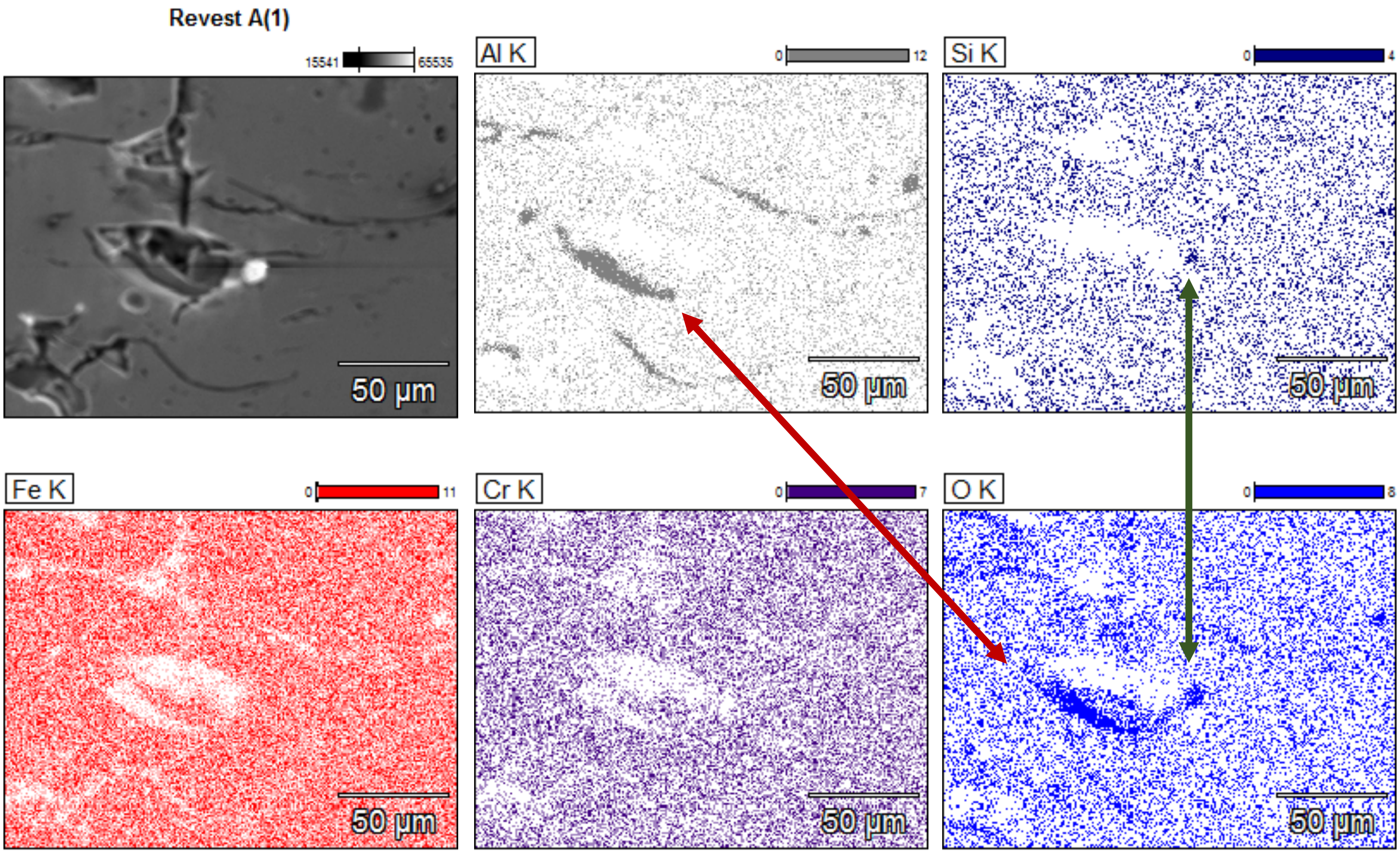
- image below magnification 100x
- Images on right magnification 500x







EDS – MEV – 20kV – 600x



Adhesion

ASTM D-4541 = Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers1

Positest AT-A: Automatic Adhesion tester da Defelsko.

Adhesion

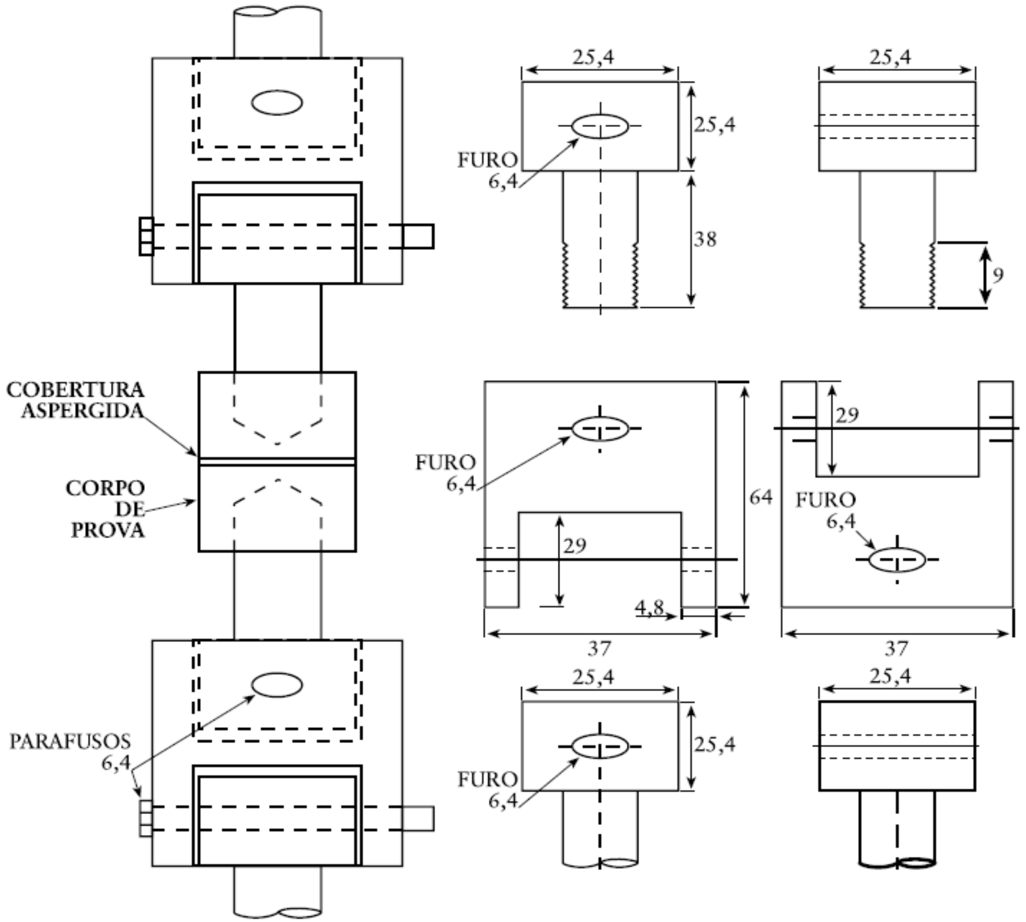
ASTM C-633 = Standard Test Method for Adhesion or Cohesion Strength of Thermal Spray Coatings1.

Action = Use viable procedure already used

The adhesion strength of the glue to the coating should be 8000 psi (56 MPa) for those curing at room temperature (150°C) and 4000 psi (28 MPa).

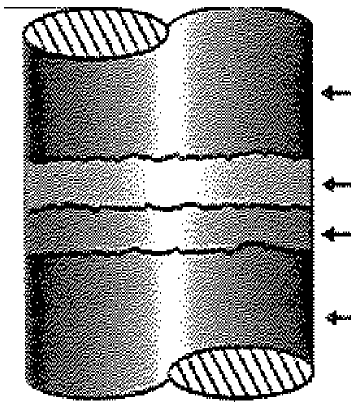
Adhesion

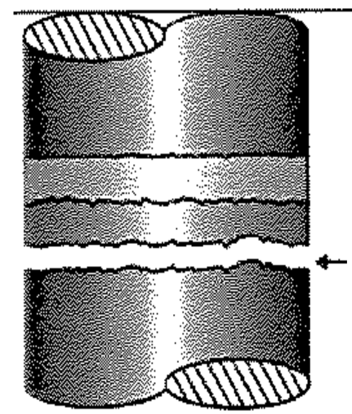
Apparatus for Adhesion Test

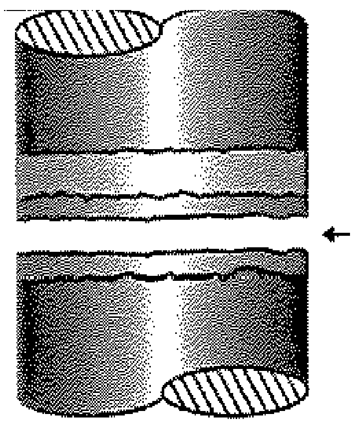


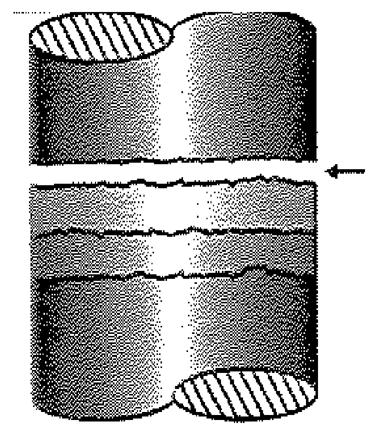
Adhesion

Mechanisms of Adhesion Failure









Thermal Expansion

Requirement = Coefficient of thermal expansion should have value close to the substrate coefficient (tube material)

Strategy = Coefficients (α) of Linear and Volumetric Expansion

Action = Mathematical Calculus

Thermal Conductivity / Diffusivity

Requirement = Thermal conductivity shall be closed to the substrate one.

ASTM E-1461 = Standard Test Method for Thermal Diffusivity by the Flash Method1

CEPEL Methodology

Use of the Netzsch LFA 447 equipment with nanoflash technology, according to ASTM E-1461.

The reading provides the value of the thermal diffusivity, and which can be converted to thermal conductivity.

Abrasive Blasting

ASTM G-76 = Standard Test Method for Conducting Erosion Tests by Solid Particle Impingement Using Gas Jets1

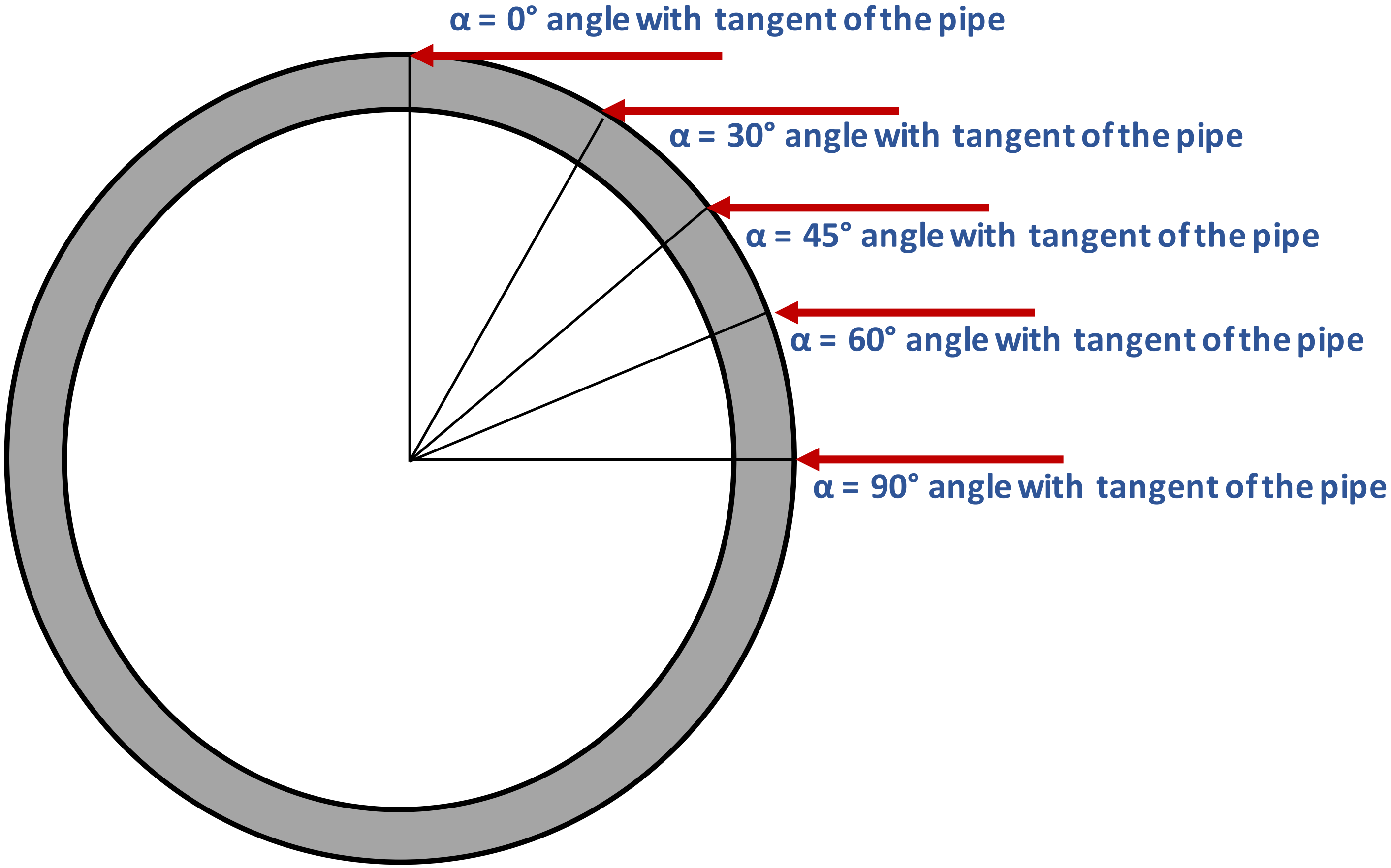
For the abrasive blasting tests on the surfaces with the proposed coatings, an installation composed of a SCHULZ compressor, model CSL 10 BR, and an ESSENCE brand Precision 1 blasting chamber according to ASTM G 76 will be used.

The blast test shall be conducted supported by an apparatus with calibrated angles of 90°, 60°, 45°, 30°.

The jet will be directed to a distance of 1 cm particles of 50 µm or 125 µm of alumina. For the test, it is sought to guarantee a particle velocity of 30 m / s in test pieces of 10 x 15 cm, with a useful session of 75 cm^2.

Abrasive Blasting

Boiler pipe cross section representation with different attack angles



Abrasive Blasting

Results obtained in the Sample submitted to blasting

Sprayed Coating	Jet Angle of Attack	Granulometry of Abrasive	Loss of Mass (mg / gram of abrasive)	Velocity of Abrasive
Sample 1	90°	50 µm	0,0997 mg/gr	To verify
Sample 2	60°	50 µm	0,0751 mg/gr	To verify
Sample 3	45°	50 µm	0,0645 mg/gr	To verify
Sample 4	30°	50 µm	0,0591 mg/gr	To verify
Sample 5	90°	125 µm	0,0771 mg/gr	To verify
Sample 6	45°	125 µm	0,0492 mg/gr	To verify

Results obtained in the Sample submitted to blasting

Carbon Steel 1020	Jet Angle of Attack	Granulometry of Abrasive	Loss of Mass (mg / gram of abrasive)	Velocity of Abrasive
Graphic	90°	50 µm	0,250 mg/gr	70 m/s
Table	90°	50 µm	0,221 mg/gr	70 m/s
Graphic	90°	50 µm	0,020 mg/gr	30 m/s
Table	90°	50 µm	0,021 mg/gr	30 m/s

Thermal Simulation and Corrosion Test

Thermal Simulation

The sample shall be submitted to temperatures of 800°C during 100 hours for the first simulation, during 1.000 hours for the second simulation, and during 2.000 hours for the third and last simulation.

ASTM G-111 = Standard Guide for Corrosion Tests in High Temperature or High Pressure Environment, or Both1

This guide covers procedures, specimens, and equipment for laboratory corrosion tests on materials under high pressure (HP) or high temperature and high pressure (HTHP) conditions.

This procedures and methods are applicable for corrosion by mass loss tests for environmental use.

In addition, this guide will help in comparing corrosion data between laboratories or testing organizations that use different equipment.

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- **Coatings for Boiler Tube Applications**

- **Normas ASTM**