Your design is as good as your materials selection

E.W. Schuring **(ECN)**

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ECN
Your energy. Our passion.

Your design is as good as your materials selection

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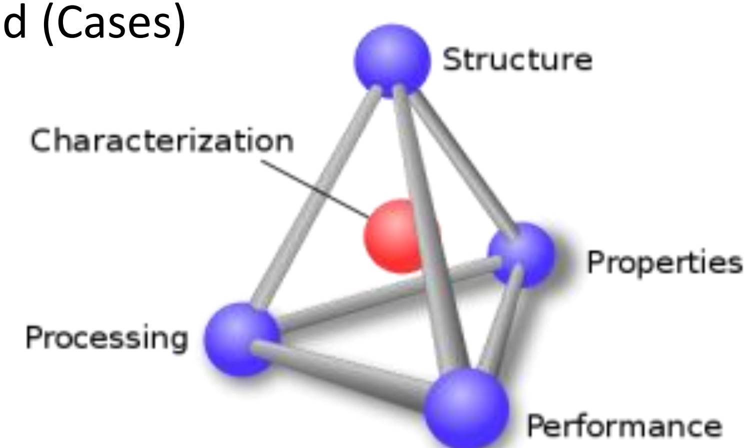
www.ecn.nl

Content

- Some in short about ECN and Environment and Engineering Engineering group
- Why Materials Science?
- Examples of applications: effect of materials selection and design on performance
- Materials knowledge back ground (Cases)
- Conclusions



ECN at a glance

Mission

To develop knowledge and technologies that enable a transition to more sustainable energy systems

5
Commercial licensing deals per year
600
Employees
+/-20
patents a year
EUR **80 M** annual turnover

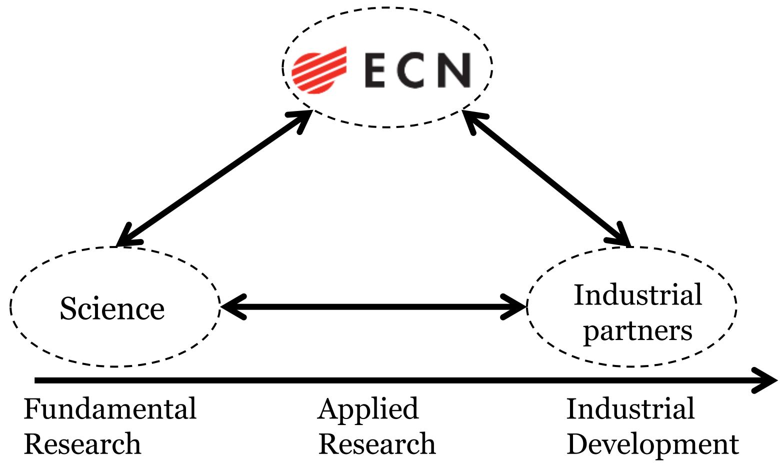
ECN Offices

Netherlands (5)
Belgium
China

ECN Focus Areas

- Solar energy
- Biomass
- Policy studies
- Energy efficiency
- Wind energy
- Environment & energy engineering

ECN aims to be a bridge between science and corporate innovation



What we do

Problem solving
Using our knowledge, technology, and facilities to solve our clients' issues

Technology development
Developing technology into prototypes and industrial applications

Studies & Policy support
Creating insights in energy technology and policy

How we can work with you

Consultancy & Services
Serving your short-term business and R&D needs

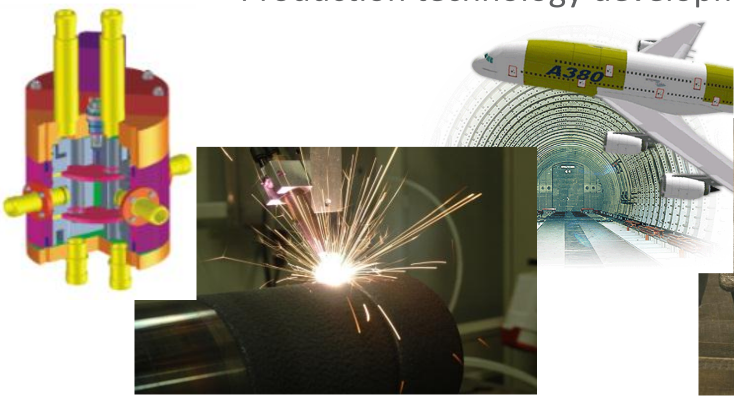
Contract R&D
Support your R&D with our knowledge, technology and (test) facilities

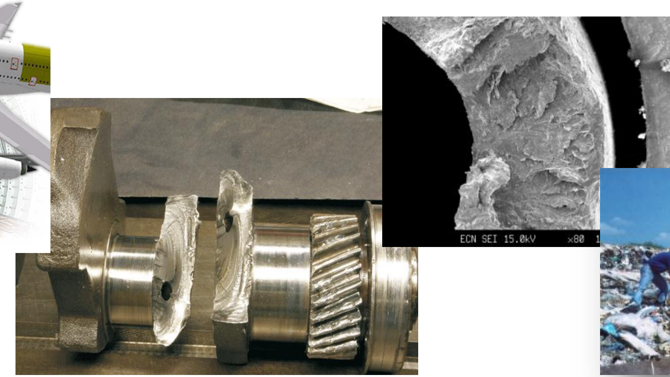
Technology development & Transfer
Implement our technology in products & processes

Joint Industry Projects
Developing tomorrow's technology together

Environment & Energy Engineering: Expanding the envelope

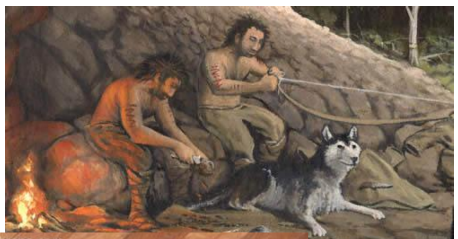
- Engineering & Realisation
  - Engineering
  - Realisation
  - Commissioning
  - HAZOP
- Materials
  - Characterisation
  - Failure analysis
  - Product optimisation
  - Production technology development
- Testing & Analysis
  - Corrosion testing
  - Lifetime prediction
  - Materials & Gas analysis
  - Pilot plant operation
- Environmental Assessment
  - Air quality measurements (PM, NO_x, CO, NH_3, BTX, C_xH_y, …)
  - Emissions modelling
  - Leaching
  - Instrument development

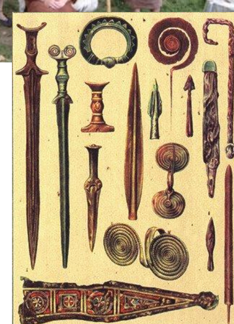


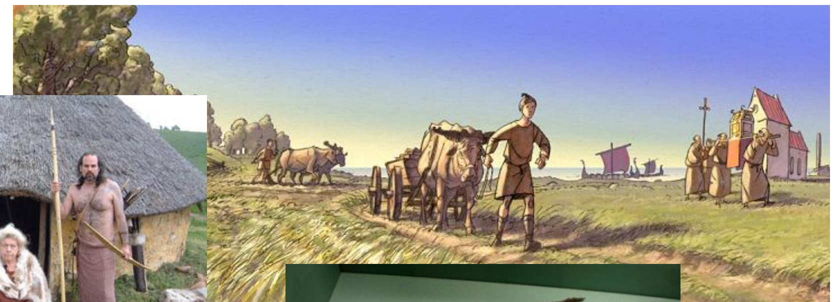


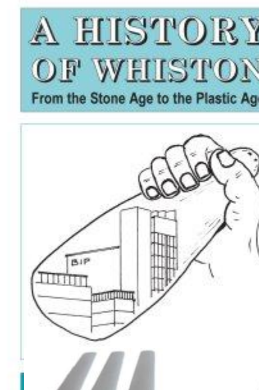
Why materials knowledge?

Importance of materials has been recognised over the ages.









Stone age → Bronze age → Iron age → Plastic age, biobased?

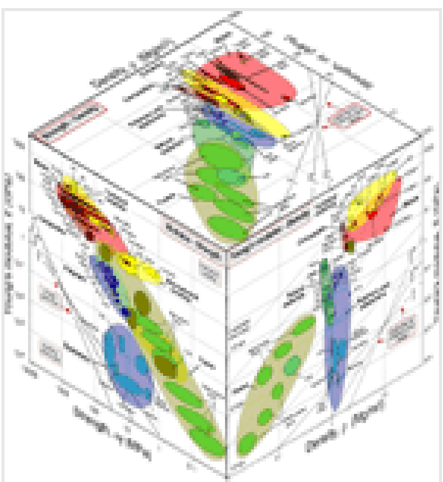
Doel van deze presentatie

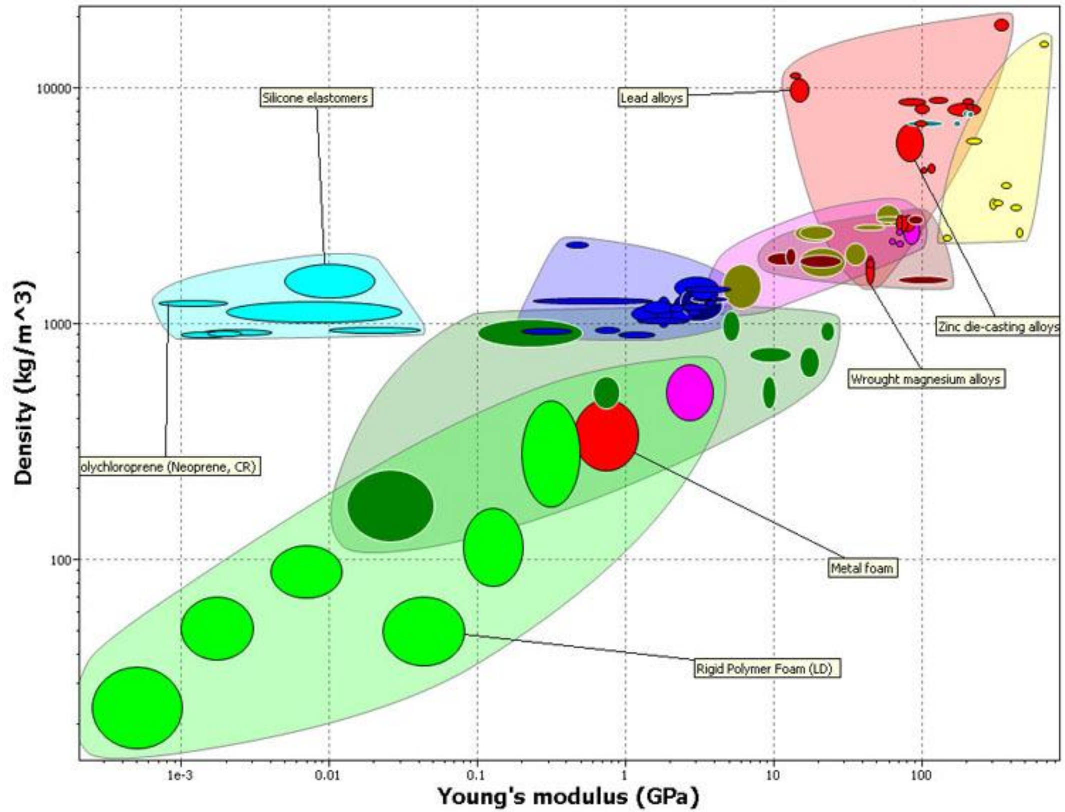
- Invloed van de materiaalkeuze op:
  - Functionaliteit: Belasting, milieu, enz..
  - Betrouwbaarheid / beschikbaarheid installatie
  - TCO
- De constructeur/engineer bepaald op de tekentafel:
  - Onderhoudskosten
  - Fabricage kosten
  - Maakbaarheid
  - Betrouwbaarheidn & Beschikbaarheid
- VOOR-denken over materiaalkeuze heeft zin, bij NA-denken bij je te laat!:
  - Materiaaleigenschappen is ‘makkelijk’ (data base, leverancier enz)
  - Systeemeigenschappen vind je niet of moeilijk in een data base → Materiaalkunde

Selection based on materials properties

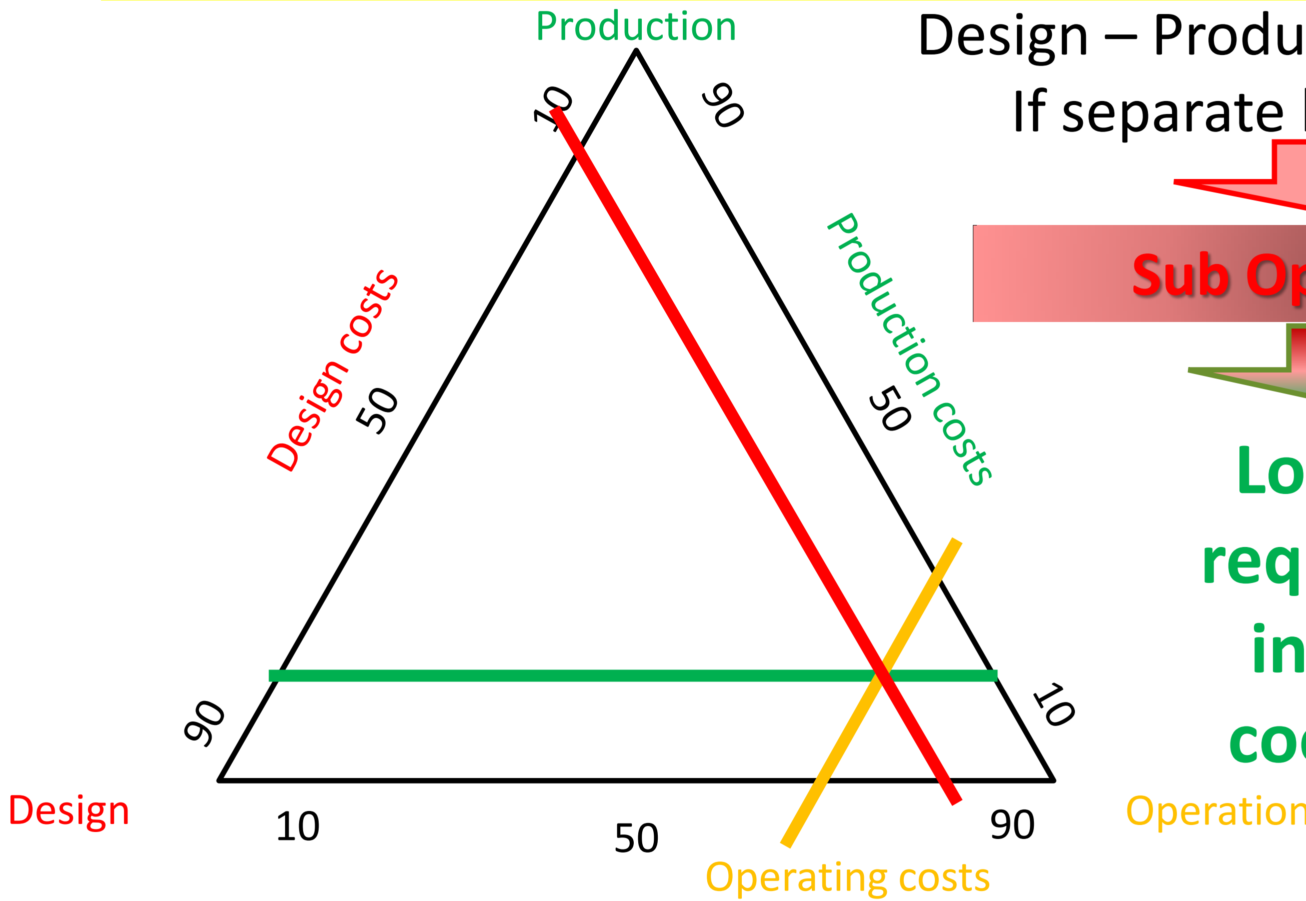
Ashby Diagrams

http://www.grantadesign.com/





Interrelation
Design-Production-Operation



Design – Production – Operation

If separate business units

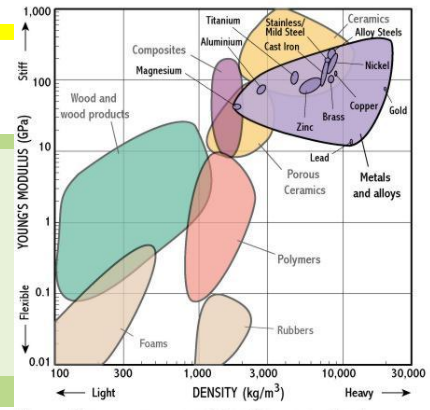
Sub Optimisation

Lowest TCO requires close interactive cooperation

Why materials knowledge and added value Materials Scientist

Materials selection based on:

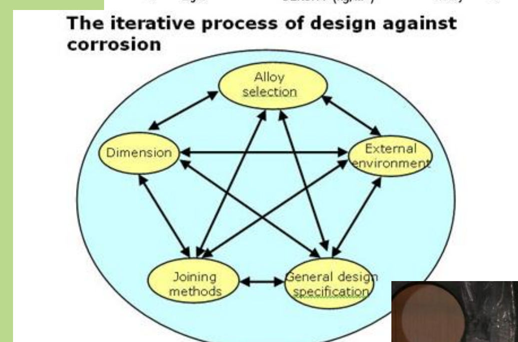
- Materials properties
  - Mechanical properties
  - Physical properties
  - Price? (<10% of total costs)



Tables, Ashbey, Engineer

System performance:

- System properties:
  - Corrosion
  - Erosion
  - (welding)



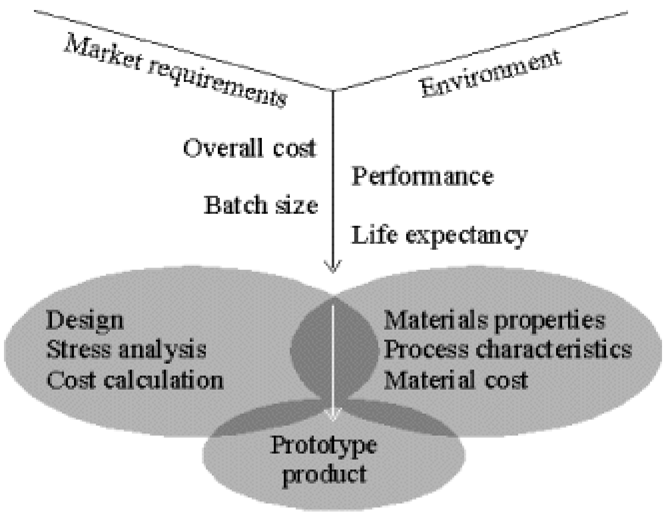
- Others
  - Weldability (expert dependent)
  - Machinability (exper dependent)

Materials Scientist

Why materials knowledge?

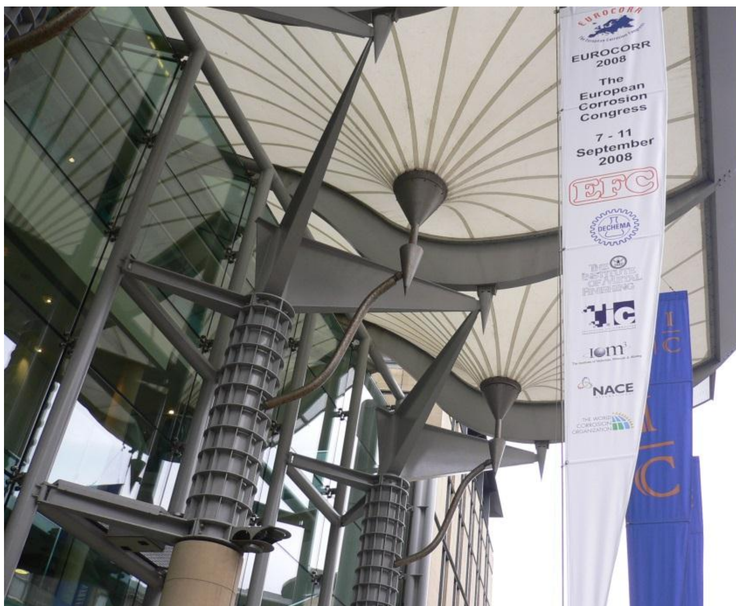
Materials selection determines total costs of owner ship:

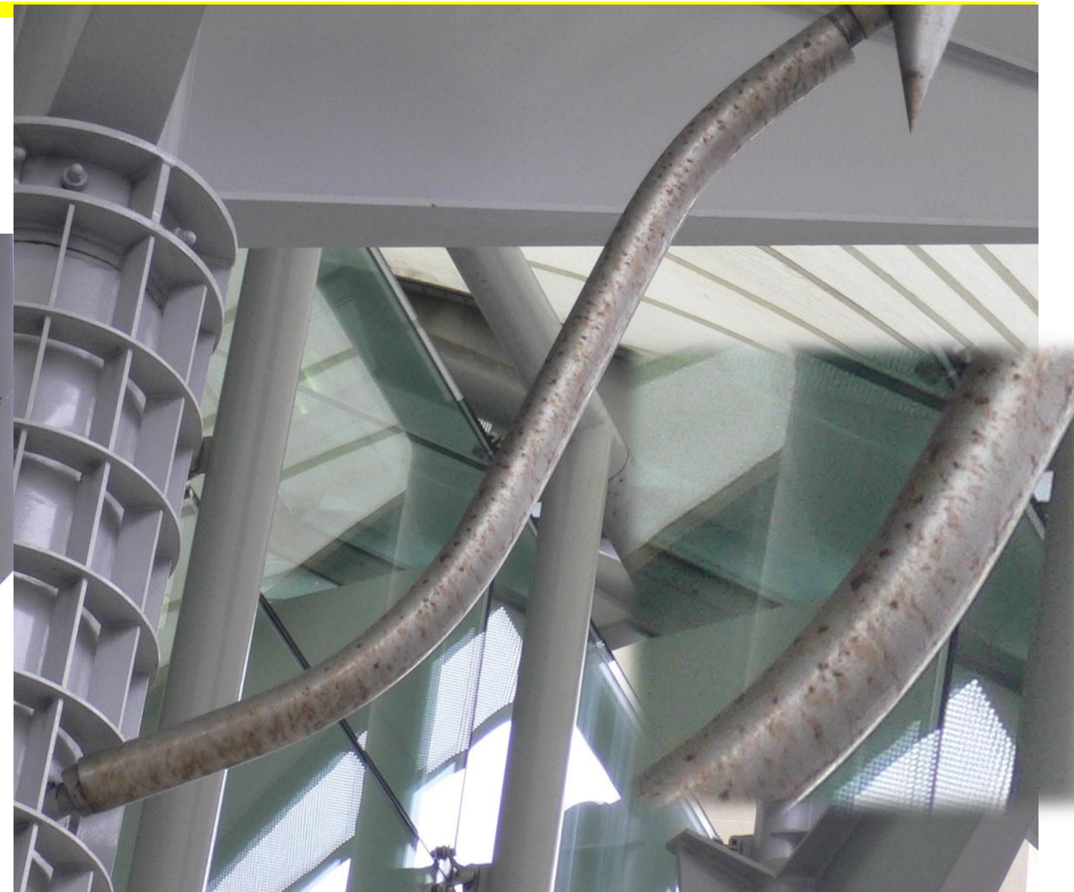
- Functionality/requirements
- Maintenance costs
- System availability & reliability
- Fabrication costs
- Design considerations
- Decommisioning costs
- Total fabrication costs



Materials Science is an Enabling Technology in reducing TCO

Design & Materials selection
EuroCorr 2008: Edinburgh





Material selection

Minister of Defence suspends acceptance of new Dutch NH90 helicopters

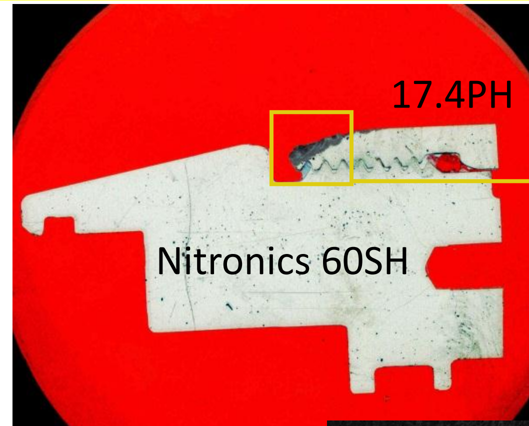
News item | 27-06-2014 | 16:35

The corrosion and wear symptoms on the NH90 helicopter are more serious than expected, leading the Ministry of Defence to suspend acceptance of the remaining 7 helicopters ordered from NHIndustries (NHI). Minister Jeanine Hennis-Plasschaert informed the House of Representatives to this effect today. The new helicopters will only be accepted if an agreement on solutions to the problems is reached with the manufacturer, including the question of who will pay for the necessary repairs. Hennis expects to have a clearer picture after the summer.

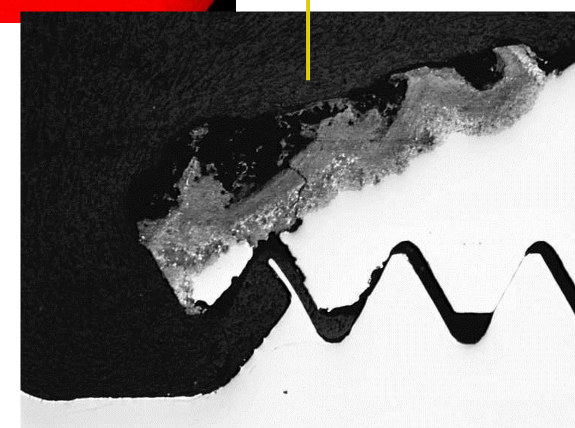
Roestvast staal, een sluipmoordenaar in zwembaden

TILBURG - Had het drama in zwembad Reeshof in Tilburg voorkomen kunnen worden? Het ministerie van VROM waarschuwde gemeenten al in 2002 dat roestvast staal in zwembaden gevaarlijk is voor de constructie. Corrosie bleek toen al de boosdoener.

Case 1: galvanic corrosion



Materials:
17Cr-4Ni
17Cr-8.5Ni-8Mn-4Si



Galvanic corrosion if:

- Potential difference >50mV
- Electrically connected
- Unfavourable surface ratios

Example:

- Environment: Salt solution
- Potential difference 46mV, varying between 20 - 100mV
- 17.4PH least noble and corrodes

Case 1: galvanic corrosion

Expertise Materials scientist

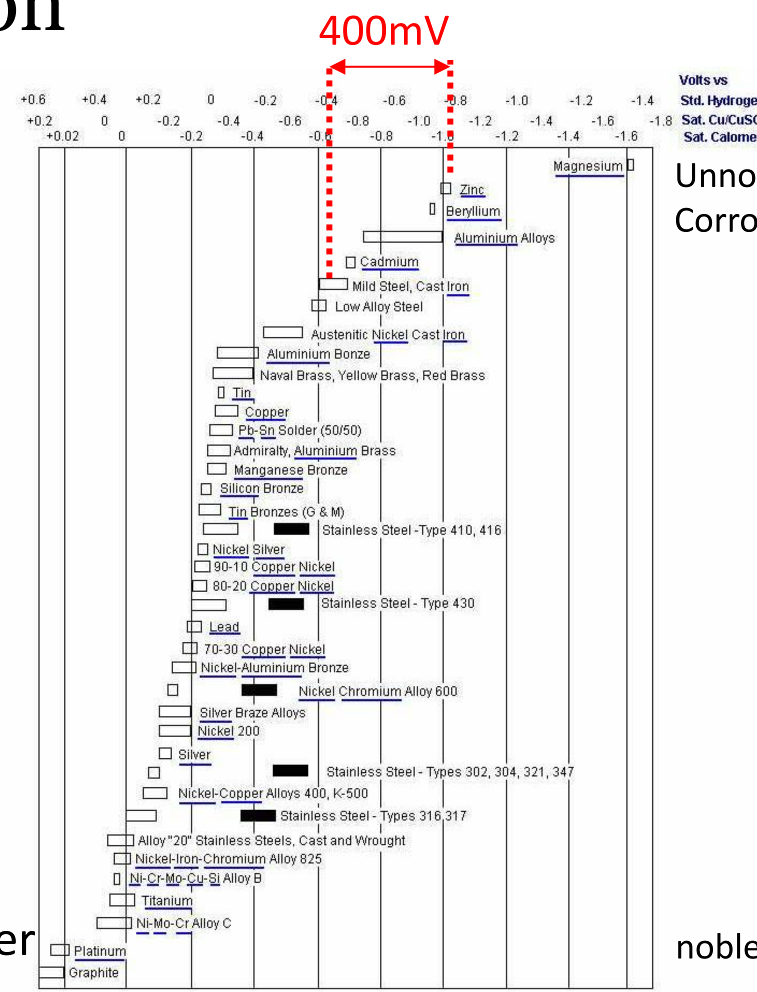
Galvanic series predicts potential differences in specific environment

Example:

Zn vs C-steel: 400mV in seawater, Zn corrodes
→galvanic protection → life time

NOTE:

Above 70°C steel becomes less noble than Zn and corrosion reverses



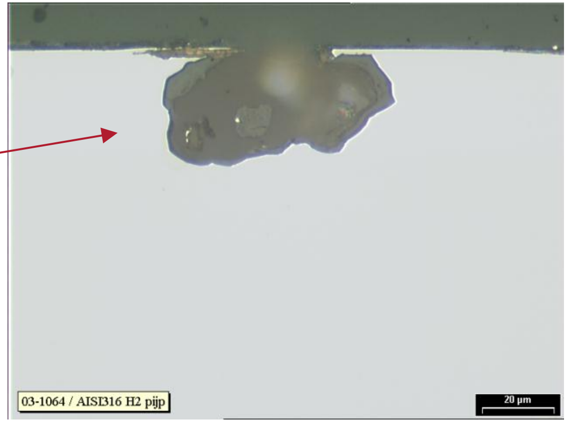
Unnoble: Corrodes

noble

Example: Galvanic series in sea water

Case 2: Corrosion, Pitting and Crevice

- Pitting of 1.4404 (AISI316L) type due to poor cleaning and presence of Cl and F
- Solution *(Maintenance costs down):*
  Improve surface: polish
  Apply cleaning (normal by rain)
  Select higher alloyed:
  1.4435 (316 higher Mo) or 904L

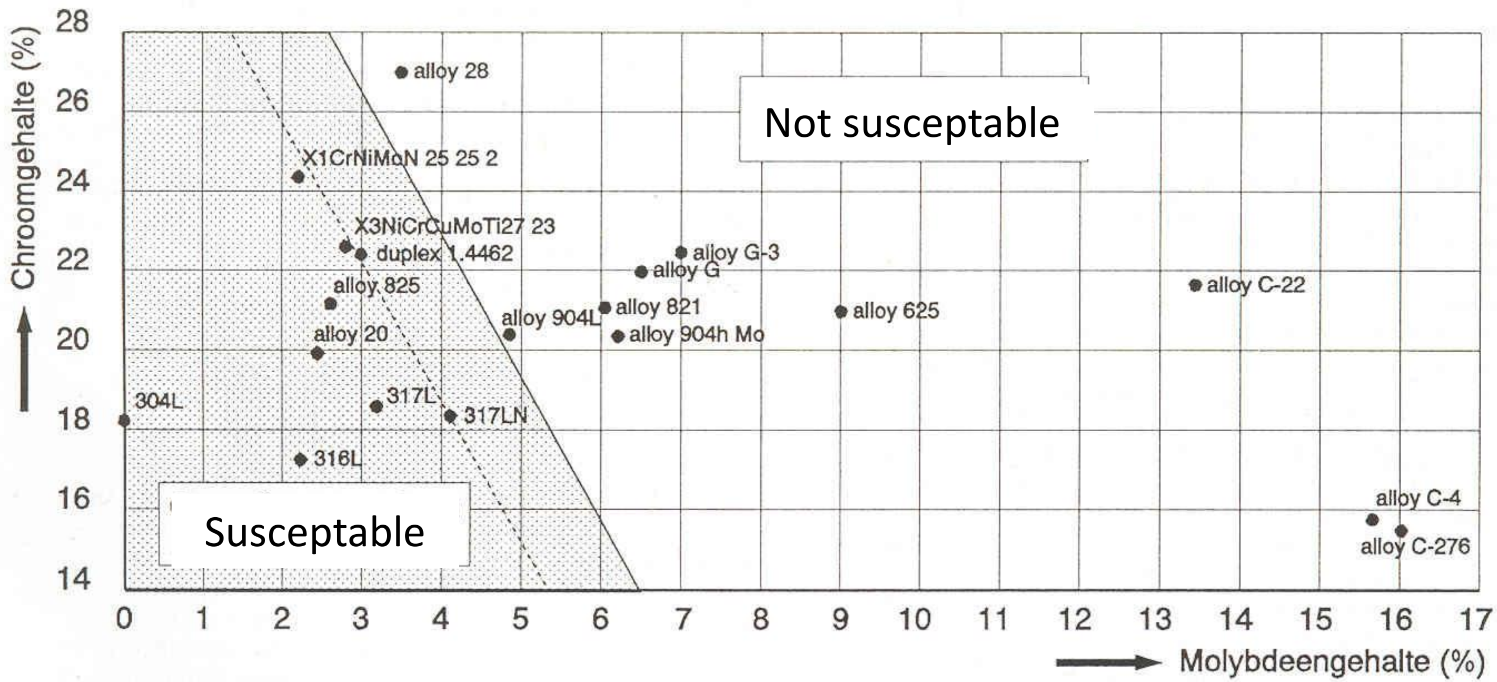


- Crevice corrosion: unfavourable design combined with material selection and application conditions

Case 2: Corrosion, Pitting and Crevice

Apart from design, correct materials selection reduces risks

Relative susceptibility to pitting and crevice corrosion. Susceptibility system dependent



Case 3: Stress corrosion cracking

- Design of new reactor for biomass experiments
- Construction under (high) tensile stress due to:
  - Internal pressure
  - Cold bending
  - Welding
- Identified (corrosion) problems:
  - Pitting
  - Stress corrosion

Parameter	Requirement
Cl-concentration	2000mg/kg (by addition of 32%HCl with pH of 1.2-1.5)
Solute	H_2O (40-60%) EtOH was removed from the solution at it decomposes
pH (catalyst)	1 (lowered by addition of 98% H_2SO_4, 10g/kg solution)
Presure(s)	50 bar
T max	220°C

Approach:

Based on material expertise:

- Material pre-selection
- Testing under design conditions

Case 3: Stress corrosion cracking

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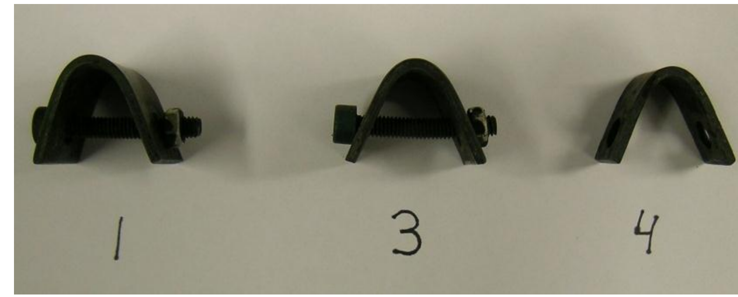
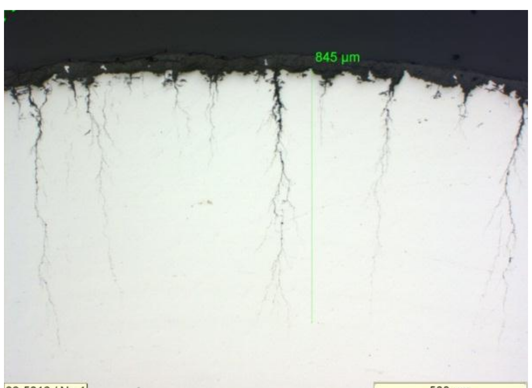
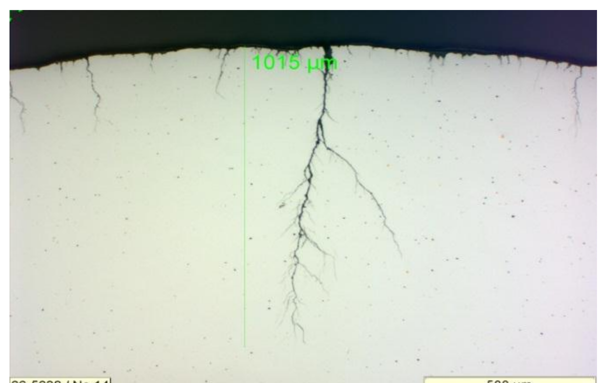


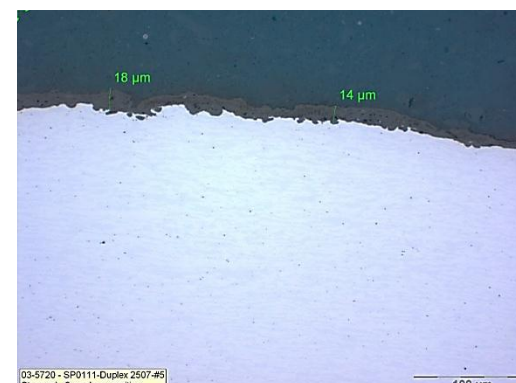
After 3 weeks of exposition



1.4404 (SS316L)



1925HMo (SCC resistant?)



Super Duplex-2507

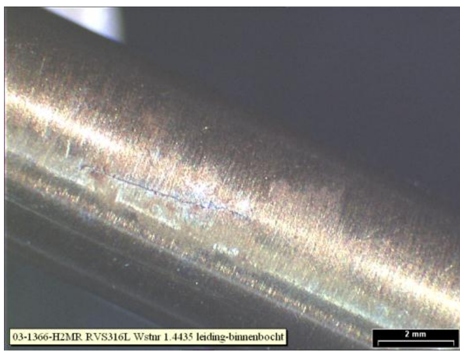
Case 4: Stress corrosion cracking

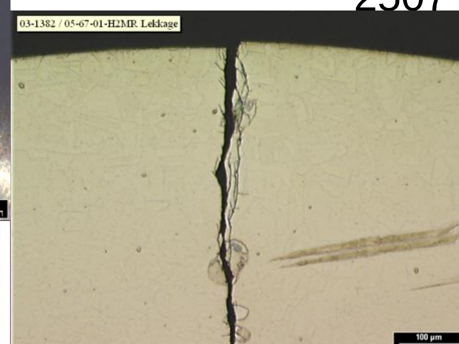
Results:

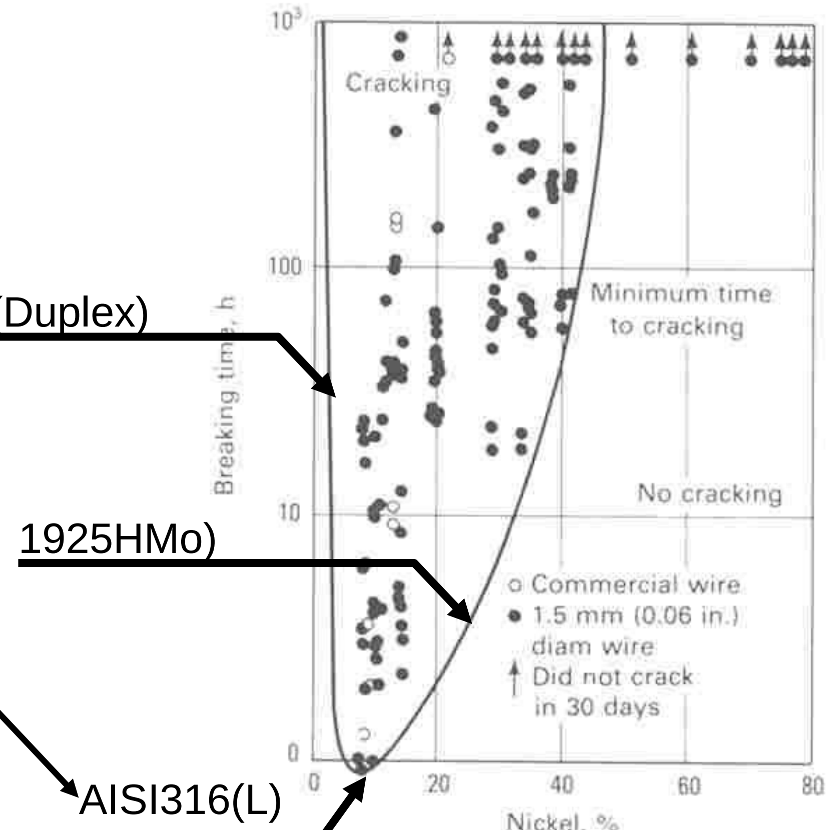
- Selection of relatively sheap material (Super Duplex-2507)
- With higher strength than austenitic SS, allowing for thinner design (lower weight) → potential cost savings.
- Installation, including joints, can be made from the same material, reducing risk for galvanic corrosion
- Reliable design:
  - High corrosion resistance
  - Predictable corrosion rate
- Better change for acceptance of the design and process

Case 3: Stress corrosion cracking

- AISI304 and 316 types SS most sensitive to SCC







Effect of Nickel on SCC in SS in a 17-24% Cr-steel in boiling 42% MgCl solution

MH vol 13 Corrosie pp 273

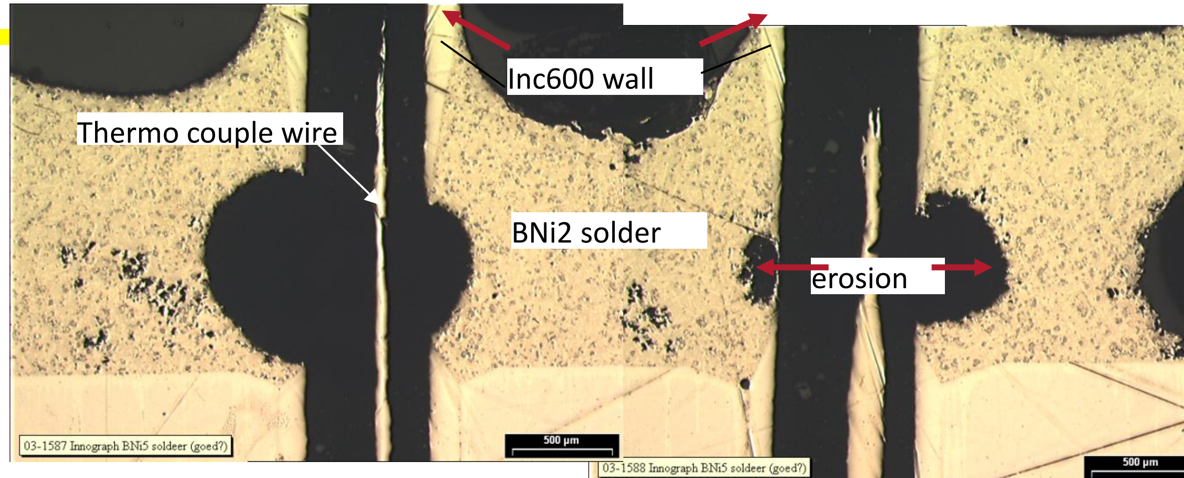
Corrosion: effect of alloying elements

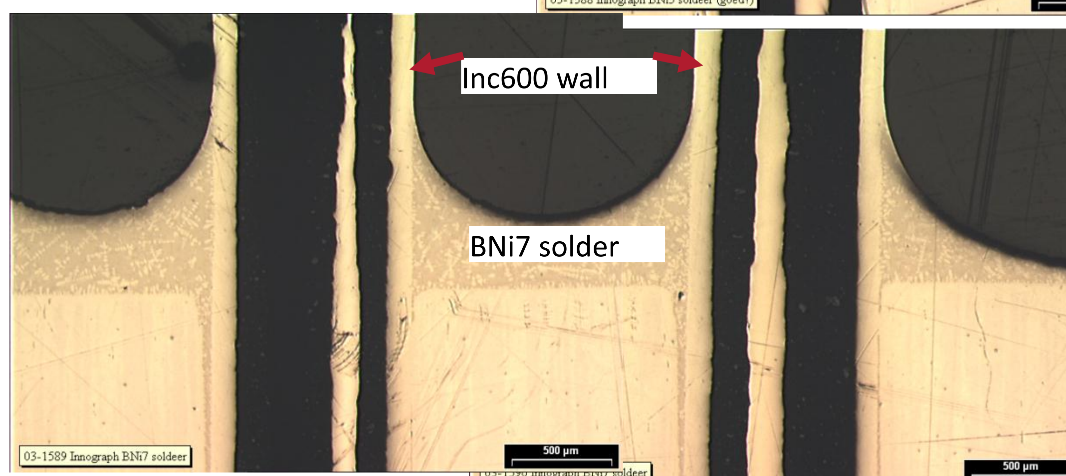
		parameter																	
		Materiaaleigenschappen										Milieu/ gebruikscondities			Ontwerpaspecten				
Corrosiemechanismen		Chemische samenstelling								Microstructuur	Hardheid	Elektrolyt	Chemie milieu (Cl, S, O2 ed)	Temperatuur	(rest)Spanningen	Materiaal combinatie(s)	Ruwheid	Speten	Verzamelpunten van vocht
		algemeen	Cr	Al	Si	Mo	Ni	Co	Ti										
Algemene corrosie-nat	Atmosferisch	■	+			+			-			■	■	■			■		
	Galvanisch	■										■				■			
	Biologisch	■	+			+		+		■		■					■		
Algemene corrosie-Hoge Temperatuur	Gesmolten zouten	■											■	■					
	Gesmolten metalen (LME)	■											■	■		■			
	Gascorrosie	■	+	+	+	+		+	-				■	■					
Locale corrosie	Filiform	■								■		■	■						
	Biologisch	■	+			+		+		■		■	■				■		
	Waterstof	■								■	■								
	Liquid Metal Emrbittlement	■												■		■			
	(Cl-) Spanningscorrosie	■	+			+	+					■	■	■	■				
	H_2S-Spanningscorrosie	■								■	■	■	■	■	■				
	Interkristallijn	■	+			+				■		■	■				■		■
	Putvormige corrosie	■	+			+				■		■	■					■	■
	Spleetcorrosie	■	+			+						■	■					■	■
	Uitloging	■								■		■	■	■		■			
	Erosie									■	■								
	Fretting	■								■	■						■		
	Cavitatie	■								■									
	Corrosievermoeiing	■								■		■	■		■		■		

Een grijs vlak betekent dat de betreffende parameter invloed heeft op het desbetreffende corrosiemechanisme

Case 5: Brazing, change in brazing material

- High boron content in BNi2 results in fast erosion of Inc600 material due to B-diffusion
- Selection of B-free solder (BNi7) solves the problem
- Good brazing joint requeres correct design



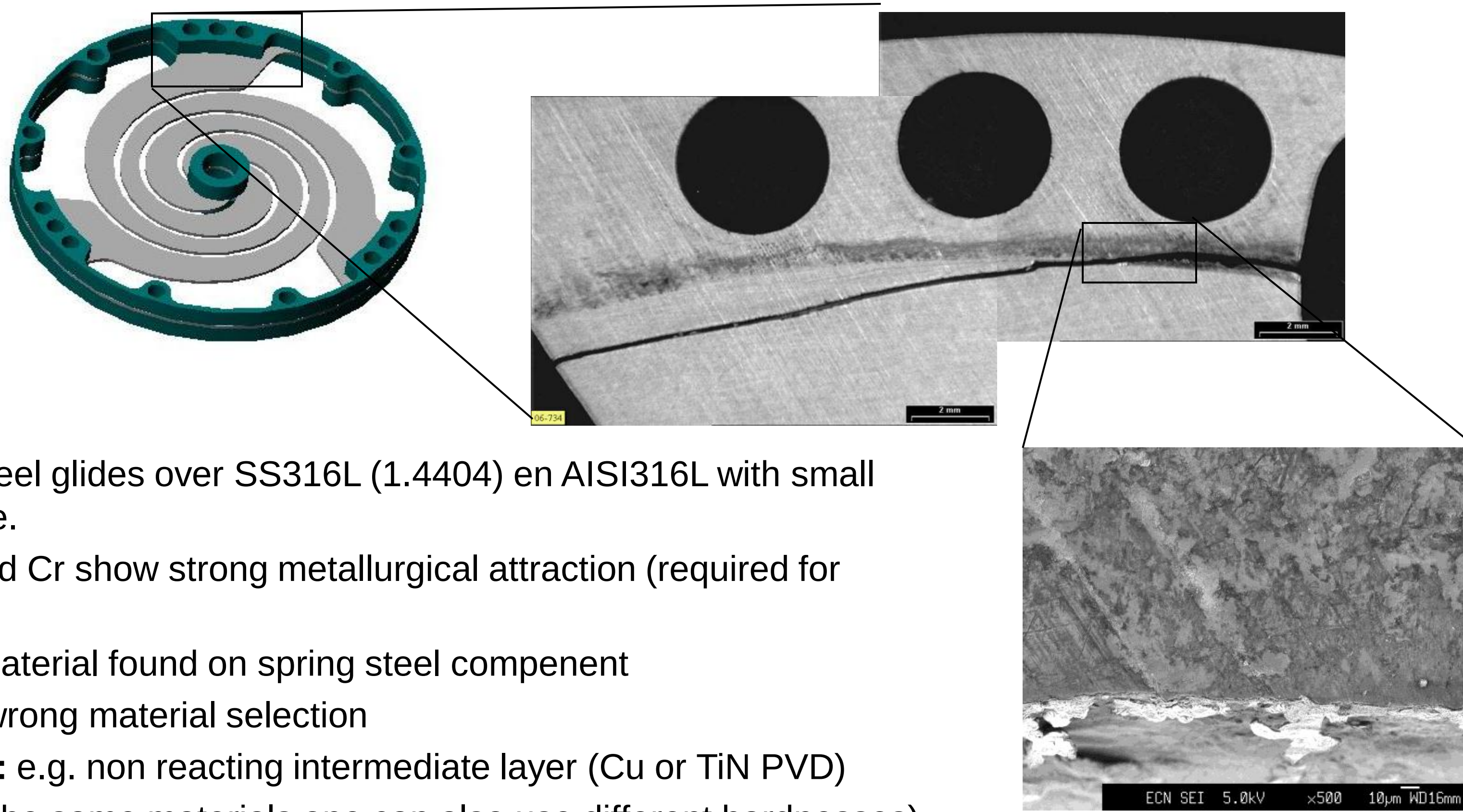


Wear, system property

	Materiaal parameter										Oppervlak				Milieu									
Slijtage mechanisme	Hardheid (basismateriaal vs deeltjes)	E-modulus	Rekgrens	Kerftaaiheid	Koudversteviging	Restspanningen	Smelttemperatuur	Microstructuur	Oxidehuid (als corrosiebescherming)	Chemische samenstelling	Wrijvingsweerstand	Ruwheid	Materiaalcombinaties	Type abrasief	Temperatuur	Snelheid	Hoek van inslag	Belasting	Belasting amplitude	Frequentie	Vochtigheid	Corrosieve invloeden	Zuurstof partieeldruk Vacuüm	Smering
Abrasief	■			■ m.n. bij keramiek	■		■	■		■		■		■	■	■	■	■						
Erosief	■	■	■	■	■			■		■				■	■	■	■	■			■	■		
Cavitatie		■	■	■				■	■	■			■	■			■			■				
Impact/ Impingement	■	■	■		■			■		■				■		■	■	■	■	■				
Erosie in een slurrie	■	■	■	■	■			■		■				■		■					■	■		
Adhesief				■	■				■	■	■	■			■	■		■			■	■		■
Schaviel				■	■				■	■	■	■						■		■	■	■		
Fretting				■	■	■			■	■ afh van mat cominatie	■	■	■		■			■	■	■	■	■	■	
Rollend	■	■	■			■		■								■		■		■				■

NOTEN:
Een grijs vlak betekent dat de betreffende parameter invloed heeft op het betreffende slijtagemechanisme
Voor een nadere beschrijving van de slijtagemechanismen wordt onder andere verwezen naar VM108

Case 6: Wear, system property-Fretting

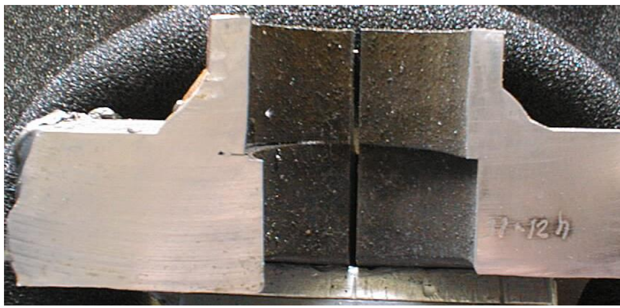
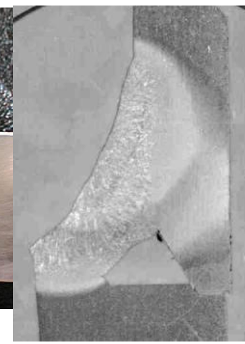


- Spring steel glides over SS316L (1.4404) en AISI316L with small amplitude.
- Fe, Ni and Cr show strong metallurgical attraction (required for fretting)
- 1.4404 material found on spring steel compenent
- **Cause:** wrong material selection
- **Solution:** e.g. non reacting intermediate layer (Cu or TiN PVD)

(In case of the same materials one can also use different hardnesses)

Case 7: Welding Heat Exchanger
Cheap design & Fabrication → high operating cost

- Unreliable heat exchanger performance and unplanned stops → High costs
- Related to welding procedure: material and design vs codes


misallignments

Welding defects

<u>Material: 15Mo3</u>

Welding process: TIG
Weld design: auto pre-centred
No full penetration in design
No pre-heat (not in code)

<u>Results:</u>

Hardness of max over 350HV
Lack of Fusion
Incomplete welding
Failure under dynamic loading (fatigue) → **unreliable → low availability → high operating costs.**

Case 7: Welding Heat Exchanger

Solution(s):

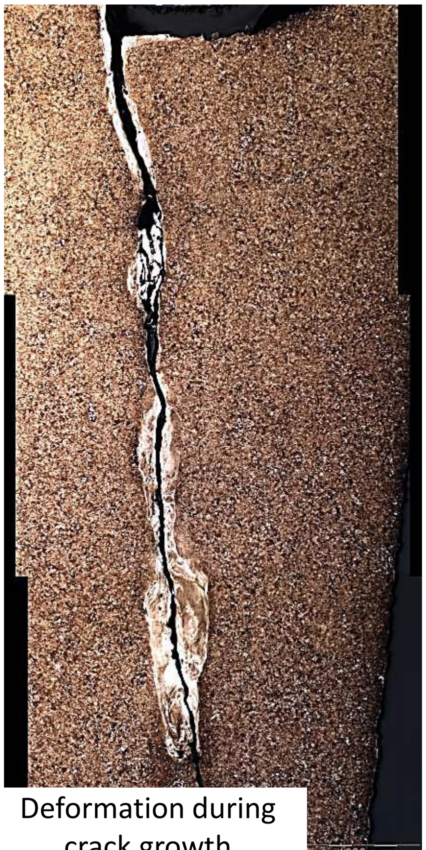
- T-joint, thick-thin, results in too high cooling rate if not pre-heated and subsequent high hardness → apply pre-heat, 50-100°C to reduce cooling rate
- Joint design: improve joint design to obtain a full-penetration weld:
  - Use a pre-opening and check weld penetration visually.

Result(s):

- No failure since implementation in the new welded joint design
- High system availability → **low operating costs (low TCO)**
- More expensive joint design, but lower total costs of operation due to high system availability

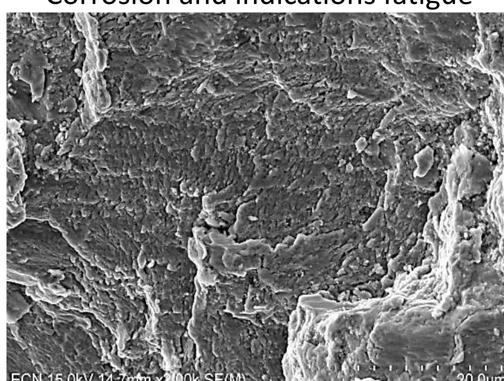
Case 8: Changed operating conditions

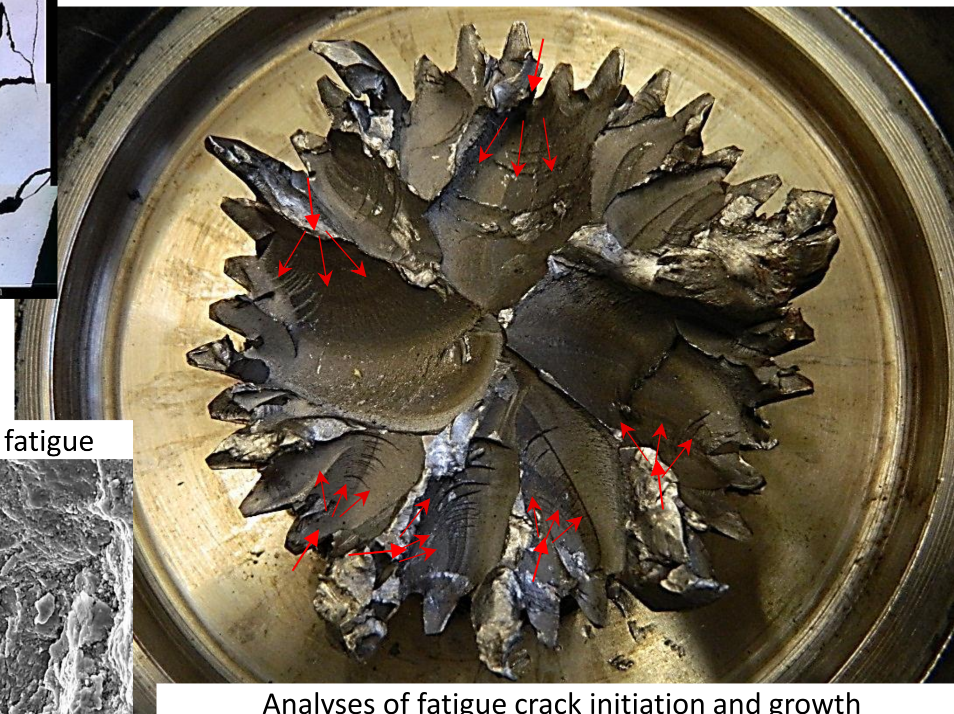
Fatigue failure crack shaft



Deformation during crack growth

Corrosion and indications fatigue



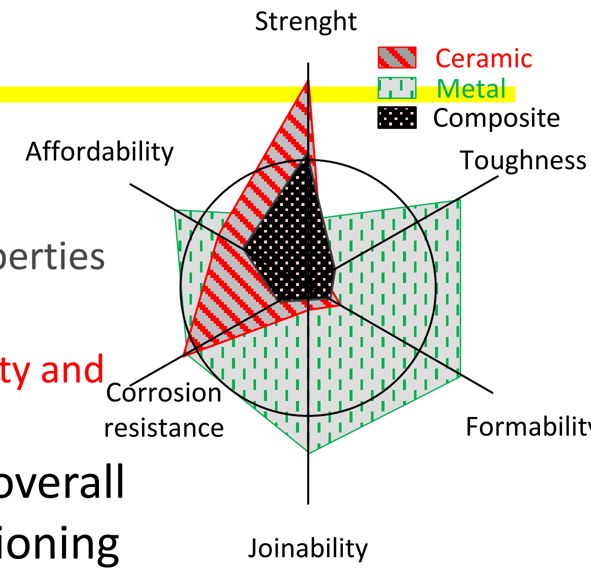


Analyses of fatigue crack initiation and growth

Conclusions

- Interactive proces:
  1. conceptual design and definition of functionality
  2. Preliminary material selection based on material and system properties
  3. First design steps: availability-fabrication methods-construction

  Design-material selection-fabrication will result in optimal functionality and lowest TCO.
- Optimal design may result in initial higher cost, but lower overall cost due to lower maintenance, operating and decommissioning costs.
- Material science is an enabling technology in TCO
- During design final material selection is an interactive process taking into account.
  – Availability of material
  – Available fabrication techniques.
  – Functional requirements final user (→ effect on system properties)



Lost your way?

There is nothing magic about material selection

- Environment & Energy Engineering-Materials Testing & Consultancy

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Thanks for your attention

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