Appendix 9

Current topics relevant to CUI

Dave Harvey (TWI)
Current Topics Relevant to CUI

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EFC-NACE Italia Section Joint Meeting, Venezia 31 March 2006

CUI – Carbon & Low alloy Steels

• Localised wastage of areas in contact with water, held by insulation or between steel and insulation
• All insulated equipment operating between −5°C and 200°C at risk
• Highest corrosion rates between 60-120°C
• 1.5 mm/y typical corrosion rate; but 3 mm/y reported
• All thermally insulated surfaces operating between −5°C to 200°C and service life > 10yr should receive adequate corrosion protection before application of thermal insulation
CUI – Austenitic / Duplex Stainless Steels

- Prone to high rates of localised attack and stress corrosion cracking under certain conditions
- Critical temperature, Cl level, pH
- Pitting threshold temperature e.g.
  - 304L >25 °C; 316L >36 °C; 2204 duplex >90 °C
- Stress corrosion cracking threshold T e.g.
  - 304L/316L >50-60 °C, 25Cr SDSS >100 °C
- Corrosion protection required on process equipment operating above threshold T:
  - Austenitic and low Mo DSS >25°C
  - DSS, SDSS and super austenitic SS >80°C

CUI – Protective Coatings

- Effective method of delaying onset of CUI:
  - Thermally sprayed Al has potential to provide protection for full service life (> 20 years)
  - Viable option for new build
  - Same surface prep QC required for TSA / painting to that for non-insulated surfaces
  - Al and SS foils are alternatives
- New build best opportunity to minimise risk of CUI:
  - Process equipment external condition and access most favourable
  - For many cases - only time steel substrate is accessible when at ambient temperature
CUI Prevention Field Application: Comparison of TSA & Paint

<table>
<thead>
<tr>
<th>Features</th>
<th>TSA</th>
<th>Conventional Paint</th>
</tr>
</thead>
<tbody>
<tr>
<td>CUI Protection</td>
<td>25 to 30 yrs; maintenance-free; inspection-free</td>
<td>5 to 13 yrs; tends to low side for on-line application</td>
</tr>
<tr>
<td>Protection in cyclic service</td>
<td>Yes</td>
<td>No effective paint system</td>
</tr>
<tr>
<td>Upper continuous Operating Temperature</td>
<td>480°C</td>
<td>175°C</td>
</tr>
<tr>
<td>Schedule impact</td>
<td>None - one coat application</td>
<td>24 hrs typically; multi coats required</td>
</tr>
<tr>
<td>Environmental impact</td>
<td>None</td>
<td>Must meet VOC &amp; disposal regulations</td>
</tr>
<tr>
<td>In-Place cost ratio</td>
<td>1.05 to 1.20</td>
<td>1.0</td>
</tr>
<tr>
<td>Durability</td>
<td>Very resistance to mechanical abuse. Minor damage does not result in CUI</td>
<td>Very susceptible to mechanical abuse. Any damage results in CUI</td>
</tr>
<tr>
<td>Required surface preparation</td>
<td>White/near white (SA 2.5)</td>
<td>White/near white (SA 2.5)</td>
</tr>
<tr>
<td>Application method(s)</td>
<td>Twin Arc spray or flame spray</td>
<td>Spray, brush and roller</td>
</tr>
<tr>
<td>Application accessibility</td>
<td>Arc/spay head to within 30° normal to surface</td>
<td>Brush/roll restricted access but life decreases</td>
</tr>
<tr>
<td>Application temperature limit</td>
<td>None but service must be dry</td>
<td>Ambient to about 60°C</td>
</tr>
<tr>
<td>Work Permit required</td>
<td>Hot work</td>
<td>Hot work</td>
</tr>
</tbody>
</table>

TSA / CUI Joint Industry Project

- PR9483: Prevention of corrosion under insulation of steel with TSA (launch May 2005)
- Objective:
  - Demonstrate long-term mitigation of CUI using TSA
- Work scope (provisional)
  - C-steel substrate
  - Insulation: Rockwool, expanded Perlite, closed cell foam
  - Benchmarking vs unpainted, painted, Al foil
  - Constant T: 40°, 90° & 140°C
  - Cyclic T: -5° to +150 °C
  - Aggressive electrolyte (3.5% NaCl) & de-ionised
# Susceptibility Score Table for CS/Low Alloy Steel

<table>
<thead>
<tr>
<th>Operating Temperature</th>
<th>Coating Status when new or last applied</th>
<th>Cladding/Insulation Condition</th>
<th>Insulation type</th>
<th>Remnant corrosion allowance</th>
<th>External condition</th>
<th>External environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constantly &gt;175°C or ≤−6°C</td>
<td>Full QA coating ≤ 8 years, or TSA ≤ 15 years</td>
<td>Good to Engineering Standards or renewed (&lt;5 years)</td>
<td>Contact free insulation, with regular inspection (every 5 years)</td>
<td>&gt; 4mm</td>
<td>Not present</td>
<td>Inside building, not steam traced and not sweating</td>
</tr>
<tr>
<td>150 - 175°C</td>
<td>Full QA coating 8-15 years or conventional coating ≤ 8 years or TSA 15-20 years</td>
<td>Average condition, overall high integrity design &amp; construction</td>
<td>Expanded Perlite, Foamglass, Closed-Cell Foam (good type)</td>
<td>2-4 mm</td>
<td>High integrity design</td>
<td>Low wetting rate (&lt;20% of the time)</td>
</tr>
<tr>
<td>−5 - 49°C and 111 - 149°C</td>
<td>Conventional coating 8-15 years or TSA &gt; 20 years</td>
<td>Average condition, conventional design &amp; construction</td>
<td>Ceramic, Asbestos, Regular Perlite, Mineral/Rock Wool (&lt;10ppm Cl)</td>
<td>1-2 mm</td>
<td>Medium integrity design</td>
<td>Medium wetting rate (20 - 50% of the time)</td>
</tr>
<tr>
<td>50° - 110°C or sweating conditions</td>
<td>Full QA or conventional coating &gt; 15 years or unpainted or unknown</td>
<td>Poor condition, damaged/weak/broken seals</td>
<td>Cal Si, Rockwool (no spec), unknown</td>
<td>&lt; 1mm</td>
<td>Low integrity design or leaking</td>
<td>High wetting rate (&gt;50% of the time) (e.g. cooling tower/deluge systems)</td>
</tr>
</tbody>
</table>

# External Chloride Stress Corrosion Cracking (SCC) Tests

- **Top right - un-coated coupon after 14 days**
- **Below - drop evaporation test rig**
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Appendix 10

Recent advancements of the EFC WP15

CUI Guideline

Maarten Lorenz
Recent advancements of the EFC WP15 CUI Guideline

Working towards a unified risk-based approach to CUI management
Set-up of the EFC WP15 CUI Guideline (1)

- Problem definition – cost analysis
- Ownership & responsibility – staff involvement
- Risk-based inspection methodology for CUI
  - unit level prioritisation
  - challenging the need for insulation
  - reality check
  - determination of risk of CUI failure
- Risk-based inspection & maintenance plans
  - inspection efforts
  - adequate coating and insulation applications
Set-up of the EFC WP15 CUI Guideline (2)

- NDT techniques for CUI
- Susceptible locations for CUI
- Appendices:
  - detailed information on available NDT methods
  - examples of CUI
  - best practices from the field
  - designing out CUI
Objective of the EFC WP15 CUI Guideline

To provide:

- A high level risk-based approach
- Adequate inspection & maintenance strategies
- Best practice from the field

...in order to manage CUI effectively

NOT to provide:

- A detailed prescription of when to inspect for CUI
- Approved NDT techniques
- Mandatory maintenance methods
Use of the EFC WP15 CUI Guideline

- To design optimised plant-specific CUI inspection & maintenance plans - tuned to local conditions
- To facilitate budget approval for implementing effective CUI management plans - life cycle cost philosophy
- To share experience, best practices & state of the art - living document
Way forward from now…

- Finalising editing of draft document
- Include representative examples => your contribution is appreciated!
- Aiming to issue first version mid 2006

CUI cannot be eliminated, but it can be managed!

The EFC WP15 CUI Guideline intends to contribute to reducing unexpected CUI failures, hence improving safety and availability.
Recent advancements of the EFC WP15 CUI Guideline

Thank you for your attention…
…any questions?
Examples… (1)
CUI of 4” insulated gas compressor recycle line
Examples…(2)
Random CUI on insulated storage tank
Examples…(3)
CUI of insulated small bore connections
Examples…(4)
Very local CUI on insulated painted pipelines
Appendix 11

RBI tank inspection strategy

Algra Rindert (RTD Group)
**RTD Tank Inspection Strategy**

**Purpose**

Safeguarding the integrity of the tank:
- while keeping the tank in service as long as possible
- within safety, health and environmental framework

Maximizing tank availability:
- through longer inspection terms
- by smartly combining planning between maintenance and production departments
Scope of work

RBI and inspection plans answer the following questions:
- What to inspect? (what objects, what part of the objects)
- When to inspect? (inspection planning)
- How to inspect? (what techniques, what procedures, to what extent)

Tank Inspection plan

Tank Inspection Plan

- Maintenance history
- Inspection history
- Client input
- RTD best practice
- Norms and guidelines
- RTD techniques and experience
**Inspection timebase**

- Maintenance history
- Visual inspection results
- Client input
- Inspection history
- RTD best practice
- Norms and guidelines

**Inspection cycle in closed-loop**

- Inspections
- Inspection planning
- RBI evaluation
- Repair coordination
- Repair plan
- Repairs and maintenance
Tank 53 customer X

New floor + coating

Tank related costs

Cleaning
Inspection
Maintenance
Production loss

years

Tank 53 customer X
optimal inspection cycle

New floor + coating

Tank related costs

Cleaning
Inspection
Maintenance
Production loss

Onstream inspection

Onstream inspection

years
API 581 RBI

- Internationally accepted guideline
- Based on an extensive statistical study
- Very flexible through safety factors
- Inter-linked with API 653 and inspections
- RTD has written tailor-made software
- Advises on what to inspect, when to inspect and how to inspect (quantify and plan NDT!)

RBI software made by RTD
Client case: risk results floor

Client case: risk results shell
Client case Tank T44 (inspection)

What if we keep inspecting tank T44 using API 581 and API 653?

Present situation:
- Damage factor floor is 145
- Damage factor shell is 1
- Corrosion rate floor is 2.1 mils per year
- ar/t = 0.43
- Inspection confidence is 0.7
- Inspection effectiveness is D1
- Next internal inspection is advised in 2005

Next internal inspection (2005)
- Tank floor is scanned, a repair plan is made and some patch plates are installed
- UT measurements are taken for the floor and corrosion rate is indeed 2.1 mils per year
- Visual inspection is performed
- Only T-scan on shell for corrosion pits, it is still in a good state
API 581 re-evaluation tankfloor (inspection)

- Consequence of failure stays the same
- Inspection confidence goes from 0.7 to 1
- Inspection effectiveness goes from D1 to A1
- ar/t factor becomes 0.31
- DF changes from 145 to 7 (interpolated)
- Next internal inspection when DF reaches 85, this is when ar/t reaches 0.54, in the year 2027

API trajectory (inspection)

- DF grows again over the years to the acceptable limit
- After first inspection DF gets smaller

Likelihood (category)
- Low Risk
- Medium Risk
- Medium-High Risk
- High Risk
## API trajectory (inspection)

### Present situation
- **tank T44**
- **Situation after internal inspection**
  - Damage factor grows to the acceptable limit of 85 in 2027

### Client case tank T44 (maintenance)

### What if the client decides to do maintenance works on the tank and on the tankpit?

### Present situation:
- The tankpit is too small to contain all the product in case of rupture
- The groundwater level is very high
- There is no leak prevention barrier on or under the tankfloor
Client case (maintenance)

- New and higher tank dikes are drawn up from concrete
- The tankpit is covered in concrete to keep groundwater out of the tankpit
- A RPB is installed (for instance coating or a double floor)

API 581 re-evaluation (maintenance)

- CoF bottom leaks becomes 1130 dollars
- CoF rupture for floor and shell becomes 1772499 dollars
- CoF shell leaks becomes 1987 dollars
- CoF financial for shell leaks remains the same
- CoF financial for shell rupture remains the same
- CoF financial for bottom leaks remains the same
- CoF financial for bottom rupture remains the same
Api 581 re-evaluation (maintenance)

- Weighted CoF shell goes from category E to category C
- Weighted CoF floor goes from category E to category C
- Acceptable damage factor floor becomes 250, the calculated damage factor was 145.
- The next inspection date is when ar/t reaches 0.53; this is in the year 2024.

### API trajectory (maintenance)

<table>
<thead>
<tr>
<th>Number of inspections and combined credit</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>ar/t E</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ar/t C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ar/t D</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table notes:**
- Tank C44 has reached a critical damage factor.
- Damage factors above 250 indicate the tank is beyond the re-evaluation phase.
API trajectory (maintenance)

Conclusions tank T44

- First RBI study yielded high damage factor because of insecurities in inspection data
- After the first inspection cycle the damage factor is much smaller (learning effect!) and the inspection term much larger
- Apart from inspections, maintenance has a very positive effect on the integrity and the RBI results
- Tank shell didn’t need inspection, so no unnecessary inspections
TankFarm Integrity Conclusions

- Turn-key service offered by RTD, also includes piping
- Cost-savings through onstream inspections
- Cost-savings through inspection interval extension
- RBI is a strong planning tool
- Easy to build inspection budgets
- Less unplanned outages
- Less unplanned maintenance and inspection
- Better integrity knowledge of the tanks

TankFarm Integrity Conclusions

- Inspections become more specific and tailor-made
- RBI also takes maintenance into account
Appendix 12

In-service equipment integrity

Jacco Rosendaal   (RTD Group)
In-service Integrity Inspection

J.F Rosendaal - March 2006 - NACE Italy

Contents

- In-service Integrity Inspection
- Know the possibilities & limitations
- Major fields of application:
  - Application: Pre-shutdown
  - Application: RBI
- In-service NDT methods
- Conclusion
In-service Integrity Inspection

Means:
- Inspect whenever you want while in-service
- No unnecessary destruction of insulation or other
- Status on interior/exterior of equipment

Possibilities & Limitations

Understanding the request

- There is no single NDT method to find all problems. Every method has charms & issues.
- What exactly is the problem? What does the client expect?
- What can our provider do & what does he needs to know / needs prepared?
- Discussion between provider & client!
- Pre-inspection, quickscan, etc...
Posibilities & limitations
Construct a solid plan

What does the client expect?
What degradations are plausible?
Knowledge of NDT possibilities
Access/ restrictions
Planning (Inspection, scaff.)

Advanced onstream Inspection plan with suitable, efficient NDT techniques

No unnecessary NDT
No miscommunication
Scope is clear: workflow efficient
Cost effective

Application: Pre-shutdown
Minimising Downtime

Common approach
Planned downtime
Extended downtime
Last minute defects are found

The RTD approach
Early in-service inspection
Downtime is shorter as you know exactly where to look with no last minute surprises
**Application: Pre-shutdown**

**Minimising Downtime**

- Severe problem >> Know where to look in shutdown and perform effective maintenance
- Minor problem >> monitor and postpone maintenance
- Clean bill of health >> leave as it is

---

**Application: Lowering RBI risk**

**Evaluate riskfactor by facts**

<table>
<thead>
<tr>
<th>Likelihood Category</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low Risk</td>
<td>Medium Risk</td>
<td>Med. High Risk</td>
<td>Medium-High Risk</td>
<td>High Risk</td>
</tr>
</tbody>
</table>

Level of NDT = Level of Risk
In-service Integrity Inspection

Application: Lowering RBI risk
Adjust riskfactor to latest facts

- Likelihood of failure will increase over time because of time-dependent material degradation

- The likelihood of failure can be reduced by improved inspection planning and good inspection methods

Application: Lowering RBI risk
Postpone required shutdown

In-service Integrity Inspection
In-service NDT methods: Screening and Measuring

- **Screening:**
  - Inspect large sections of equipment relatively ***fast*** with ***low detail***
  - Method only indicates there is something out of the ordinary, nothing more

- **Measuring:**
  - Inspect small sections of equipment relatively ***slow*** with ***high detail***
  - Method gives accurate figures and numbers

In-service Integrity Inspection

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In-service Screening: Equivalent of UT spot check

What is UT spot check?
- Wallthickness measurement at one single point.
- Mapping according to grid
- Only global degradation; detection of local corrosion is sheer luck

In-service Integrity Inspection
In-service Screening:
Equivalent of UT spot check

What is RTD Incotest?
- Wall thickness screening in one single area.
- Mapping according to grid
- Only global degradation; detection of local corrosion is sheer luck

Remote control
In-service Integrity Inspection

**In-service Screening:** Equivalent of UT spot check

- **UT spotcheck**
  - Requires removal of insulation
  - Measurements once during shutdown period
  - Gives exact wall thickness

- **RTD-Incotest**
  - In-service through insulation
  - Measuring whenever customer sees fit
  - Gives average wall thickness

![Graph showing in-service integrity inspection data](image)
In-service Screening: Screening for suspicious locations

In-service Integrity Inspection

False Call

Severe Corrosion

In-service Integrity Inspection

Graph showing Amp (mV) vs. Distance (m)

In-service Integrity Inspection
In-service Integrity Inspection

In-service Screening:
Screening for suspicious locations

- Jetty lines / piperacks
- Roadcrossing with sleeve
- Pipebridge

In-service measuring:
Detailed (Follow-up) Inspection

- Wet insulation (problem cause)
- Starting CUI (problem detection)
- WT measurements (remaining lifetime)
- Sediment or dirt (potential problem)
In-service Integrity Inspection

In-service measuring:
Detailed (Follow-up) Inspection

In Conclusion:
In-service Integrity Inspection

Means:
- Inspect whenever you want while in-service
- No unnecessary destruction of insulation or other
- Status on interior/exterior of equipment
- Decrease downtime - know where to look!
- No last minute surprises
- No problems? >> lower RBI risk >> extend operation period

In-service Integrity Inspection
Thank you for your attention
Appendix 13

Artificial Neural Network for process control and monitoring

Giovanni Zangari  (Process control consulting)
A physical phenomenon is described by a set of variables correlated by physical laws:

\[ y = f(a_1 x_1, b_2 x_2, \ldots n_0) \]

ANN represents an extreme and flexible attempt to codify the relationship between a set of variables (real, discrete and boolean).

ANNs application field:
- Image and speech;
- Banking and business;
- Medical instrumentation;
- Industrial process;
- Social and biology
Condition for a suitable application of an ANN model:
• hard definition and calibration of a deterministic mathematical model
• unsatisfactory performance of other techniques (i.e. Linear and Not-Linear multiple regression)
• not exportability of similar model

Requirements for the application of an ANN model:
• Availability of a set of process observation enough to cover the range of variability of the variables

Required Procedures in the Development of an Artificial Neural Network Model

The list below presents the main activities carried out during the development of an ANN in a suitably order. Some of them are iteratively repeated to achieve the best performance.

• Process variables definition and collection (Input / Output)
• Normalization
• Process variables selection (PCA)
• Process data filtering (out-layer selection)
• Sample extraction to obtain a more uniform distribution
• Training, testing and model definition
ARTIFICIAL NEURAL NETWORK - ANN
INDUSTRIAL APPLICATIONS

• CASTING STEEL (case 1: SOLIDIFICATION)
• ROLLING MILL (case 2, 3, 4: THERMAL EVOLUTION)

• IMAGE CLASSIFICATION (case 5: STRIP DEFECT)
• TIME SERIES (case 6: ELECTRIC POWER DEMAND)

• VIRTUAL INSTRUMENT (case 7: ORGANIC COMPOUNDS CONTENT; case 8: MECHANICAL PROPERTIES OF STEEL)
• CORROSION CLASSIFICATION (case 9: IDENTIFICATION OF LOCALIZED CORROSION BY ELECTROCHEMICAL NOISE - work in progress)
The continuous casting process is described by time dependent variables. A reference data set is made of sample of only correct processes. If an unknown sample is similar to one (or more) from the reference data set, the probability that it regards a correct process increases (otherwise the process should be not correct, not steady or not frequent).

An Associative Memory based on a ANN is trained to codify correct process sample (transient or unspecified process condition are neglected). The network is trained to reproduce in output the same input pattern.

The RMS error is calculated from the difference between the input and output. This identifies a process quality index. The higher the index (the lower the RMS error), the higher the probability that the process is similar to a correct one.

Input Process Variables
- Steel level in the mould:
  - Standard deviation of mould steel level oscillation
  - Mould steel level measure
  - Time trend of mould steel level
- Mould wall temperature:
  - Measured temperature
  - Standard deviation of temperature
- Cooling water:
  - Standard deviation of flow rate
  - Standard deviation of delta temperature
- Casting speed:
  - Standard deviation

The on line version produce the signal below; in most of cases these are related to low quality products. The red circles reasonably identify the time when a product with defect occurred that can be associated to not steady state process condition. The green squares identifies the ANN model response with an RMS error above a threshold.
ROLLING MILL (THERMAL EVOLUTION)
Induction Furnace, Hot Finishing Mill (HFM) and Down Coiler

Bar Temperature Control
Furnaces and mechanical devices

Hot Finishing Mill (HFM)
The Bar is rolled to strip

Run Out Table (ROT)
Steel Strip Cooling with Laminar water cooling facility

CASE 2
Calculation of bar head temperature exiting the last induction furnace to validate pyrometer measurement

CASE 3
Calculation of the bar head temperature entering the first stand of the hot rolling mill to set up

CASE 4
Calculation of the number of cooling elements to achieve a target strip temperature on the down coiler

Pyrometer
Induction furnace n.9

Pyrometer
Induction furnace n.10

Steel bar
Line direction

CASE 2: Calculation of bar head temperature exiting the last induction furnace to validate pyrometer measurement

The ANN Calculate the bar temperature exiting the last induction furnace n.10.
The measure provided by the pyrometer is not reliable due to the presence of scale on bar surface.

Input Process Variables
• steel grade
• strip geometry (thickness, width)
• line speed
• strip temperature after the last but one induction furnace n.9
• electric power supplied by the last induction furnace

Predicted Variable
• strip temperature after the last induction furnace n.10
ROLLING MILL (THERMAL EVOLUTION)

CASE 2: Calculation of bar head temperature exiting the last induction furnace to validate pyrometer measurement

Temperature of the bar out of the Induction Furnace n.10 measured (blue line) vs. predicted (red line) with the Neural Model

- **Input Process Variables**
  - steel grade
  - strip geometry (thickness, width)
  - rolling speed
  - strip temperature after the last induction furnace
  - bar time in the coil box
  - inner temperature of the coil box
  - hydraulic descaling pressure
  - mechanical descaling on/off
  - Burners on/off

- **Predicted Variable**
  - bar temperature entering the hot rolling mill

- **Induction Furnace**
  - Bar Temperature Range Variability: 900°C - 1200°C
  - Mean Error: -0.34°C
  - Standard Deviation: 3.5°C
  - Obs. with abs. error lower than 10°C: 98%
  - Correlation Coefficient (R²): 0.91

ROLLING MILL (THERMAL EVOLUTION)

CASE 3: Calculation of the bar head temperature entering the first stand of the Hot Rolling Mill to set up

The bar head temperature is used to set up the mill.

The measure made by pyrometer is not reliable due to the presence on the bar surface of water, mist and scale.

Moreover, the measure is not available in time for setting up the mill.

An ANN model acts as a virtual pyrometer providing a more reliable and in-time estimation of the bar head temperature.
**ROLLING MILL (THERMAL EVOLUTION)**

**CASE 3:** Calculation of the bar head temperature entering the first stand of the hot rolling mill to set up

The on-line version of the ANN calculates the bar temperature with an absolute error lower than 10°C in the 96% of process observations.

**ROLLING MILL (THERMAL EVOLUTION)**

**CASE 4:** Calculation of the number of cooling elements on the ROT to achieve a target strip temperature on the down coiler.

An ANN model calculates the number of laminar water cooling elements to achieve a strip target temperature during coiling. Also the model can estimate the strip down coiler temperature knowing a water cooling configuration.

The ANN model has been firstly preferred to an equivalent deterministic model because of the necessity to quickly carry out a model. Both the models provide the same performance.

**Input Process Variables**
- steel grade
- strip geometry (thickness, width)
- rolling speed
- strip temperature after the HFM mill
- coiler strip temperature

**Predicted Variables**
- ROT laminar water cooling facility configuration
ROLLING MILL (THERMAL EVOLUTION)

CASE 4: Calculation of the number of cooling elements on the ROT to achieve a target strip temperature on the down coiler.

The on-line version of the ANN calculates the number of water cooling elements with an error lower than 2 elements in the 94% of process observations.

IMAGE CLASSIFICATION

CASE 5: CLASSIFICATION OF STRIP SURFACE DEFECT PROVIDED BY AN INSPECTION SYSTEM

Input feature for defect description:
1. Steel grade
2. defect geometrical dimension
3. picture contrast in grey scale
4. two-dimensional elongation ratio
5. cyclic phenomenon and frequency
6. Strip position
An ANN model performs a time series calculation predicting the electric power demand of a steel work plant. The input pattern is the power demand of the last 60 minutes and calculate the power demand of the following minutes.

The online version of the ANN model calculates the power demand of the further 5 minutes with the following average error.

<table>
<thead>
<tr>
<th>[min]</th>
<th>[MW] error</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.9</td>
</tr>
<tr>
<td>2</td>
<td>7.5</td>
</tr>
<tr>
<td>3</td>
<td>7.8</td>
</tr>
<tr>
<td>4</td>
<td>7.9</td>
</tr>
<tr>
<td>5</td>
<td>8.2</td>
</tr>
</tbody>
</table>

Prediction of electric power demand of the following 15 minutes from calculation time (t0): measured (blue) and calculated (violet)
CASE 7: PREDICTION OF TOC/BOD AND CHROMIUM CONTENT FROM A WASTE WATER TREATING PLANT

The TOC/BOD or chromium content of industrial water after treatment cannot be a fast measure to perform. As a consequence a waste water treating process is not easy to control.

An ANN model acts as a virtual instrument providing a real time estimation of the organic compound content.

CASE 8: PREDICTION OF THE MECHANICAL PROPERTIES OF HOT ROLLED STEEL STRIP (work in progress)

The mechanical properties (Yield Stress, Ultimate Tensile Stress, Elongation and Hardness) of hot rolled steel strip are a function of the rolling and cooling operative procedures.

Input variables:
- Steel chemical composition
- Strip thickness
- Strip speed out of the last rolling stand
- Strip thermal evolution during coiling

Output variables:
- Yield Stress
- Ultimate Tensile Stress
- Elongation
- Vickers Hardness

Ultimate Tensile Stress: measured vs. calculated

Sample number: 1 4 7 10 13 16 19 22 25 28 31 34 37 40 43 46 49 52 55 58 61
CORROSION CLASSIFICATION
CASE 9: IDENTIFICATION OF LOCALIZED CORROSION USING ELECTROCHEMICAL NOISE (work in progress)

The presence of Localized corrosion is identified by analysing the complete electrical signal (current and potential) collected in a time window, its elementary statistical indexes and the parameters provided by FFT performing a multi-variate analysis with a sequence of two Artificial Neural Networks.

The records processed by the ANNs are made of the following information:
- Direct Current signal
- Direct Potential signal
- Slope of interpolating 1st order curve
- Standard deviation
- Skewness
- Kurtosis
- FFT-parameters

The first ANN is an Associative Memory. It classifies uniform and localized corrosion sample: for this reason the ANN is trained only with uniform corrosion samples. The RMS error made by the ANN, processing an unknown sample, identifies the probability to be a localized corrosion sample (applying similarity criteria).

Once a case of not uniform corrosion is identified, a second ANN classifies the type of localized corrosion (pitting, crevice and others).

DESCRIPTION OF THE MAIN ARTIFICIAL NEURAL NETWORK FAMILIES

ANN FAMILIES
- Multi-layer Perceptron using Back Propagation training algorithm (MLP-BP)
- Radial Basis Function (RBF)
- Learning Vector Quantifier (LVQ)
- Constraint Satisfaction Associative Memory (ANN-AM)
Multi-layer Perceptron Network using Back Propagation training algorithm (MLP-BP)

The MLP-BP neural network is employed in both classification problems (producing Boolean and integer output number) and in the prediction of real variables (with real type output number).

The ANN model is used in recall presenting the input pattern on the nodes of the input layer and projecting their activation signal to the next layers, up to the output layer.

The model training procedure concerns the back-ward correction of the connections (weights) between nodes of different layers starting from the output layer to the input one knowing the error between the network output and the target. The knowledge of the physical phenomenon is then codified on the weights.

Radial Basis Function (RBF)

The RBF neural network is similar to the BP-ANN regarding the application fields (Boolean discrete and real variables) and the inner structure also including an extra layer containing RBF nodes corresponding to the centroids of a Cluster Analysis.

The model training procedure concerns first the unsupervised calculation of centroids (RBF layer nodes) by Cluster Analysis and then the back-ward correction of the weights as for the BP-ANN.
Learning Vector Quantization (LVQ)

The LVQ network is suitable only for classification problem. It is similar to RBF ANN because of the presence of the Kohonen layer containing nodes calculated with Cluster Analysis. The nodes of the Kohonen layer identify an attractive pole or prototypes of a class.

### Constraint Satisfaction Associative Memory (ANN-AM)

An **Associative Memory** codifies on the weights of a BP ANN family the association between the sample of a data set. It is trained to reproduce in output the same pattern presented in input. The recall phase can be performed in two different strategies.

**Case 1:** evaluation of the **affinity** of an unknown observation with the data set used in the ANN-AM training: the RMS error can be considered the affinity index: the higher the error, the lower the affinity.

**Case 2:** in case an input pattern has affinity with the training set and the value of a variable is lost, this can be evaluated with a recursive recall of the same pattern.
MAIN ITEMS INVOLVED IN THE TRAINING AND TEST OF NEURAL MODELS

Any ANN developing Tool provides the possibility to perform the activities listed in the figures on the left.

Once the training phase is over, the ANN model is put into ANSI-C source code, ready to be integrated with other existing codes.

Phase 1: Selection of input variables

Phase 2: Selection of the neural structure

Phase 3: Selection of the train and test data set

Phase 4: Scheduling of the training procedure

Phase 5: Plot of the RMS error and classification rate during training