GEOCAP
Geothermal Capacity Building Program Indonesia - Netherlands

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Methods and Techniques in Geothermal Power Plant inspection

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Table of contents

Content

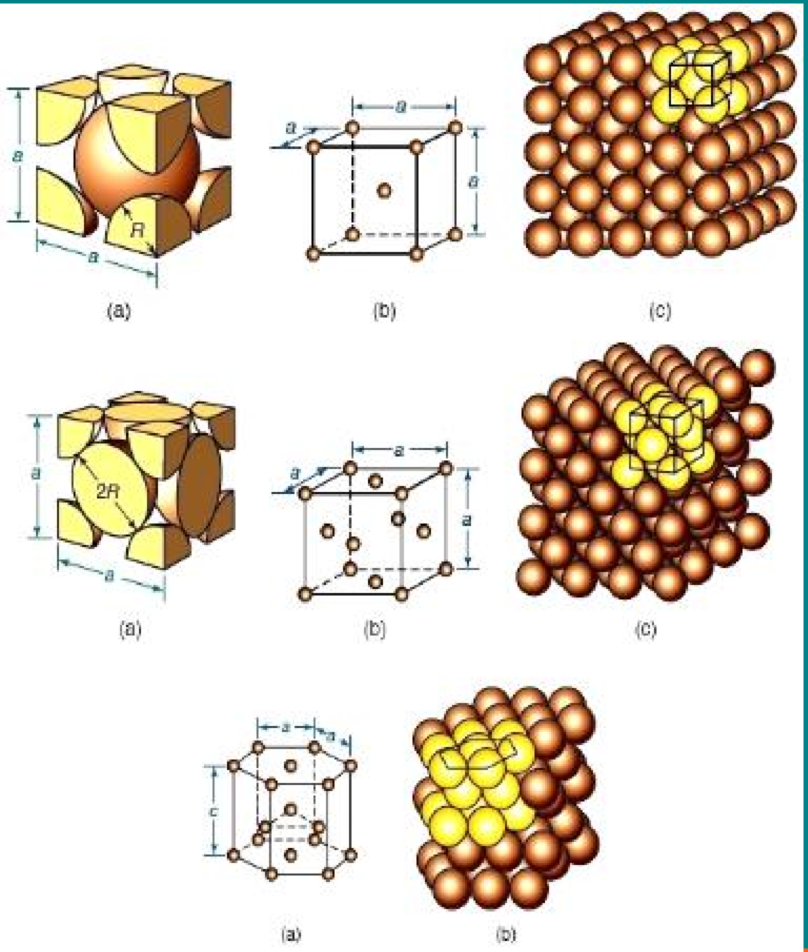
- Introduction
- Material properties
  - **Metals**
  - Polymers
- Material degradation
- Inspection general
- Non destructive evaluation (NDE)
- Failure analyses
- Reporting
- Test

Introduction of metals and metal alloys Structure and behavior

Characteristic of Metals:

- a crystal structure (ordered atoms)
- a shiny surface
- good electrical conductivity (free electrons)
- good to very good heat conductivity
- good to very good deformable

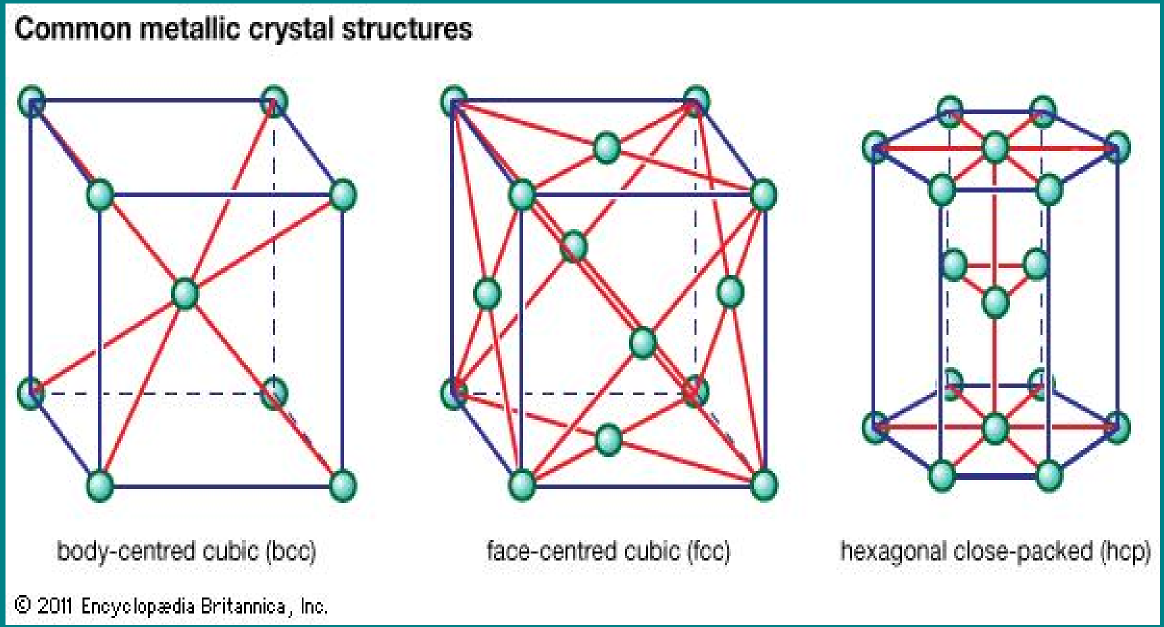
Metals have ordered atomic lattice (crystal)



Body centred cubic

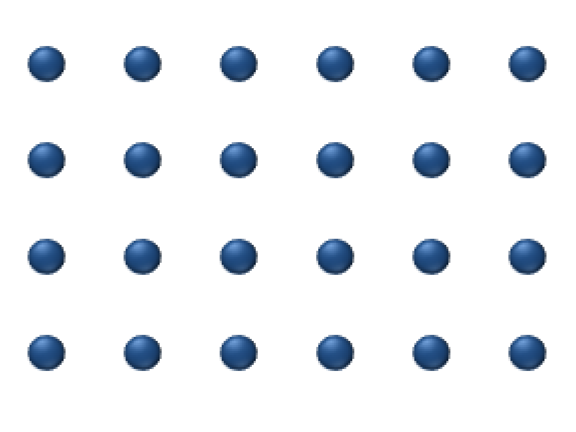
Fase-centred cubic

Hexagonal close packed



FBCC = Ferritic CC = Austenitic

Diffusion



Displacement from matter in matter

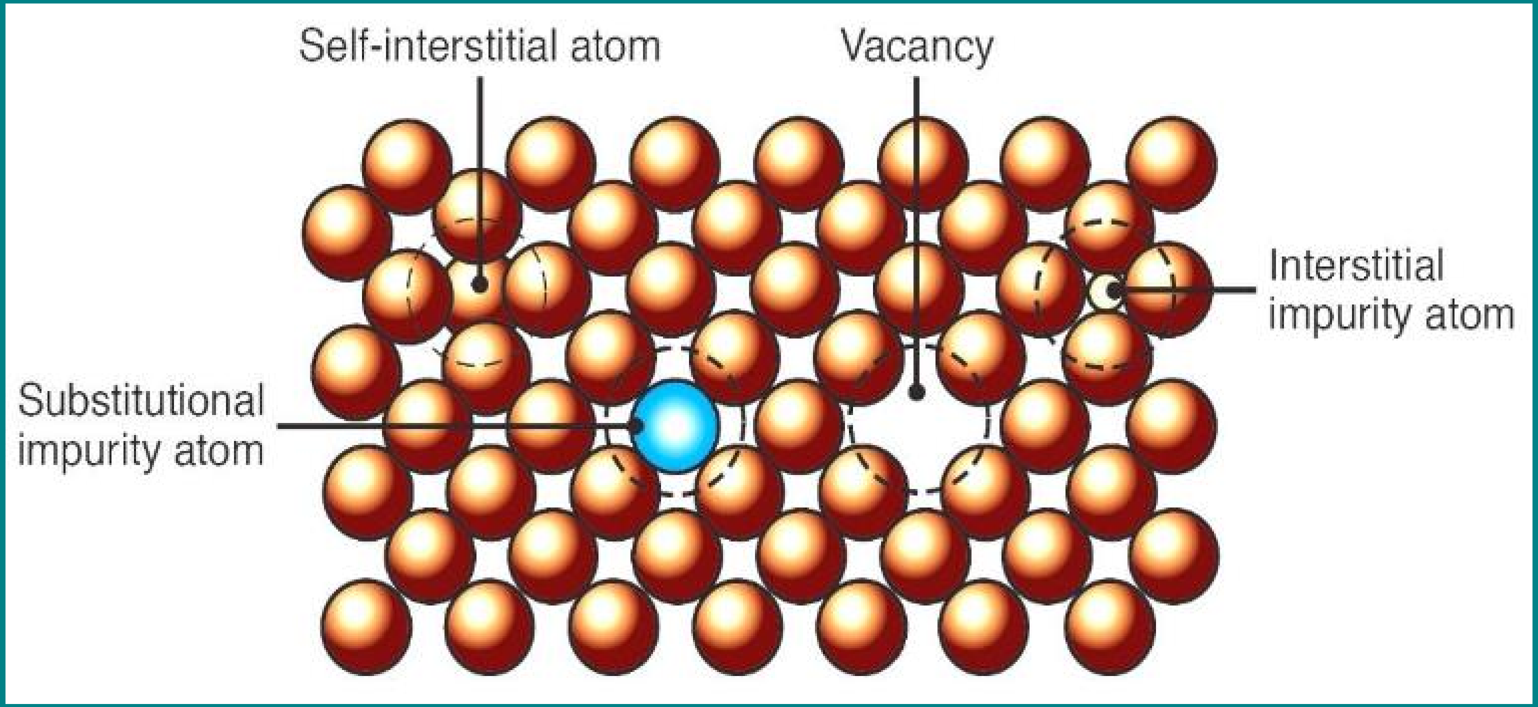
Thermodynamic steered process (concentration differences, temperature, etc.)

Effect occurs in gas, liquid and solids (metals)

In metals concerns diffusion in solid material:

- Internal diffusion (displacement from metal atoms crystal of the same atoms)
- Inter diffusion (displacement from “strange” atoms into the crystal from the metal)
- H^+ diffusion → H_2 gas expansion on grain boundries

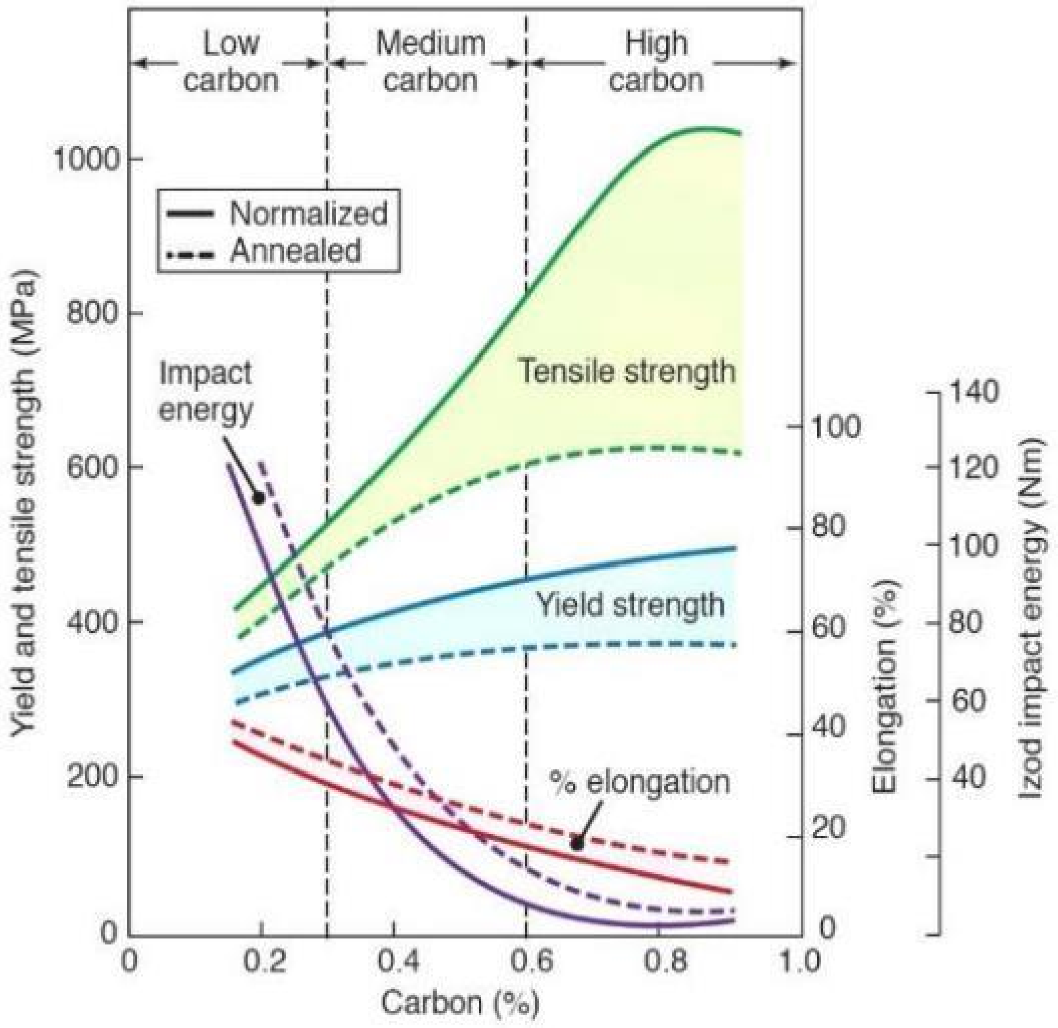
Alloy
(impurty “foreign” atom into the crystal)



Alloy

Example of “foreign” elements added to change properties:

- Carbon (C)
- Chromium (Cr)
- Manganese (Mg)
- Molybdenum (Mo)
- Nickel (Ni)



For example:

- Stainless steel ≈18% Cr, 8% Ni (Inox, 304)
- Duplex steel ≈ 22% Cr, 5% Ni, 3% Mo

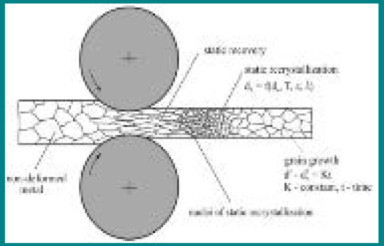
Alternatives to change the mechanical properties

Heat treatment:

- Annealing (slowly cooling)
- Tempering (heating to specific temperature and slowly cooled)
- Quenching (quick cooling), harden steel

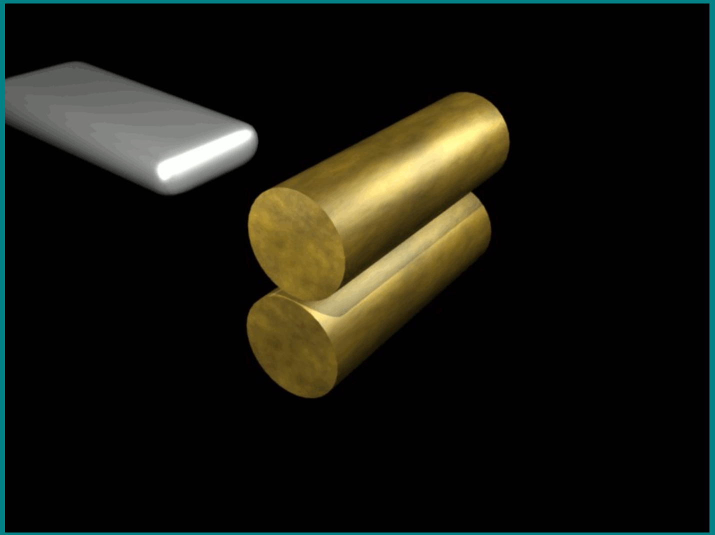
Mechanical treatment:

Work hardening (cold working)



Thermo-mechanical treatment:

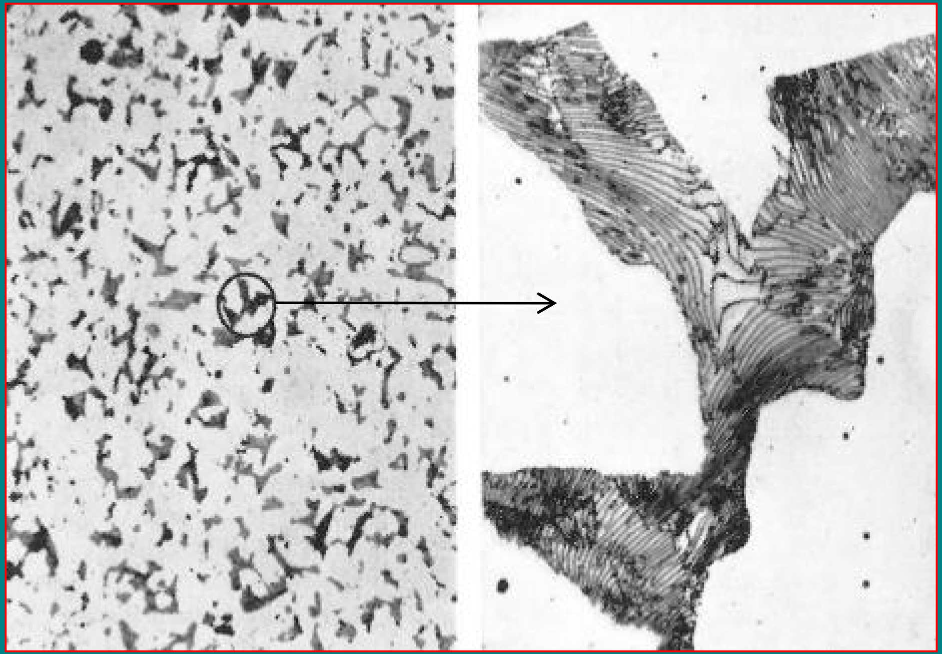
Combination of both two



Steel deformation by rolling

Making sword (temperature and mechanical)

Cooling speed influences structure



Ferrite (light phase) + perlite (dark phase) formed by slowly cooling (annealing)

Martensite (needle structure) formed by quick cooling (quenching).

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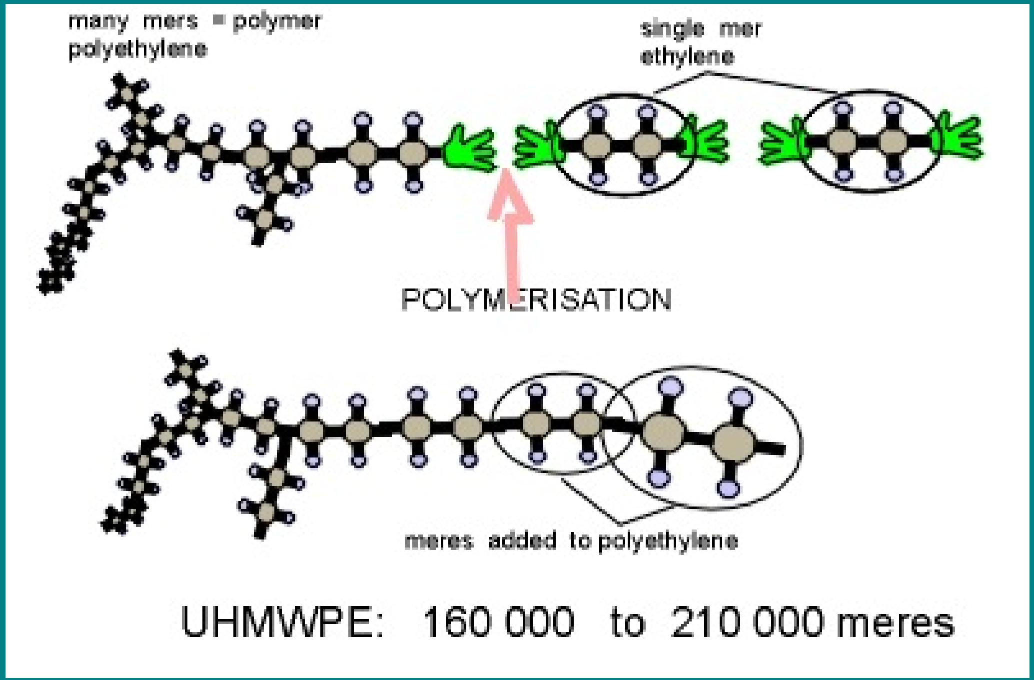
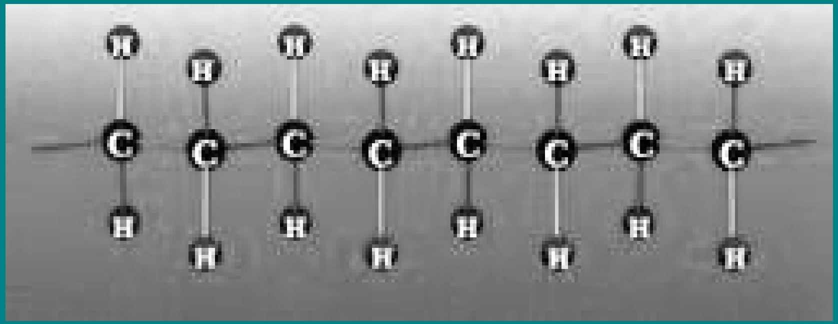
Introduction polymers.

- Polymer = Greek: *poly* (many) + *meras* (parts)
- "material that consist of long chains of repeating molecules groups" (*monomers*)
- Most monomers: main molecule is the carbon (C) atom (→ organic materials)



Physical structure

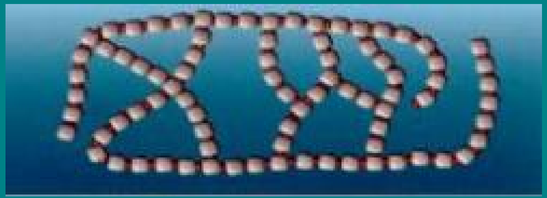


- Very long chains
- Different chain length and configuration
  - (paraffin, LDPE, MDPE, HDPE)
- Partly crystalline of amorf (glasslike)

Melting point and glass transition temperature (T_g)

- Above melting point it can be processed again: Thermoplastic
- Sometimes cross-linked: XLPE (cable isolation), Thermosets (GRP)

Amorf Semi-cristalline



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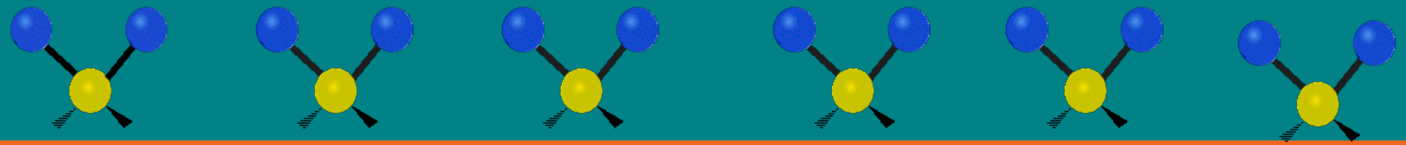
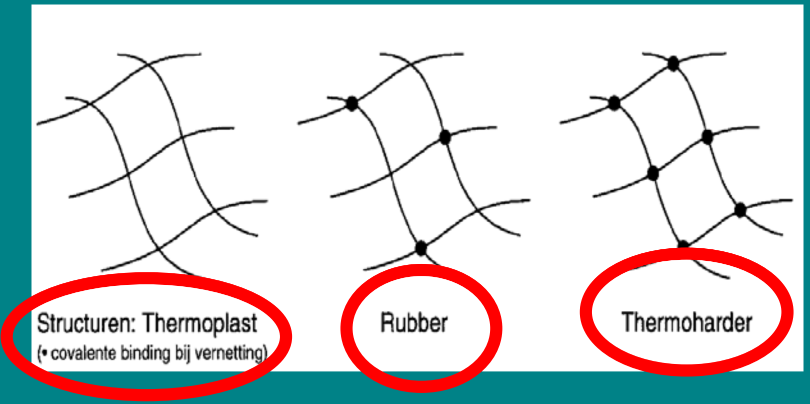
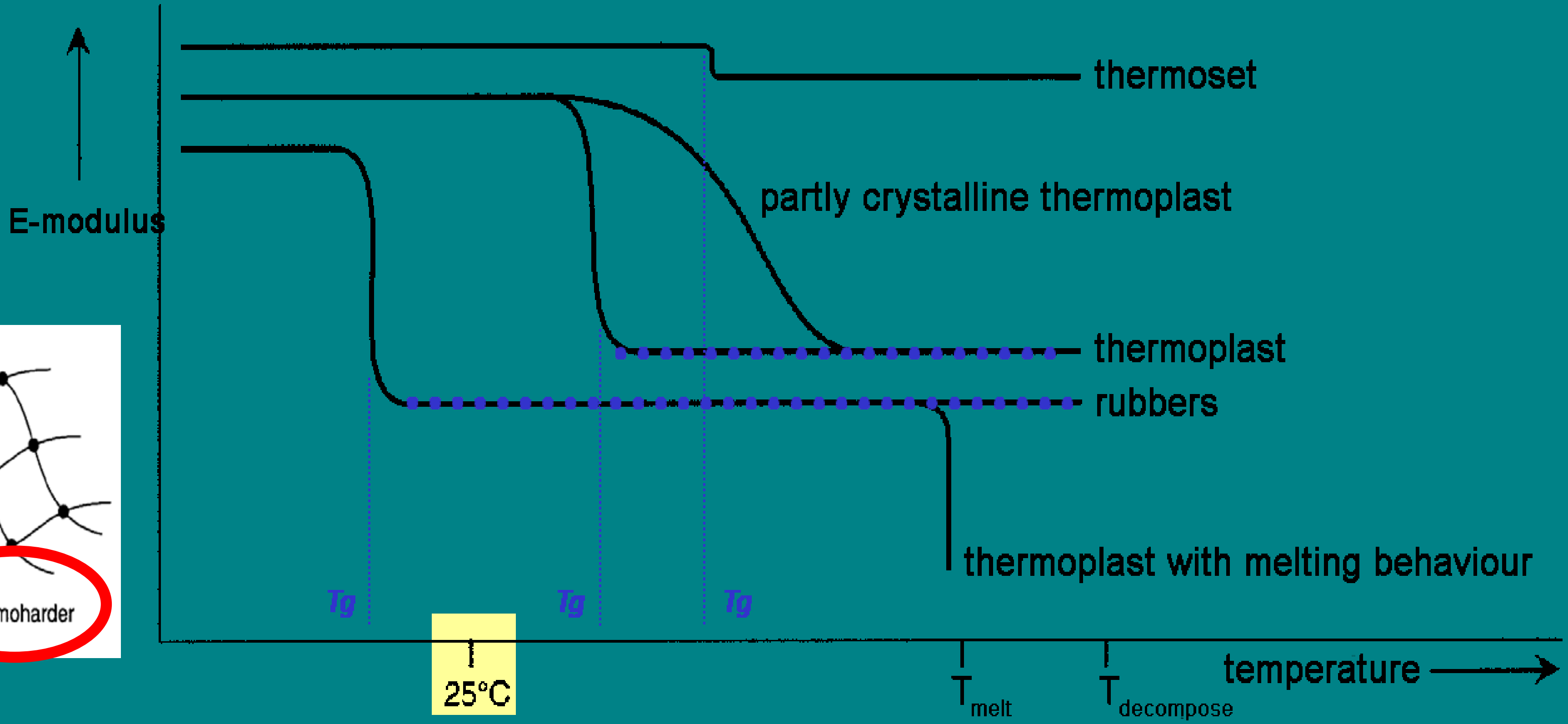


Thermoplastic, Thermosets and Rubber

- Above glass transition temperature (Tg) in de rubber phase (soft)





Coatings

- Coating is a polymer (cross linked)
- Application is critical:
  - Roughness of steel
  - Steel surface free of impurities
  - Humidity and temperature
  - Primer for good bonding between coating and steel

Glass fibre reinforced plastic (FRP)

- First FRP pipe installed in 1950's

- In the 60's the 1st vessels of FRP made and still in use at DSM the Netherlands

FRP

- FRP
  - Different sizes possible
  - Chemical resistance

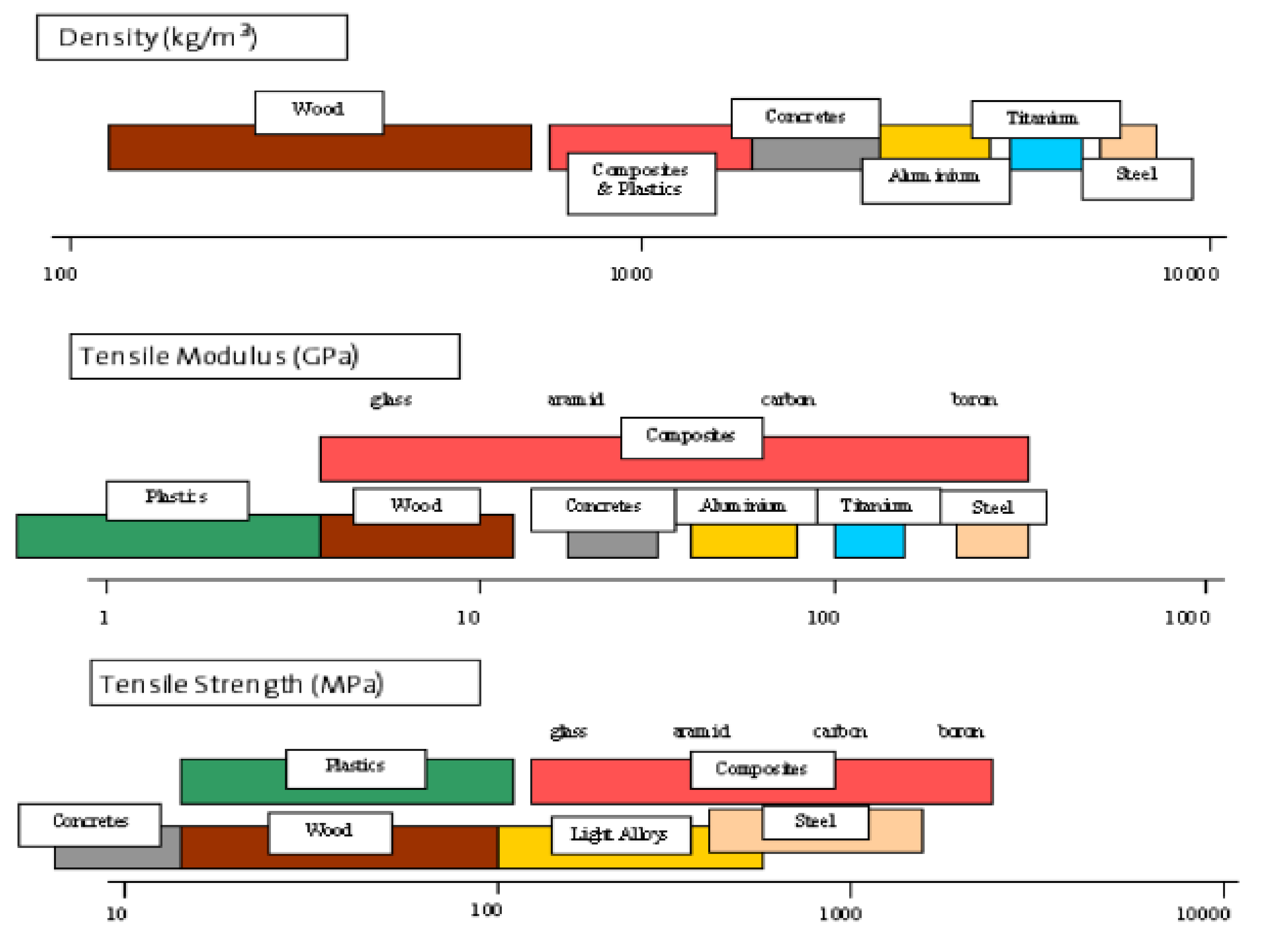
- FRP also called;
  - FRP (fiber reinforced polyester)
  - GRE (glasfiber reinforced epoxy)
  - GRP (glasfiber reinforced polyester)
  - Thermoharder/Thermoset
  - Composite

FRP

- Reinforcement:
  - Glass fibers (E-glass, C-glass, E-CR glass)
  - Carbon fibers
  - Polymer fibers (twaron, keflar)
  - Natural fibers (flax)
  - Sand

- Resin:
  - Polyester
  - Epoxy
  - Vinylester

Different properties different materials



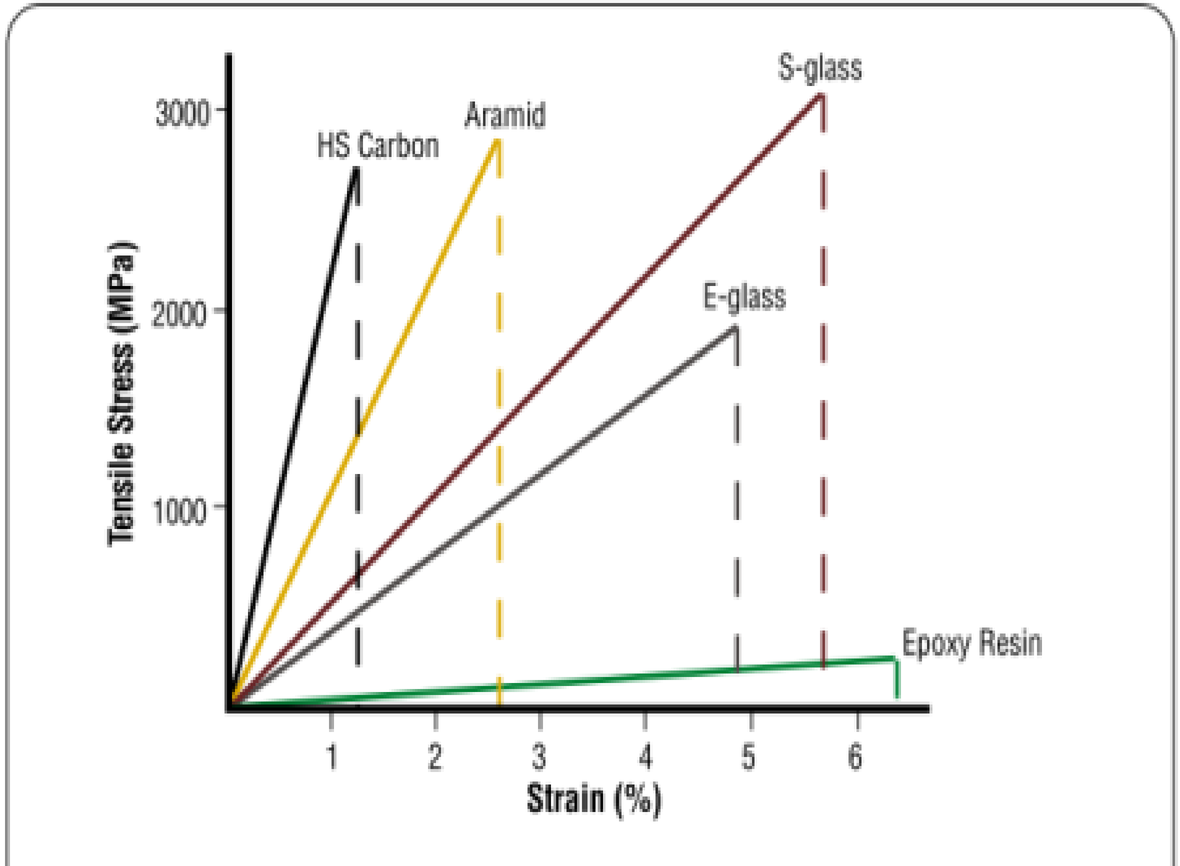
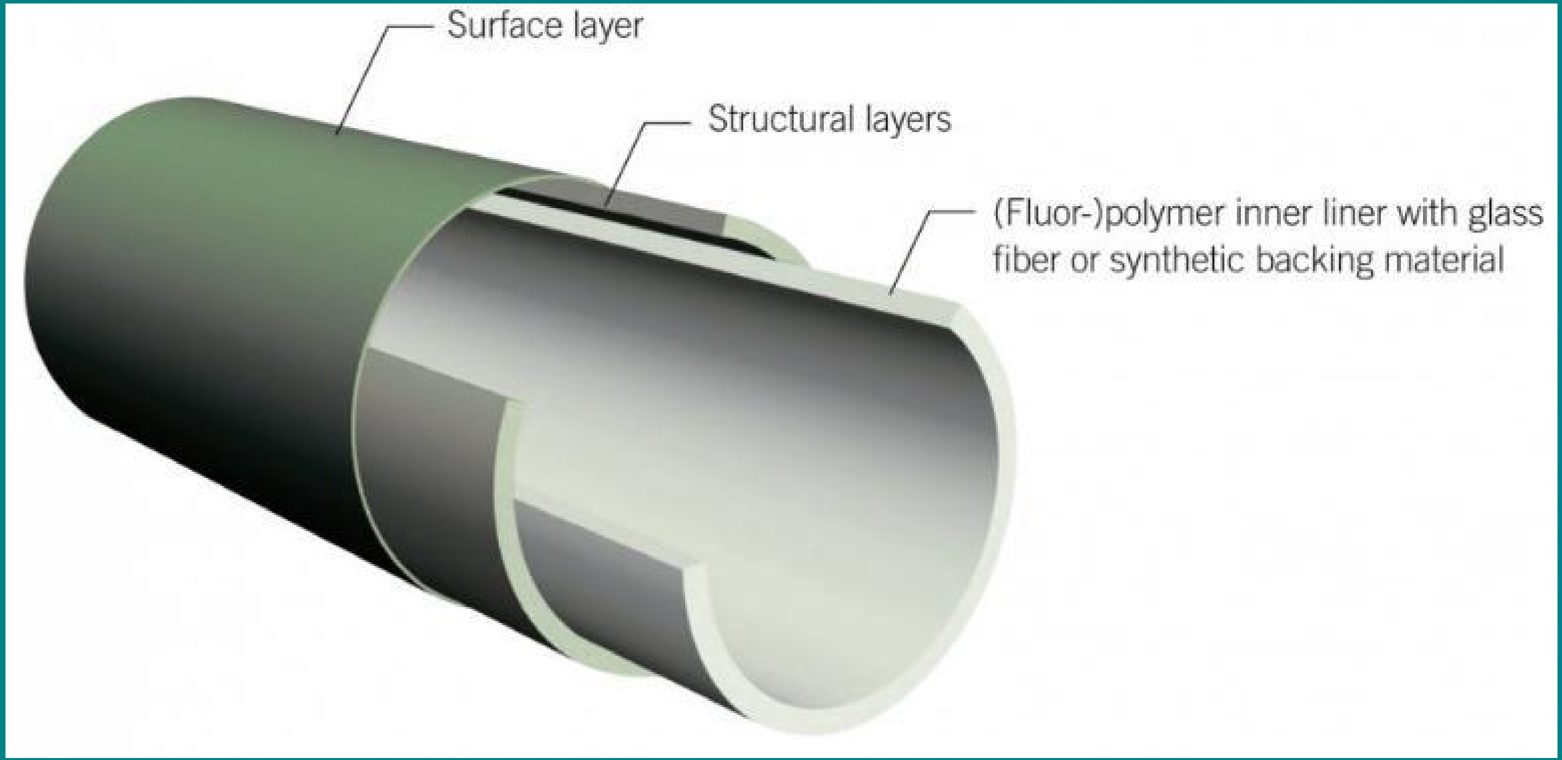


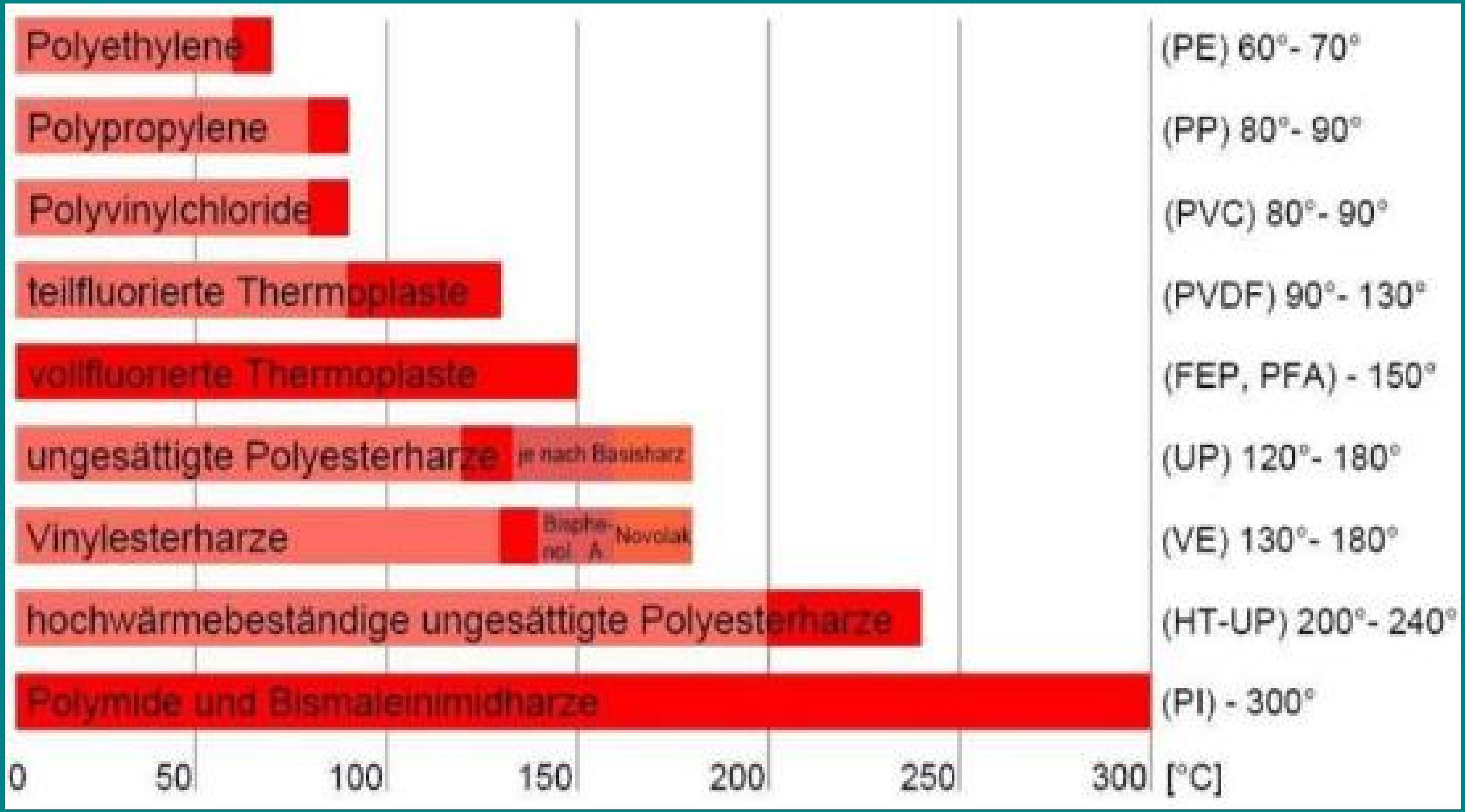
Fig. 12

Additional layers (dual laminate)

- Inner liner
- PE, max. 60°C
- PVC, max. 60-70°C
- C-PVC, max. 85°C
- PP, max. 90°C
- PVDF, max. 130°C
- ECTFE, max. 110°C
- FEP, max. 140°C
- MFA, max. 160°C
- PFA, max. 180°C
- Modified PTFE, e.g. TFM max. 200°C



Plastics and maximum temperatures



Same polymer, different properties:

- Strengthen by extra side chains (PP) and blends (Noryl WW).
- Additives, fibres, softeners (PVC) or oil in rubbers
- Additive like lead in cables (“lead free cables?”), antimone as flame retardants
- Carbon black as UV stabiliser (+ hardener + dielectric)
- Nylon (polyamide): PA 6,6 PA 4,6 PA 11 PA 12 etc.
- Method of processing (press, blow moulding, extruding,…) and process conditions (time, p, T). Effect on % crystallinity (cooling speed), frozen stress and molecule orientation
- Joint techniques (welding, gluing, mechanical)

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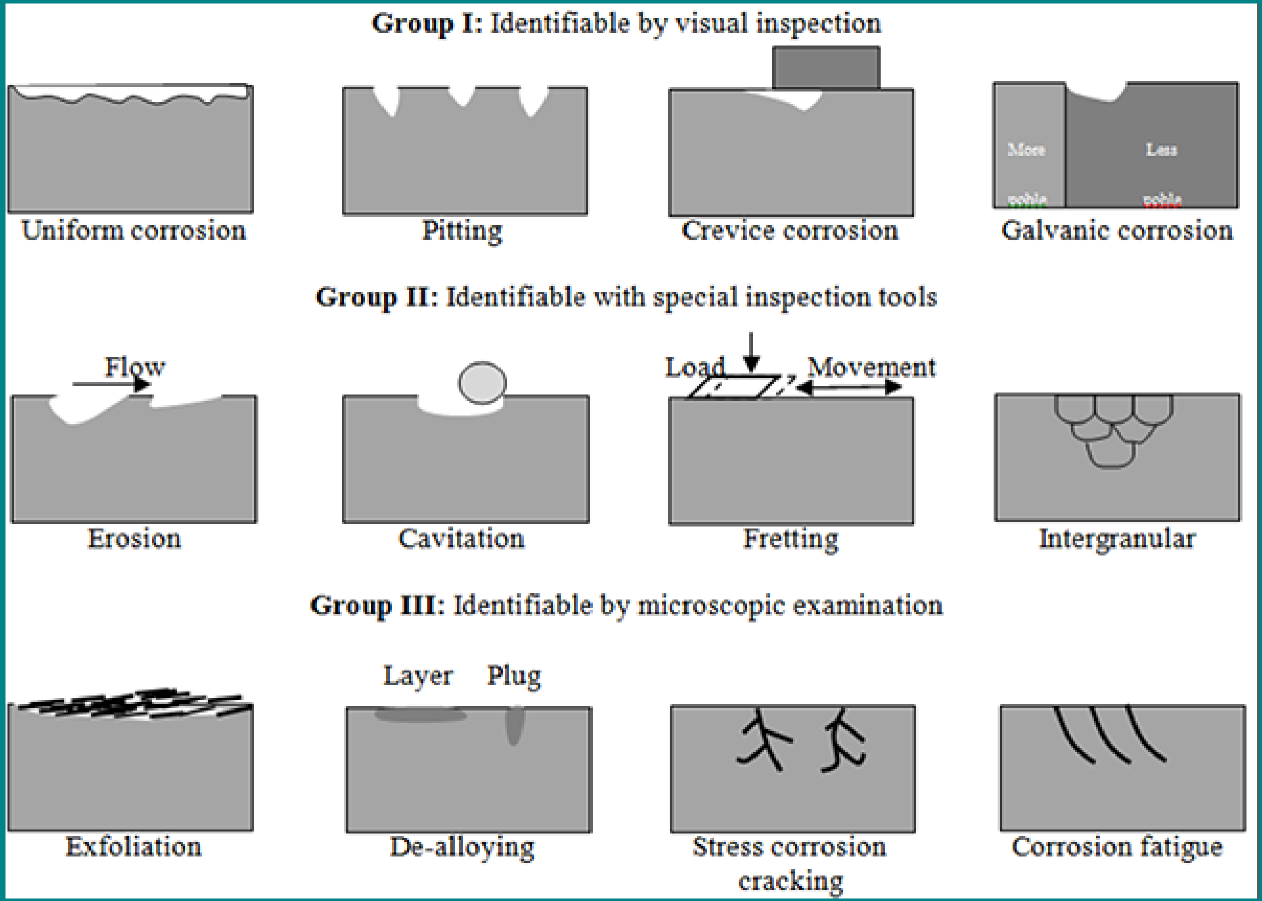
What is corrosion?

- Corrosion: attack of the metal
- Corrosion means degradation of the metal
- Corrosion is an electrochemical proces
- Most common corrosion reaction is steel in water

Types of Corrosion

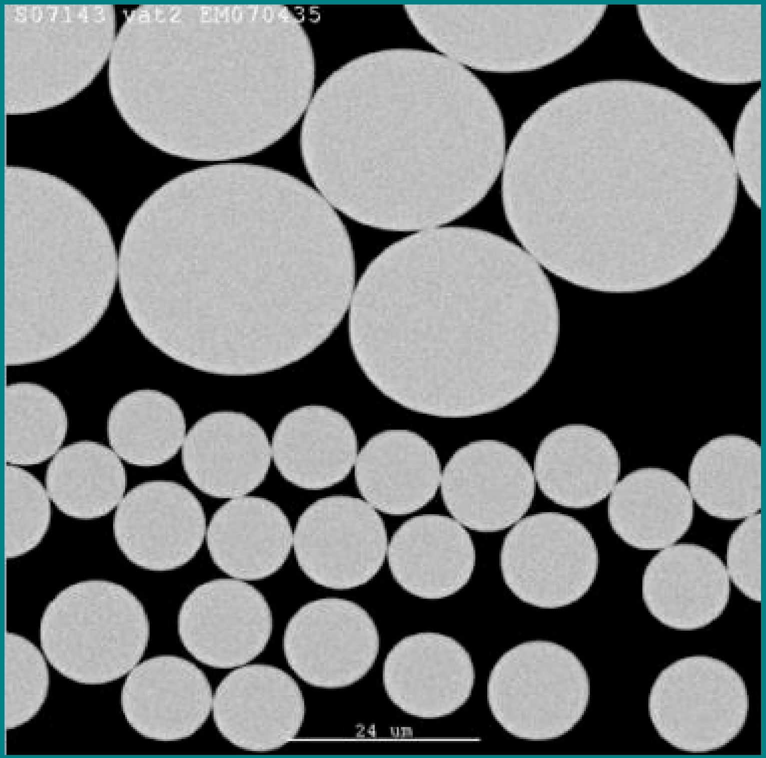
- General corrosion
- Pitting corrosion (under deposit corrosion)
- crevice corrosion
- Tribo-erosion (Erosion-corrosion)
- Galvanic corrosion
- MIC (microbiological induced corrosion)
- Stress corrosion
- Base corrosion
- Corrosion related to specific metals
  - For example stainless steel

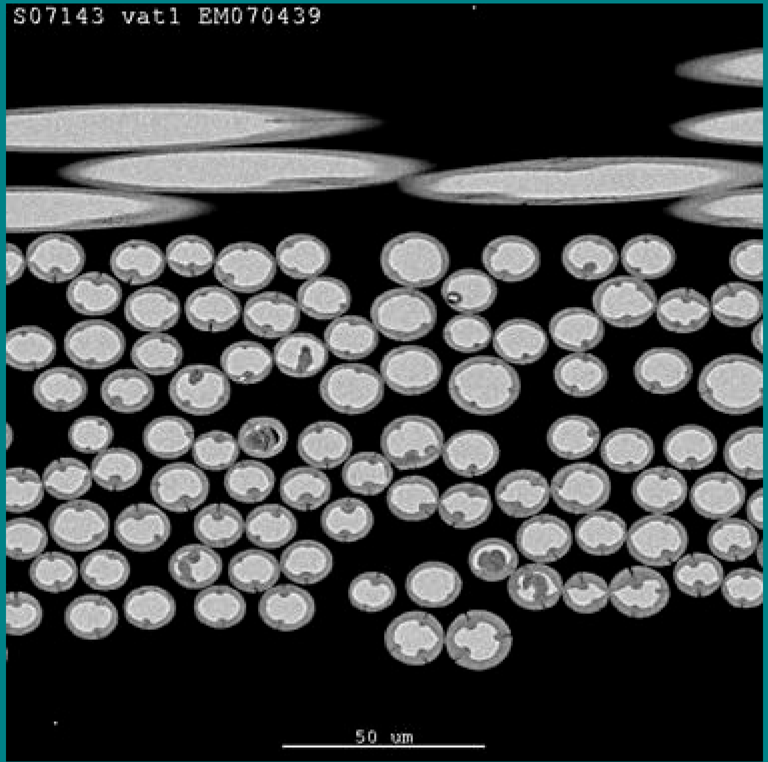


General corrosion

Chemical degradation of GRP

- Degradation of the resin visual as cracks in surface or visual glass fibers on surface
- Degradation of glassfibers (loss of adhesion see pictures)





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Material fail mechanisms:

- Material fatigue
- Thermal fatigue (high cycle/low cycle)
- Mechanical
- Overload
- Creep
- Oxidation
- Overheating
- Embrittlement
- Thermal degradation
- Sunlight degradation
- Cavitation
- Erosion
- Hydrogen embrittlement
- Carburizing
- Corrosion

Damage cases from practice

- Use your common sense
- Stay critical
- Start with an global investigation, focus can be later
- Use the right measurement technique
- See what the components tell you, they don’t lies

Know the installation

- Use all the information out of the monitoring sensors (scada)
  - Temperature drop (loss of insulation)
  - Pressure increase (scaling)
- Plant setup and parameters
- Information from old inspections and failures

Inspection standardisation

- Make a risk assessment for all the parts in the installation
- Make an inspection protocol with more peoples (inspector, user, installation manufacturer, etc.)
- Make for each part of the installation a standard inspection protocol
- Follow the protocol but always look to ‘outsite the “box”’
- Review this document after each inspection and failure

Inspection protocol					
Date:		Location:			
Equipment:		Number:			
Inspection:	Periodic ◯	RBI ◯			
Instalation part:					
Insulation:	Yes ◯	No ◯			
Vessel outsite					
	good	fair	bad	n.a.	remark
Insulation	◯	◯	◯	◯	
Tracing	◯	◯	◯	◯	
wall	◯	◯	◯	◯	
weld	◯	◯	◯	◯	
manhole	◯	◯	◯	◯	
support	◯	◯	◯	◯	
pipelines	◯	◯	◯	◯	
pipe line support	◯	◯	◯	◯	
coating	◯	◯	◯	◯	
earting	◯	◯	◯	◯	
Power/signal cable	◯	◯	◯	◯	
Remarks					
Inspector:					
Date:					

Common failures in steam/supply

Major component	Plant type				common failure modes	Failure causes			
	Dry flash	Single flash	Double flash	Binary		Scaling	Corrosion	Erosion	Other
Down hole pump		X*	X*	X	No or reduced output	X	X		Motor failure Seal failure Bearing failure
Wellhead valves & control	X	X	X	X	Steam leakage Seizure Incomplete shutoff			X	Due to moister flashing in valve body
Steam piping	X	X	X		Excessive pressure drop Excessive condensation Leaks		X	X	Epoxy failure Compression fitting failure
Steam cyclone separators		X	X		Excessive moister in steam output Leaks	X	X		
Flesh vessels	X				Leaks	X	X		Internal and external corrosion
Brine piping		X	X	X	Leaks Plugging	X	X		Stress due rapid heating
Brine booster pump		X*	X*	X	No or reduced output	X	X		Motor failure Seal failure Bearing failure
Final moister separator	X	X	X		Excessive moister in steam output leaks	X	X		

Common failures in geothermal plant

Major component	Plant type				common failure modes	Failure causes			
	Dry flash	Singel flash	Dubble flash	Binary		Scaling	Corrosion	Erosion	Other
Common failures in heat exchangers									
Evaporator				X	Organic vapour leakage				Material defects (cracks) Seal failure
Condensor	X	X	X	X	Insufficient cooling Closed heat exchange tubes Leakage	X	X	X	Suspended material in cooling water Material defects in heat exchanger tubes
Common failures in Turbine generator and controls									
Steam turbine	X	X	X		Reduced or no output		X		Stress corrosion cracking Corrosion fatigue
Organic vapour turbine				X	Reduced or no output	X	X		Fatique
Dual-admission turbine			X		Reduced or no output	X	X		Stress corrosion cracking Corrosion fatigue
Control system	X	X	X	X	Various depending upon system components				Various component failures

Common problems and effected components (1)

Problem	Affected Components
Corrosion (all forms)	Turbine blades/nozzles/rotor, pipelines, vessels, expansion bellows, NCG pipelines, wells, fluid collection and disposal systems, all components, valves, condensers, electrical systems
Scaling	Turbine blades, first stage nozzle box, wells, pipelines, reinjection pumps, separators, condenser tubes, valves, let-down valves at well heads, pumps
Stress corrosion cracking	Turbine blades/rotor, stainless steel vessels, piping, pipe elbows, heat exchangers, 316/304 stainless steel rupture disks, security valves, wherever 300 series stainless steel is used, duplex stainless steel, some higher Ni alloys, condensers, valve shafts
Erosion corrosion	Turbine blades/rotor, LP blades' last stage, steam separators, production piping, reinjection piping, process piping, gland seal system, valve seats
Microbiologically influenced corrosion	Cooling towers (including concrete above vapor space), heat exchangers, pipelines, tube and shell main condenser, condenser tubes, valves
Fatigue	Turbine blades/rotor, pipelines, condensers, heat exchangers, rotating equipment
Corrosion fatigue	Turbine blades/rotor, pipelines, condensers, condenser tubes, rotating equipment

Common problems and effected components (2)

Problem	Affected Components
Solid particle erosion	First stage nozzle box, turbine blades/nozzles/seals, well components, pipelines
Wear (all forms)	Turbine blades/rotor, valve stem, steam seals, steam scrubbers, valves, steam equipment exhaust, compressors
Coating failure	Turbine casing, pipelines, well/line valves, silencers, epoxy coating on mild steel condenser, cooling tower fan gearboxes, miscellaneous plant structural material, Teflon linings, circulating water pipes, Sulfatreat pressure vessels
Creep	Teflon linings
Yielding	Wells
Fracture	Well casing, turbine blades, stainless steel vessels, pipelines, welds
Combination	Turbine blades

Source last 5 sheets "A brief overview of geothermal energy and its reliability implications"; The journal of the reliability information centre, august 2012

Start with an overall view

Keep distance with the first check

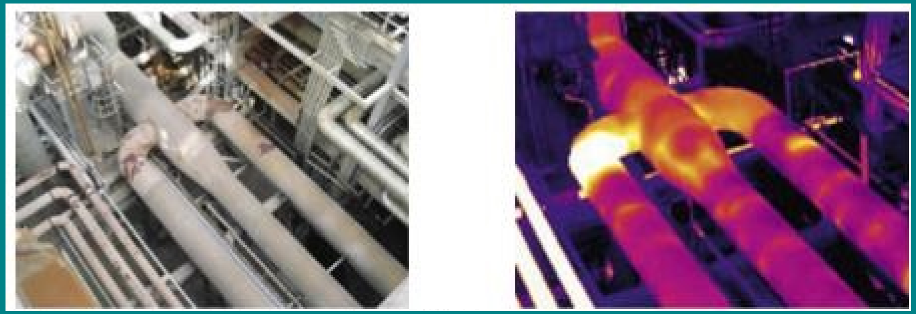
- Look for changes in colour
- Look for deformations
- Look for temperature changes

Infra red inspection examples

- Build up of deposits

- Overheating electromotor

- Refractory lining breakdown



Infra red inspection examples

- Failure in lining

- Wrong installation of insulation
  - Also this type effect when water is penetrated the insulation material.

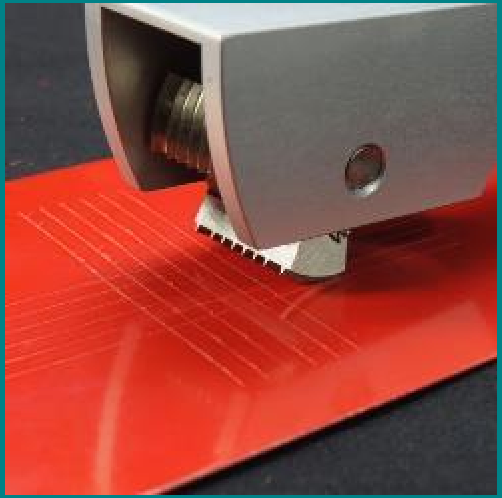
Points of attention in the installation

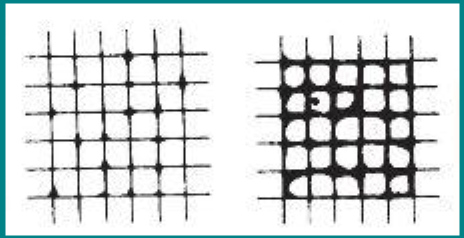
- Pipe bending (Erosion)
- Pipe connections (welds or flanges)
- Valves (leakage and check of still working)
- Polymer surfaces (coating and full products) (UV)
- Wires (cracking of the sheath)
- Piping supports
- Location with high possibilities of scaling

Coating inspection

- Visual check for;
  - Cracks
  - Blisters
  - Discoloration

- Destructive testing
  - Spark test
  - Adhesion (cross cut test)





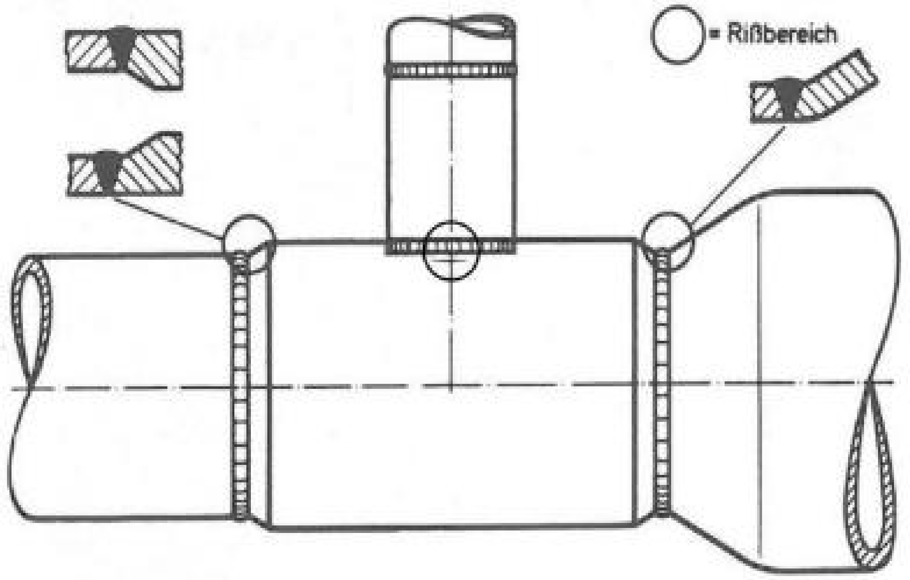
Valves

- Check for leakage and corrosion
- Check for working of valve (open and close)

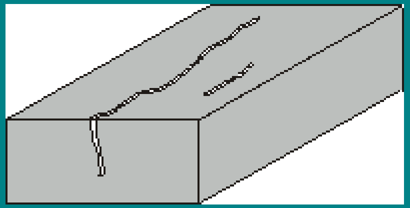
Steam duct

Complex geometry in combination with welds

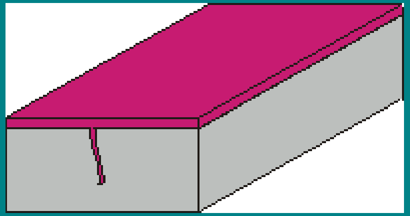
- 3-D stress (different shapes doesn't fit perfect)
- Weakness by holes
- Welding (Heat Affected Zone (HAZ) has a lower creep strength than the basis material)
- Forces and momentum by tapped duct



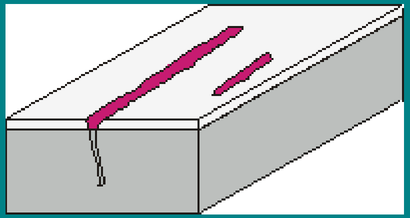
Penetrant investigation



Cleaning of the surface of suspected location



Apply penetrant on the surface and leave it for 15 minutes.
After 15 minutes, remove the penetrant with dry paper



Apply developer on the surface with airbrush. Penetrant will be absorbed out of the cracks.
Red colour penetrant can be use on locations with enough light.
Fluorecent penetrant on dark locations

Crack will be easy visual after using the developer

Fieldwork microscopy: Replica (1)

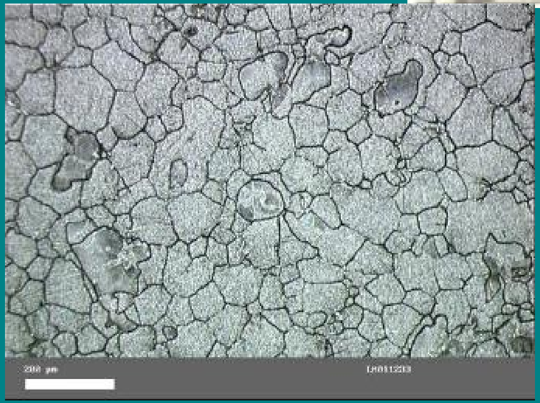
- Preparation surface of part
  - Grind, sandpaper and polishing

- Preparation surface by etching

Fieldwork microscopy: Replica (2)

- Print (negative) of prepared surface
  - Droplet of softener between foil and surface

- Replica sample



- Grain structure

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Non Destructive Testing

Why perform NDT at all? (1/ 2)

1. Safeguarding the reliability of products, components, installations
2. Preventing accidents & loss of human life
3. User benefits:
   - Good reputation
   - Improving products
   - Production process surveillance and reducing production cost
   - Constant level of quality

>>>

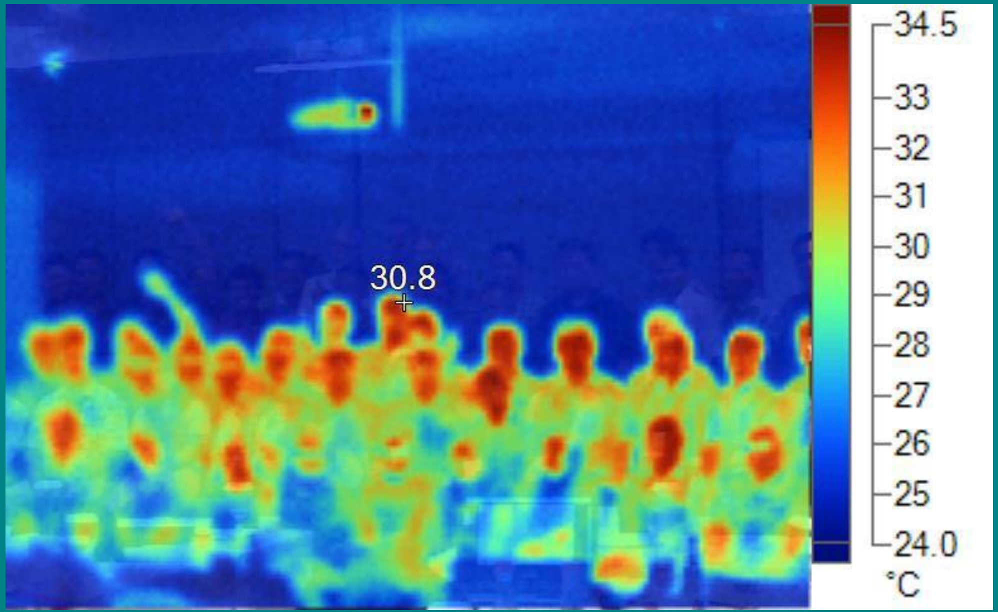
Non Destructive Testing

Why perform NDT at all? (2/2)

4. Timely planning of maintenance: acquisition of parts and services, saving future planned and unplanned down time

5. Planning of revisions based on the assessed condition of an installation /component

Exemple of NDT of Inspector course, March 2017, Bandung



NDT can help preventing....

Result of collapsing boiler component; Algeria 2004, 100 casualties.

- Low pressure steam turbine failure

NDT can help preventing.....

Steam pipe collapse in a coal fired plant in The NL, 2013; miraculously no casualties

Non Destructive Testing

- **At new build plants**

  1. Testing per each component
  2. Integral installation tests

- **During In-service period of a plant (once its operation started)**

  1. Installation in shutdown
     A. Intrusively: (much) dismounting work
     B. Non-intrusively: no or limited dismounting only
  2. Installation in operation (‘on stream’)
     C. On line, *continuous* -measurements (“Condition Monitoring”)
     D. On stream *repeating* measurements, e.g. 1 x per month or 1 x year

Non Destructive Testing

NEW BUILD INSTALLATION → **COMMISSIONING** → **IN-SERVICE PERIOD**

3 years 1 years 40 years

Typical timeline for a large electric power generation plant

Applicable NDT and indeed other type of testing programmes can differ greatly during these stages!

Non Destructive Testing

NDT at new build installations

Features:

1. Not just *component* quality, but moreover: the quality of the *manufacturing* process (e.g. welding) is checked
2. Abundancy of international standards and guidelines
3. Often: routine application / heavily protocolled testing

Non Destructive Testing

NDT in the in-service period of an installation; Features:

1. Aimed at damage and degradation that develop during plant operation;aimed at suspect and critical parts and areas of components :Risk Based Inspection (RBI) approach
2. Little , often *inadequate* standardisation for NDT
3. Follow-up by Fracture Mechanical Analyses after detection of flaw indications and observed material degradation : “Fitness for Purpose“ analysis to make ‘Run/Repair / Replace’ decisions.
4. NDT data to feed into Remaining Life Time Analysis (LTA), answering: how much life time remains and which precautions should be taken into account and at what price

Common NDT Methods & Techniques

Most common industrial ND testing methods* :

- VT: Visual Testing**
- UT: Ultrasonic Testing***
- ET: Eddy current Testing
- MT: Magnetic Testing
- PT: (Dye) Penetrant Testing
- RT: Radiographic Testing**
- LT: Leak Testing
- IT: Infrared Thermography
- AT: Acoustic Emission Testing

*) Within the limits of a testing *method*, several testing *techniques* are used, e.g.: UT-PA and UT-TOFD are two different *techniques*, that belong to the "realm" of the ultrasonic testing *method*

**) There is a distinction between *inspection* and *visual testing*, which is usually: the former is performed with *the naked eye* and the latter with *equipment* (e.g. camera, endoscope) ; in practice it these words are being mixed up!

***) '*Volumetrical*' testing methods : looking (deep) into the volume, opposite to *surface* testing methods

NDT Method: Visual Testing (VT)-1

- VT: Visual Testing

  Important aspect for all NDT but more specifically for VT and RT:
  Vision tests

  - Naked eye (= Visual Inspection)
  - Magnifying glass
  - Endoscope (fiberscope, borescope);
    - video-endoscope
  - TV camera testing

NDT Method: Visual Testing (VT)-2

- Endoscope inspection: widely used and the start of further testing. Industrial use (L) and home applications within reach nowadays (R)

NDT Method: Ultrasonic Testing-1

- UT: Ultrasonic Testing
  - Manual vs automated testing: AUT
  - Pulse echo: PE (single angle)
  - Time of Flight Diffraction: TOFD
  - Phased Array: PA

NDT Method: Ultrasonic Testing-3

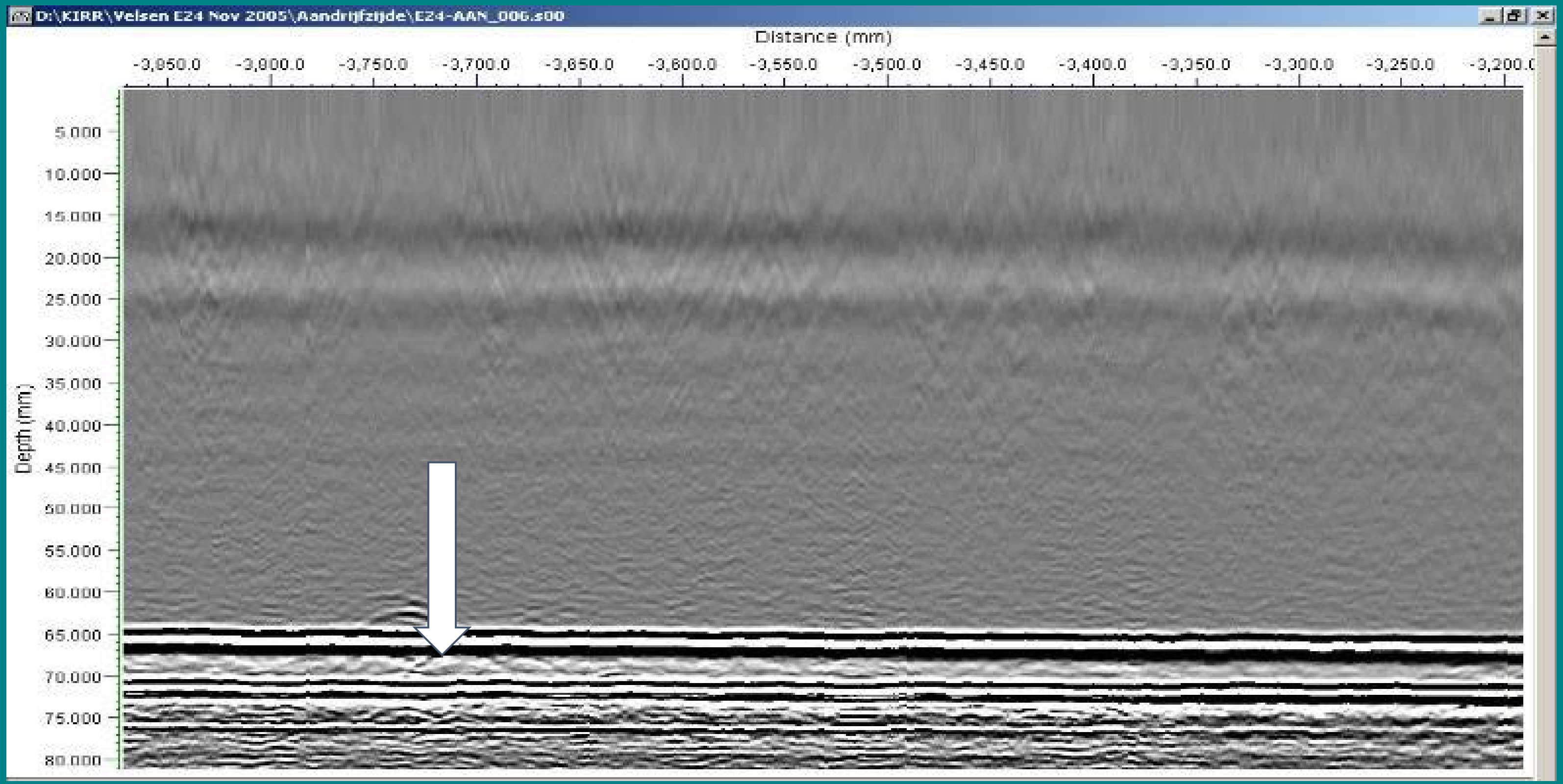
Testing on difficult to reach Places:

- Online-off manipulator to test a specific steam turbine from inside its inlet nozzle;
- UT probe with special shoe.

test piece with spark eroded slots, for calibration..

Mock up for testing handling of the manipulator

In situ inspection of generator retaining rings



Wall thickness

UT-TOFD image with a crack indication at RR's inner surface.

Vertically: UT time-of-flight > wall thickness by back wall echo

Horizontally: circumferential position

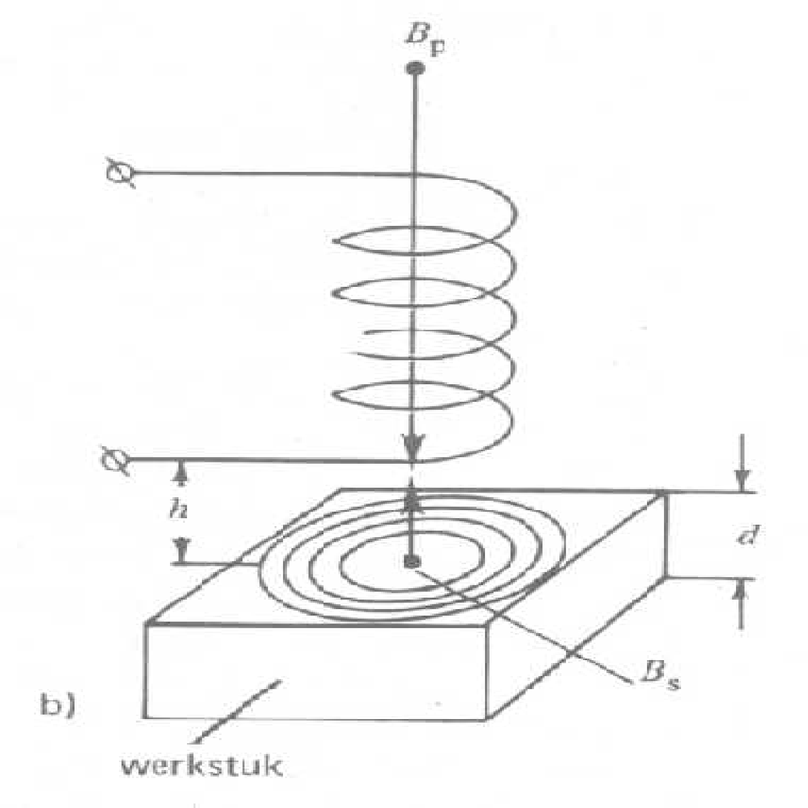
NDT Method: Eddy current Testing (ET)

- ET: Eddy Current Testing
  - Surface Testing (any metallic material)
  - Tube Testing (mostly: Heat exchangers)

Specific ET techniques:

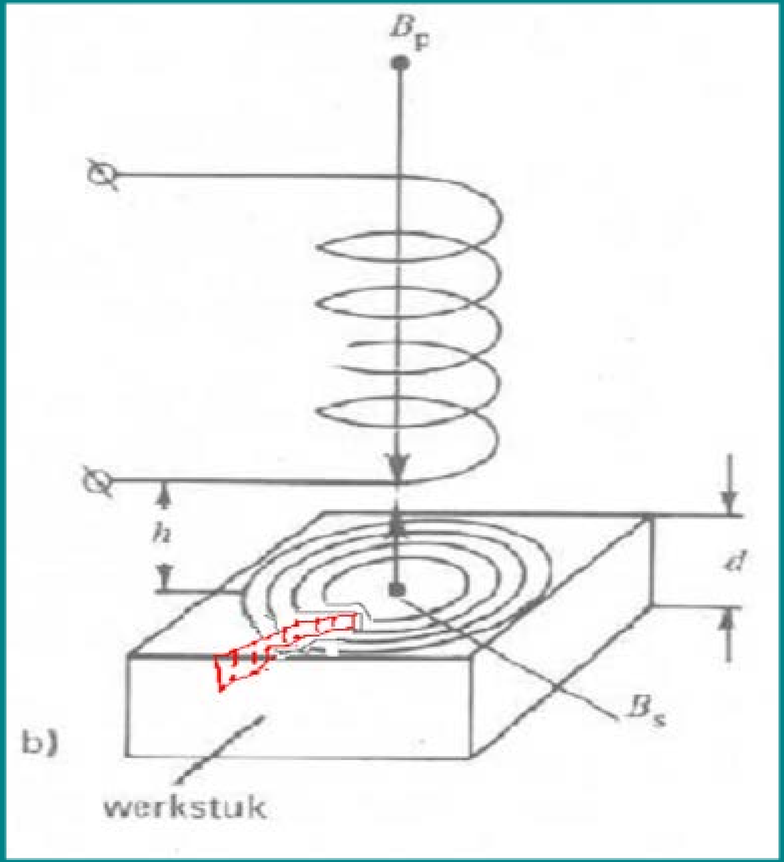
- Remote field ET (RFEC =RFT)
- Partial Premagnetisation technique (PSEC)
- Pulsed ET (PEC)
- Cross wound probes for weld testing

Electromagnetic induction of eddy currents



An alternating magnetic field (generated by a current carrying coil) induces eddy currents in a electrical conducting material (a metal); these currents counteract their source

Electromagnetic induction of eddy currents



This counteracting effect changes at flaws that occur at the surface or just below it (subsurface defects)

Tube testing of heat exchangers

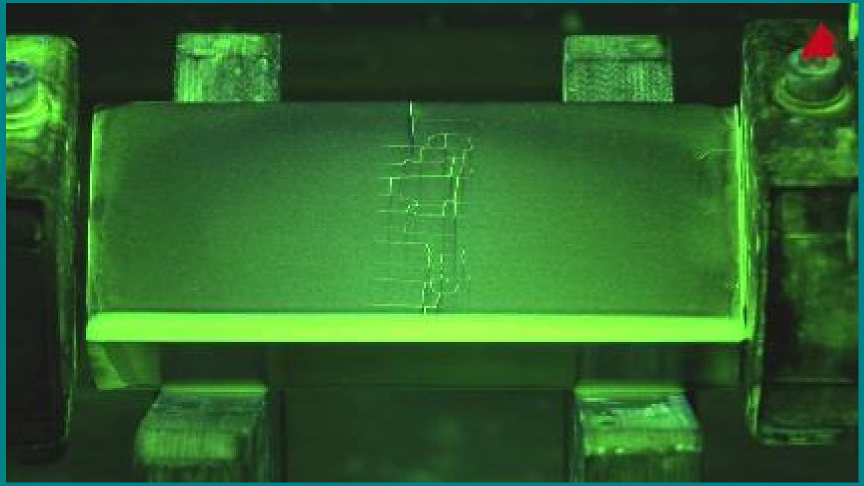
- Flexibele ET (RFT) taster

Example of an RFT probe that can negociate curved tubes

ET Heat exchanger testing :

Manual probe insertion for small numbers ;
Mechanical or pneumatical probe pusher-pullers are used for larger numbers (in all pipes)

NDT method: Magnetic Testing (MT)



- Magnetic test rigs for production and large numbers
- Application of magnetic yokes
- Coil technique
- Applying a large current in the test object itself
- MFL : magnetic flux leakage test Hall sensors
- Black & white and UV technique

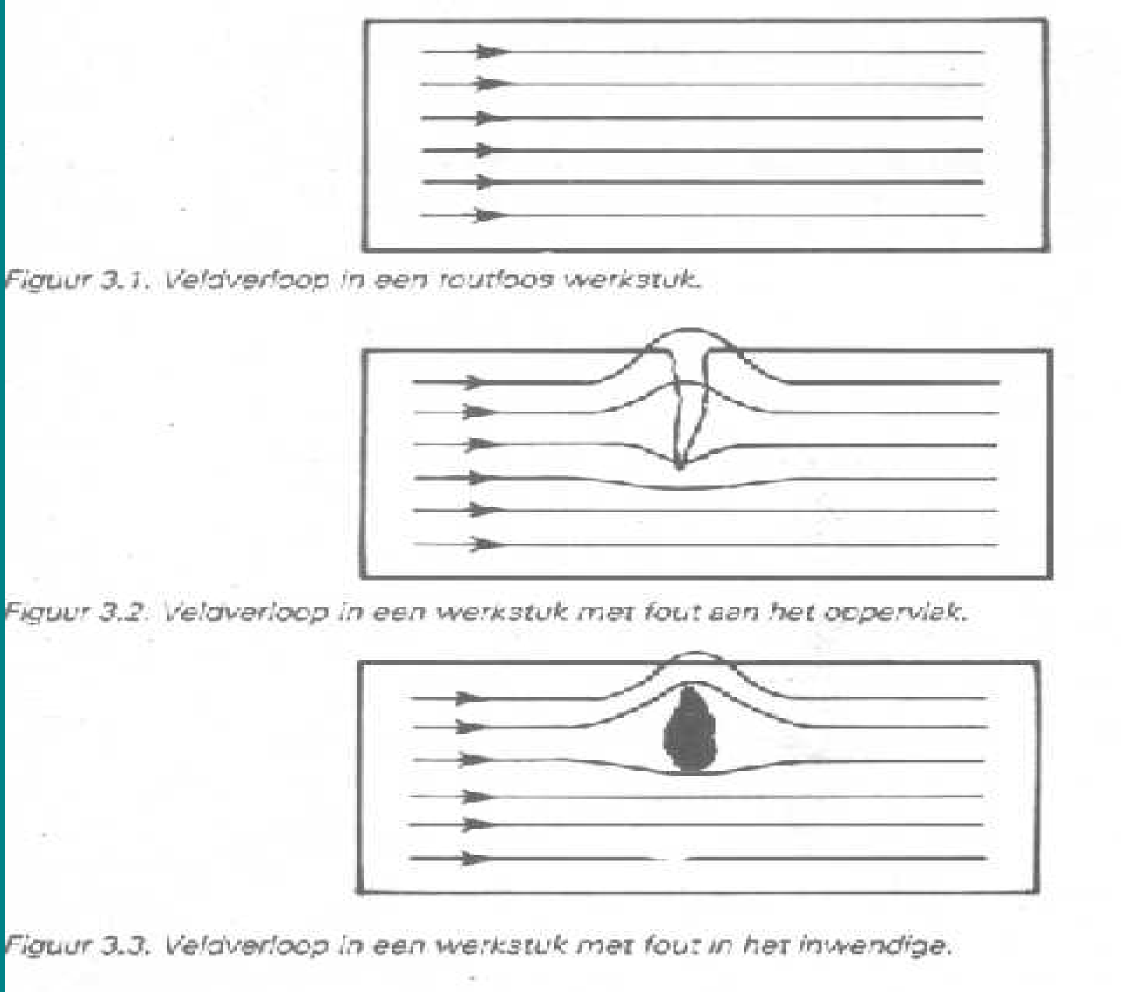
MT-UV test:
surface cracks
visible Fe-powder

Magnetic testing (MT)

Applying yoke - UV technique :

What essential item is missing?

Magnetic testing



Principles of the MT method

Clean surface

Crack or other flaw type: magnetic field lines extend out of the test piece attracting magnetic particles in the applied fluid

Some 'subsurface' capability: visible at surface

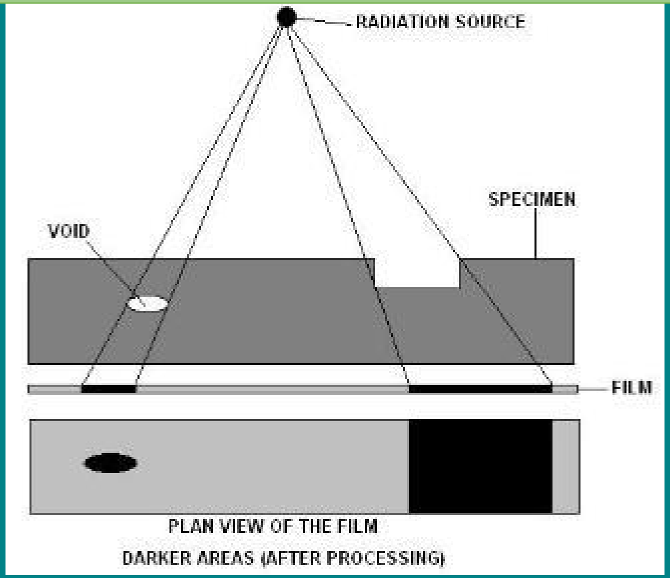
NDT method: dye Penetrant Testing (PT)

- Red /white method
- UV technique
- HT capability: powder applied

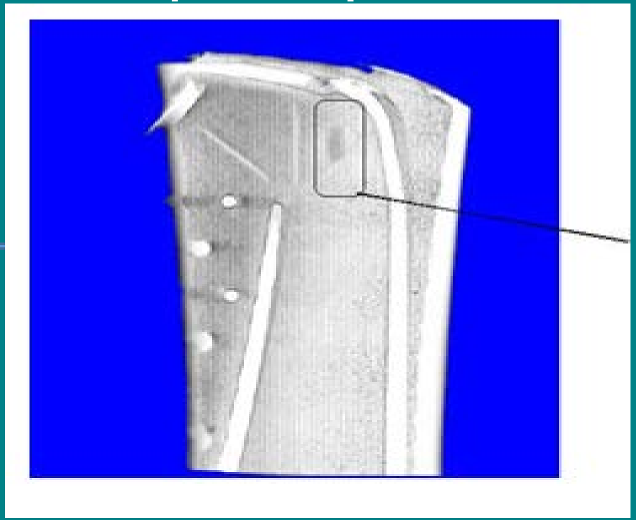
Aspects: imflammability and health concerns of the applied solvents

Radiographic Testing (RT)

- Industrial X-Ray
- Industrial Gamma ray: radioactive isotopes
- Aspects:
  - RT film technique being replaced gradually by digital RT technique
  - Radiation hazard, no simultaneous work can take place
  - Newer tomographic RT : far greater capability
  - Transport and storage becoming more and more strictly regulated



RT principle



3D tomography of a Turbine blade

NDT Method: Leak Testing (LT)

- Many techniques:
  - Pressure drop technique
  - Vacuum decay technique
  - Soap bubble test
  - Tracer gas, (NH_3, SF_6,H_2, He)
  - …….

Leak Testing (LT) method

Helium Leak Testing of new build titanium condensers

This is the most sensitive of all LT techniques; at the steam side the volume is filled with a 5-10% He/air mix and the tubes inside are evacuated at both ends with plates (one shown here); the helium that enters the group of evacuated tubes is detected with a mass spectrometer that is in the loop of the pump connected to the plate with a vacuum hose

Infrared Thermography method (IT)

- Using surface temperature differences
- Passively: “just watching”
- Actively: by inducing a heat pulse/ applying a temperature transient in the test piece

A large current is inducing a magnetic field in the stator core which in turn induces eddy currents to flow in the core laminations ; an IR camera establishes hot spots

AT (or: AE) Method

- AT: Acoustic Emission: “listening to things happening” at a larger range than UT can penetrate; lower frequencies used (100 -300 kHz)
  - promise: on stream integral monitoring of installations
  - problem: validation

AE probe attached to steam pipe

Acoustic Emission Testing Method

Piezo crystal sensor mounted at a wave guide to stick out of the insulation, thereby avoiding coupling problems as a result of temperature transients. Cables are led to a control box; one sensor every 2 or 3 meter

Content

- Introduction
- Material properties
- Material degradation
- Inspection general
- Non destructive testing inspection (NDT)
- **Failure analyses**
- Reporting

Failure mode

- NDT can prevent many failures
- But the possibly of a failure is always there

Generator failure in USA, 2013

When a failure occurs

Last minute risk analysis (LMRA)

- Asses the situation! What are the risks and is the situation different from usual?
- Reduce risks! Which measure can I take to reduce the risks?
- Take action! Take measures to safely perform the work needed for the failure.

When in doubt contact executive!!

When approaching a failure

- Own safety first
- Personal protective equipment
  - Helmet
  - Hand gloves
  - Safety shoes
  - Safety glasses
  - Breath protection

Different route cause possibilities of failure (start with open mind!)

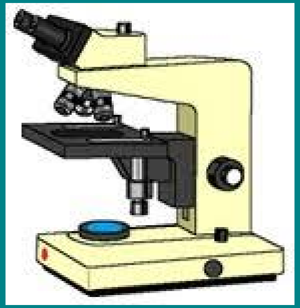
- Design mistake
- Production failure
- Transport
- Unprofessional mounting
- Usage mistake
- Use
- Overdue maintenance
- Wear
- Repair
- Natural disasters
- Maintenance on object next to the fail location
- etc.

Investigating a failure cause

XRF, PMI

Investigate material characteristics

- Chemical composition (metals) (XRF, PMI)
- Micro-structure (LM-SEM-EDS)
- Tensile strength
- Yield strength
- Elongation at break
- Hardness (relation with tensile strength)
- Charpy impact strength
- Creep strength

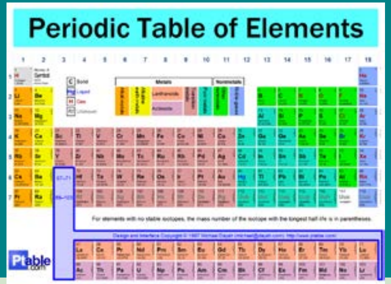


Tensile test

Types microscope

- Stereomicroscope (3D image up to 100x)
  - Fracture surface
  - Corrosion products
- Light microscope
  - Till 2600x magnification
  - Preparation necessary
  - Grain structure visual

- Electron microscope (SEM)
  - High magnification, 100.000x and high depth of fields
  - Vacuum necessary

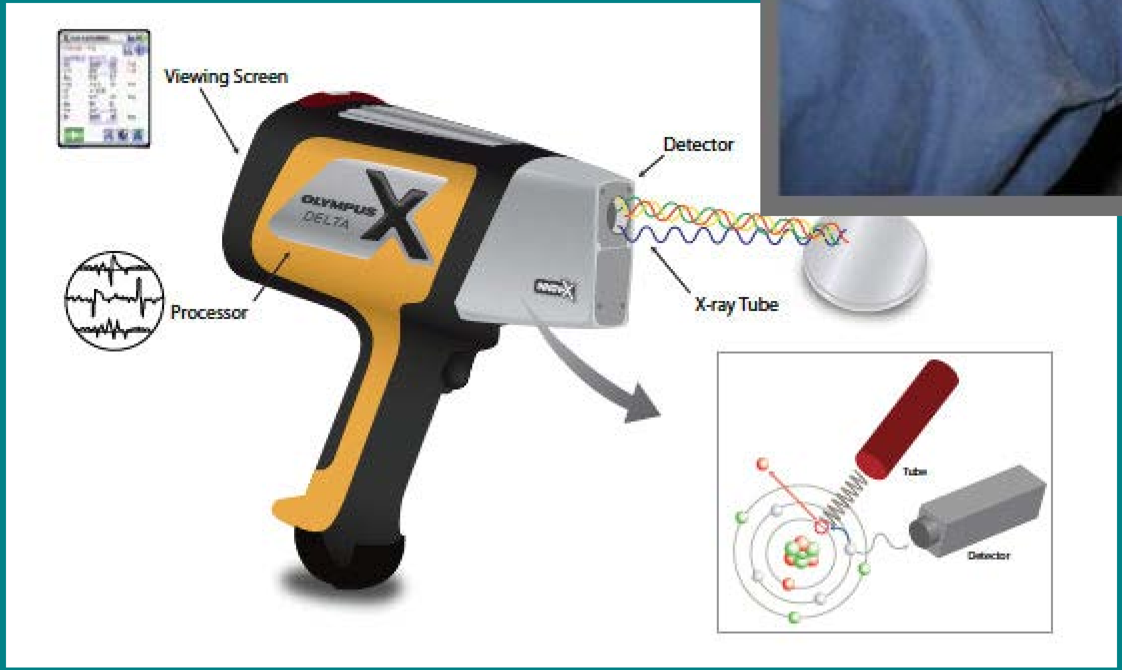


Microscopic investigation. Why?

- Failure starts small
  - The most cracks started small
- “reading” of the material tells you something about the history
  - Material doesn’t lie, but you have to know were to look
- Condition of component is based on the condition of the separate part were it’s built from
  - Material properties like strength and brittleness are based on crystal and even atom level
- Small degradation predict big failures
  - Hardly visual corrosion can predict corrosion failure on long term

XRF/PMI

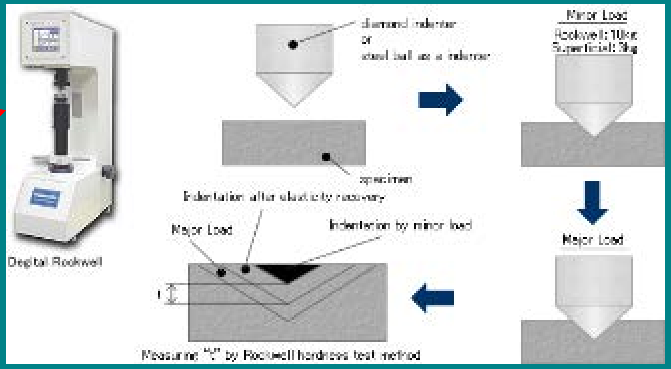
- Bulk element analysis

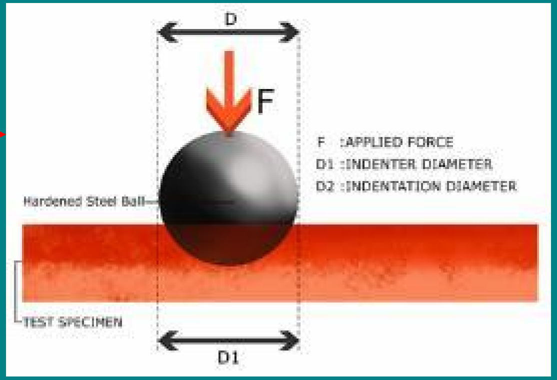


Hardness

Laboratory

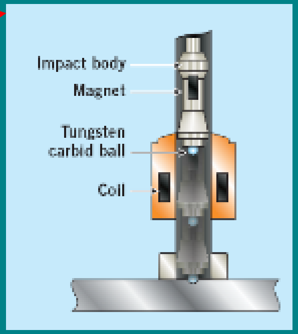
- Static
  - Hardness Vickers
  - Micro Vickers
  - Hardness Rockwell
  - Hardness Brinell

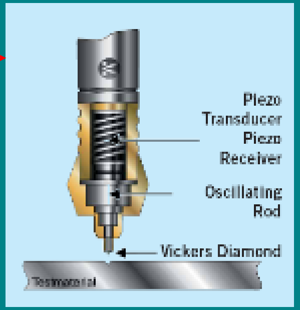




On-site

- Dynamic
  - Equotip (Rebound)
  - Microdur (UCI)
  - Through Diamond Technique (TIV)





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Reporting

- Document all failures in a systematic way
- Make a database of failure reports

Advantage (already when database is being built up):

- Expert tool for failure analysis: a help for the researcher to establish the failure mechanism
- Capture experience in consistent way → older – very experienced personnel – will once retire!

Use of failure database

Advantages (database with large amount of entries):

- Identify critical areas
- Possibly, adapt inspection plans (standard time interval → RBI, Risk-Based Inspections)
- With statistical representative data, this allows for:
  - Accurate determination of failure rates
  - Accurate FME(C)A’s (failure mode, effect and criticality analysis)
  - Reliability modeling
  - Spare part analysis
  - RAMS-analysis

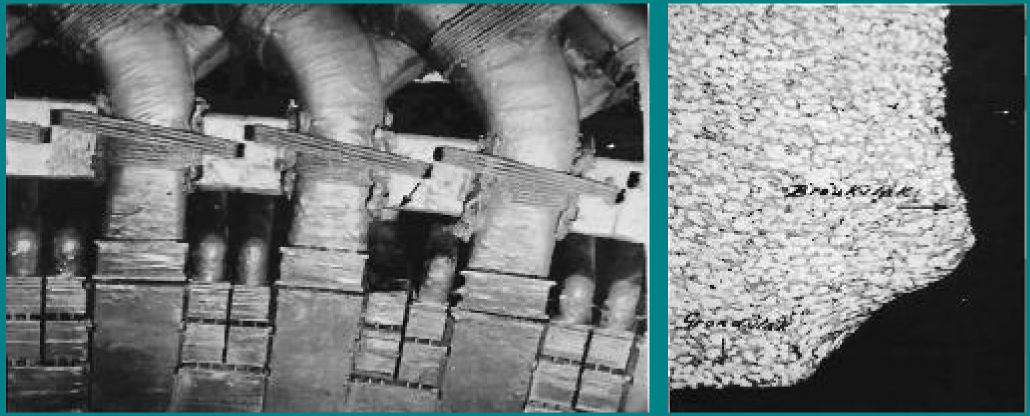
RAMS-analysis

Helpful tool in assessing the following points:

- *Reliability* is a product's or system's ability to perform a specific function and may be given as design reliability or operational reliability.
- *Availability* is the ability of a system to be kept in a functioning state.
- *Maintainability* is determined by the ease with which the product or system can be repaired or maintained.
- *Safety* is the requirement not to harm people, the environment, or any other assets during a system's life cycle.

Database use in the Netherlands

A failure database has been maintained for the power generating companies in The Netherlands by KEMA since 1974



Example of generator failure from 1974

The database includes failures from

- Coal-fired power plants
- Nuclear power plants
- Natural gas-fired CHPP's (gas turbine, steam turbine, HRSG)
- Blast furnace gas-fired CHPP's
- Geothermal

Use: expert tool for failure investigators

Database entries

Yellow coloured fields need to be filled in.

Categories:
- General information
- Plant info
- Operational conditions
- Sampling
- Diagnosis

Information to be extracted from failure report

FAILURE SUMMARY <<FAILURE ID NR >>

General information	
Type of installation	
Component	
Failure ID number	
Code	
Year	
Source	
Plant Info	
Company / plant / unit	
Operating hours since	
System / component	
Type	
Operational conditions	
Operating pressure / temperature	
Medium / flow velocity	
Sampling	
Sample location	
Sample material	
Sample dimensions	
Diagnosis	
Shape of failure	
Location of failure	
Cause of failure	
Advise	

Database entries (explanation 1/2)

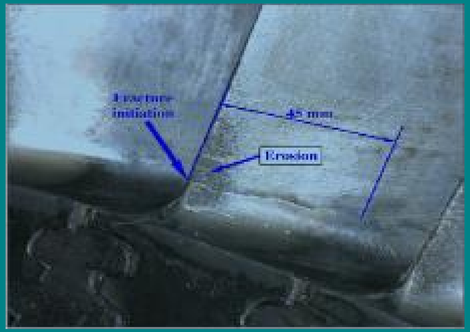
General information	
Type of installation	Dry steam / flash / binary cycle / ORC
Component	(e.g. turbine)
Failure ID number	(to be entered by database manager)
Code	(e.g. KKS-code, is something in use in Indonesia?)
Year	Year when failure was evident
Source	Reference to failure report
Plant Info	
Company / plant / unit	(e.g. Patuha unit 1)
Operating hours	(e.g. 100,000 hrs)
System / component	(e.g. turbine blade, L-0)
Type	

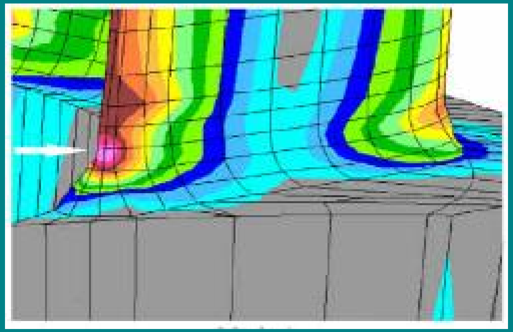
Database entries (explanation 2/2)

Operational conditions	at failure location according to design
Operating pressure / temperature	On location of failure
Medium / pH / flow velocity	e.g. steam pressure, composition, etc.
Sampling	
Sample location	Location of sampling (as specific as possible)
Sample material	
Sample dimensions	
Diagnosis	
Shape of failure	E.g. fatigue, creep, corrosion, erosion, scaling...
Location of failure	
Cause of failure	To be extracted from report
Advice	To be extracted from report

Example failure report (open source (1))

- 28 MW geothermal unit in Mexico
- 37 of 62 L-0 blades cracked at trailing edge
- Lab evaluation showed HCF as failure mechanism and crack initiation was accelerated by steam erosion and corrosion
- Advice is to minimize low load operation as much as possible (natural frequency)





General information	
Type of installation	
Component	Steam turbine
Failure ID number	
Code	
Year	2006-2008
Source	Mazur Z, García-Illescas R, Porcayo-Calderón J. Last st blades failure analysis of 28 MW geothermal turbine. *En Anal*, **2009**, *16*, 1020-32
Plant Info	
Company / plant / unit	28 MW geothermal unit
Operating hours until failure	59,700 hours
System / component	Last stage blade
Type	
Operational conditions at failure location according to design	
Operating pressure / temperature	
Medium / pH / flow velocity	Rotational velocity 3,600 rpm; Von-Mises stress at failur location = 569.2 MPa (yield strength = 762 MPa)
Sampling	
Sample location	Fracture zone: the blade section where the blade transiti radius airfoil-root platform begins.
Sample material	AISI 420
Sample dimensions	
Diagnosis	
Shape of failure	High Cycle Fatigue (HCF)
Location of failure	Fracture zone at 37 failed blades: the blade section whe blade transition radius airfoil-root platform begins. Crack initiate at the trailing edge
Cause of failure	High Cycle Fatigue (HCF) where crack initiation was accelerated by erosion picks on the blade surface due to steam recirculation flow and corrosion.
Advice	Avoid low load situations

Example failure report from (open source (2))

- Well casing failures in different plants in Greece.
- Rising of wellhead, casing joint decoupling, buckling of well casing, collapse and possible buckling of well casing tieback, wellhead leakage.
- Cause is thermal stress while producing or cooling the well.
- Advice to apply slow heating and improve casing design.

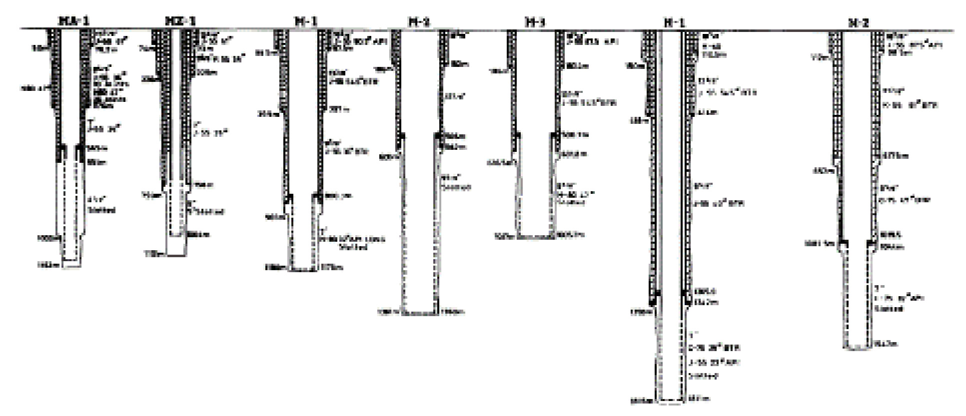


Fig. 1. Casing details of deep geothermal wells on Milos (MA-1, MZ-1, M-1, M-2, M-3) and Nisyros (N-1, N-2) (BTR — Buttress).

eral information	
e of installation	
nponent	Well casing
ure ID number	
le	
r	
rce	Chiotis E, Vrellis G. Analysis of casing failures of deep geothe wells in Greece. *Geothermics*, **1995**, *24*, 695-705.
nt Info	
npany / plant / unit	Milos MZ-1, MA-1, M-1, M-2, M-3 and Nisyros N-1, N-2
erating hours until failure	
tem / component	Wellhead (MA-1, MZ-1), casing joint (M-1), casing (N-1), tieba casing (N-1), wellhead (M-2)
e	
erational	
erating pressure / temperature	Overpressure (due to self-sealing rock) / temperature between 320°C (increasing with depth, 0 - ~1500m)
dium / pH / flow velocity	Geothermal fluids: the geothermal brines are acid and corrosiv abundant in CO_2 and H_2S; high content of NaCl (up to 75,000 and SiO_2 (up to 1,000 ppm); water dominated rather than vapo dominated
npling	
nple location	
nple material	
nple dimensions	
gnosis	
pe of failure	0.5 rising of wellhead (MA-1, MZ-1), casing joint decoupling (M buckling of well casing (N-1), collapse and possible buckling o casing tieback (N-1), wellhead leakage (M-2)
ation of failure	
se of failure	Thermal stress while producing or cooling the well
ice	Unacceptable thermal stresses could have been avoided by a combination of slow preheating before production and proper design (o.a. bad cementing). For a proper casing design, esti the neutral temperature (estimation is described in the paper)

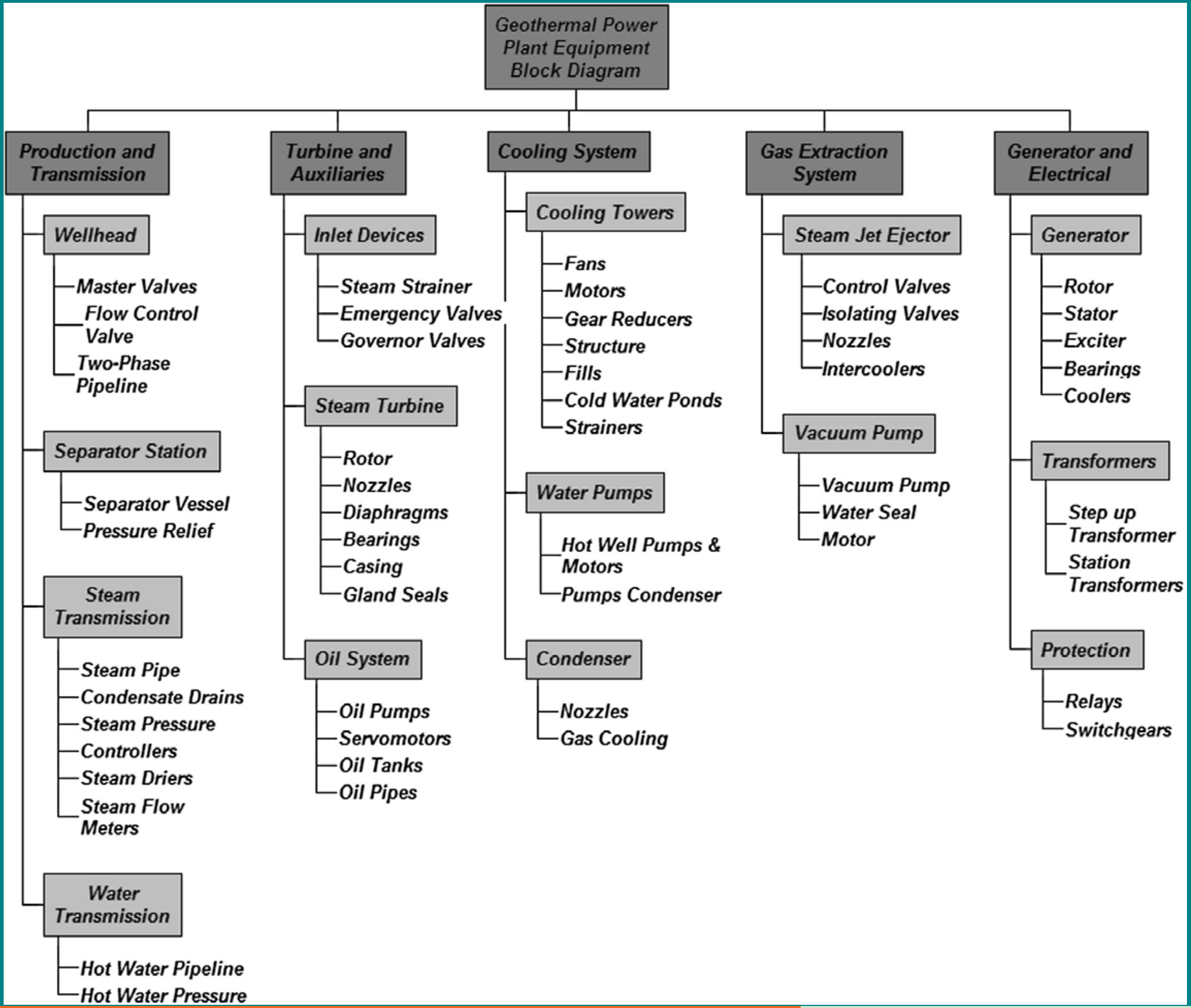
Types of failures

On basis of best expert guess, an FMEA was made by Feili et al. (2013) showing top risks, including following failure modes:

- Wrong control signal
- Failed traps
- Scaling on rotor & diaphragm blades
- Blocking of nozzles
- Fouled cooling tower fins
- Blocked pipes
- Scaling problems
- Corrosion problems
- Failure of transformers
- Failure of motors

Potential failure locations

- By this division the weak component will easily become visible



What can be gained?

- A failure database is an expert tool for failure investigators.
- Sufficient statistics and failure reports will identify risks, allowing for:
  - RBI (Risk Based Inspections)
  - Reliability, availability and maintainability improvement
  - Spare part analysis

Systeem: HP-MP-LP-EVAPORATOR — 65% fraction present in damage investigation all boilers

Functie: EVAPORATE WATER TO STEAM — 9% estimate for heat recovery boilers

											time to initiation, given occurence (yrs)				time to failure, given occurence (yrs)			
	Failure mechanisme	Failure consequence	Failure RC / Influence factor	Counter measure	Probability of occurence	Degradation trajectory present?	Prev / Corrective measure	Probability class	Severity class	Risk	Low	Average	Standard deviation	High	Low	Average	Standard deviation	High
1	opposed flow	lower life expectancy boiler tubes	pressure difference other than expected	apply non-return valve			P	3	3	9								
2	variations in drum level	uneven evaporation, f.e. film evaporation resulting in tube failure	too small drum, no circulation pump in HP evaporator	flowmeter			P	2	2	4								
3	pitting corrosion inside tubes	damage tube bundles	layup corrosion at lenghty stops	conservation when stopped	4%	Y	P	1	3	3		7.3	3.2			7.7	4.5	
14	stress corrosion cracking	tube failure in bends	bends not heat-treated in combination with material used	inspection	2%	Y	P	1	2	2		5.8	2.9			6.3	3.2	

Example of FMECA performed for evaporator based on failure statistics

Lets do the test!

- Go on internet (WIFI connection; ...., Password;.......)
- Make teams of 4
- Login on the website www.kahoot.it or download the app
- Fill in the game pin
- Fill in your name or nick name
- Start the test

- HAVE FUN.