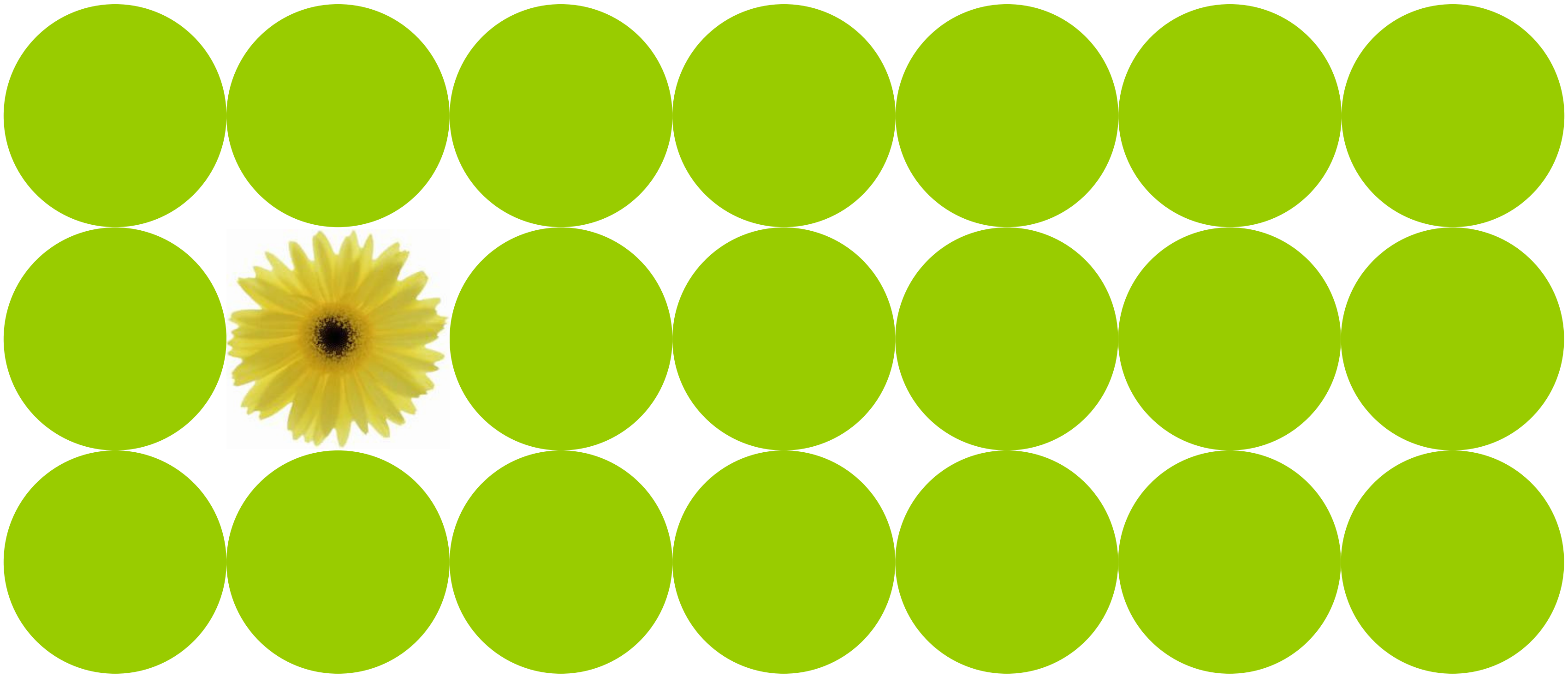
Aluminium as a viable solution for offshore wind turbines



Dr. Simon Jupp

Deep Sea Offshore Wind R&D Seminar, 20. January 2011

Climate matters

- Hydro’s mission – to create a more viable society – implies making solutions to the climate challenge an inherent part of our business model
- **The Business Opportunity: Reduce emissions and improve energy efficiency**
- Technology a key driver

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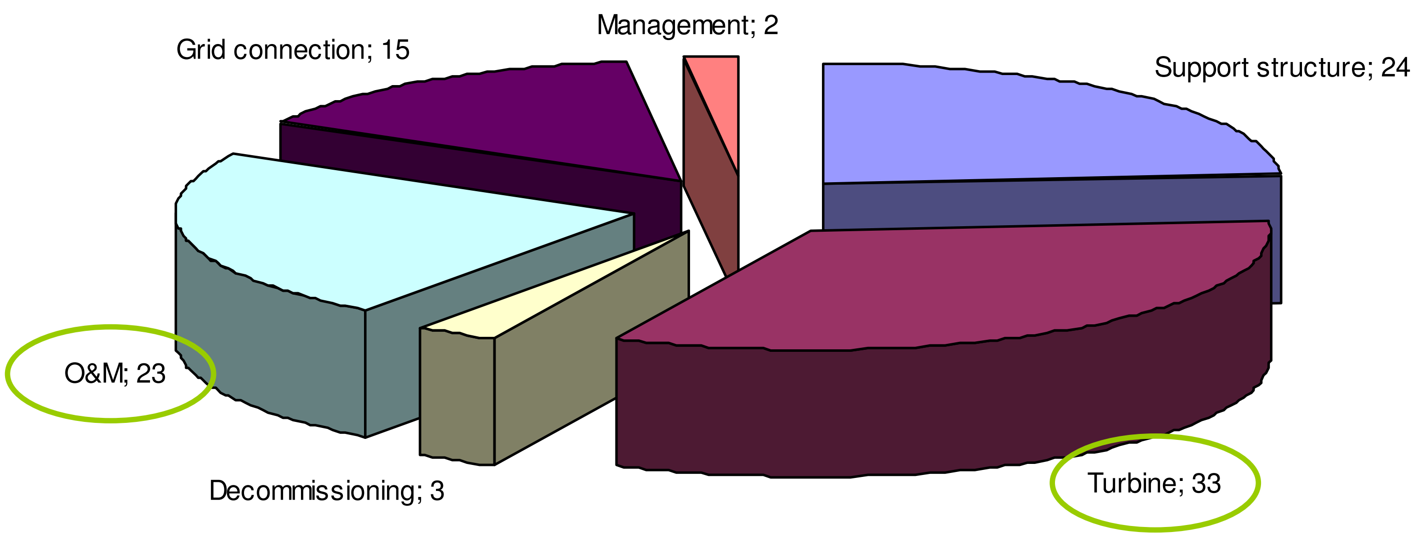
Why aluminium?

Cost analysis for offshore wind turbine



Source: Kurian and Ganapathy 2010

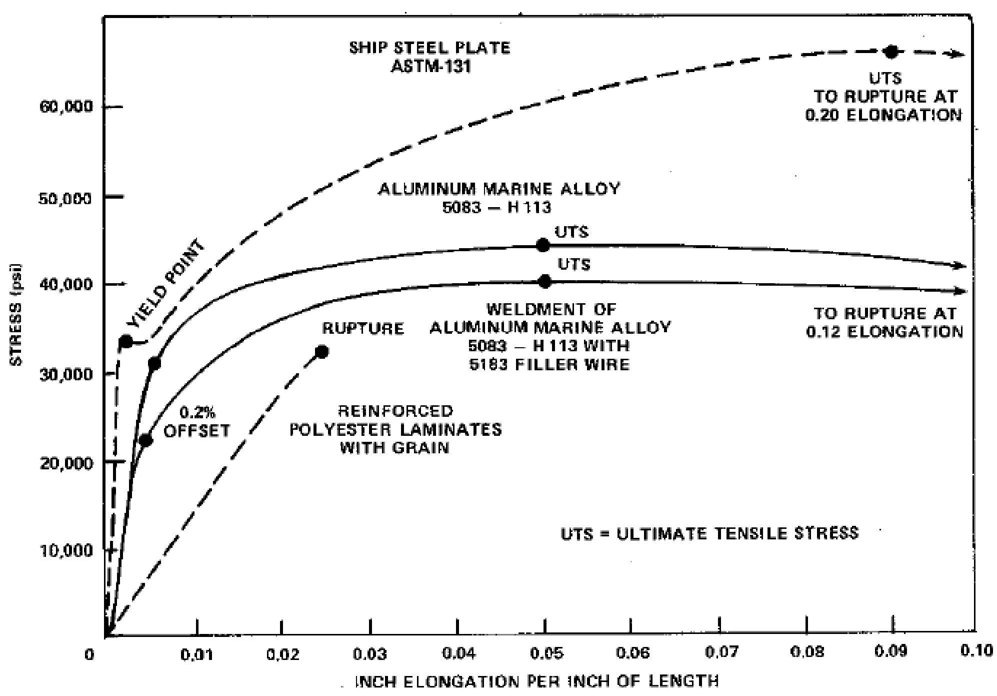
Why aluminium?

- Lightweight
- Built-in fire protection
- Ease of inspection
- High thermal conductivity
- Recyclability→ End-of-use value
- Wide range of surface treatments

Mechanical properties comparison

Weight-normalised strength (σ_y/ρ)

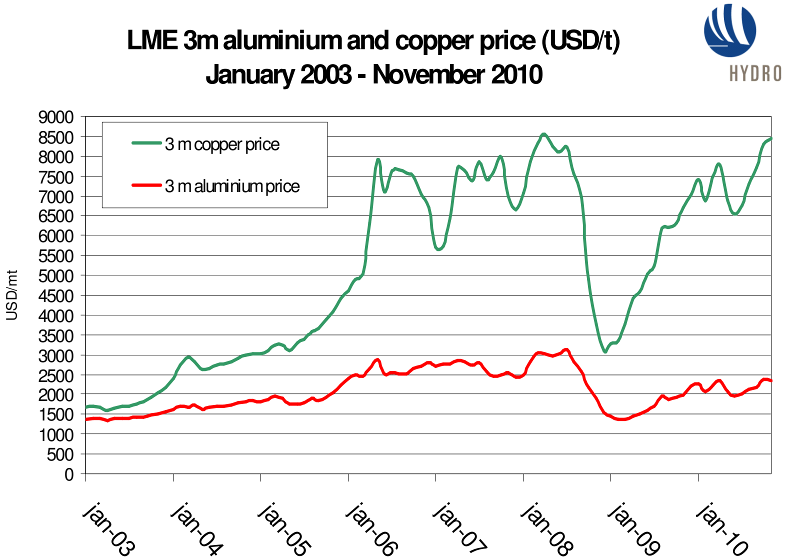
Mild steel (ASTM 131)	235 MPa/7.8 = 30
5083 H113 aluminium	155 MPa/2.7 = 57
E-glass GFRP	170 MPa/2.0 = 85



Electrical conductivity

Functionality

Aluminium is a good electrical conductor → 60% IACS



Cost of 100% IACS

Cu ~ 8500 US$/tonne
Al ~ 2400 US$/tonne

} 3,5 Factor

ρ_{Cu} = 8900 kg/m^3
ρ_{Al} = 2700 kg/m^3

} 3,3 Factor

100% IACS = 1 g_{Cu}= 1.12 x 10^{-2} cm^2 x 100 cm = 0.0085 US$
100% IACS = 0.5 g_{Al} = 1.87 x 10^{-2} cm^2 x 100 cm = 0.0012 US$

} 7 Factor

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Lightweight structure (e.g. nacelle)

- Aluminium stiffeners weigh 40%-50% less than steel stiffeners with the same deflection resistance
- The weight disadvantage to GRP is equalized by the advantage in stiffness.

	Steel	Aluminium	Aluminium	Aluminium
Moment in inertia in mm^4	$38.9\ 10^6$	$116.6\ 10^6$	$116.7\ 10^6$	$117.3\ 10^6$
E x I (N/mm^2)	$8.17\ 10^{12}$	$8.16\ 10^{12}$	$8.17\ 10^{12}$	$8.21\ 10^{12}$
h (mm)	240	240	300	330
b(mm)	120	240	200	200
w (mm)	6.2	12	6	6
t (mm)	9.8	18.3	12.9	10
Unit weight (kg/m)	30.7	30.3	18.4	15.8
Weight in % of the steel beam	100 %	99 %	60 %	51 %

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Lightweight in nacelle equipment

The weight advantage of aluminium can also be used in nacelle equipment parts:

- Helicopter Hoist Platforms
- Electrical cabinets
- Floor sheets
- Steps and ladders
- Ventilation channels
- Transformers
- Cabling

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Built-in fire protection

- Aluminium is incombustible and does not contribute to a fire
  - Wide use of aluminium profiles in fire protection doors
- There is no need for additional lightning protection (an aluminium skin builds a natural Faraday´s cage)
- Aluminium has no electrostatic potential

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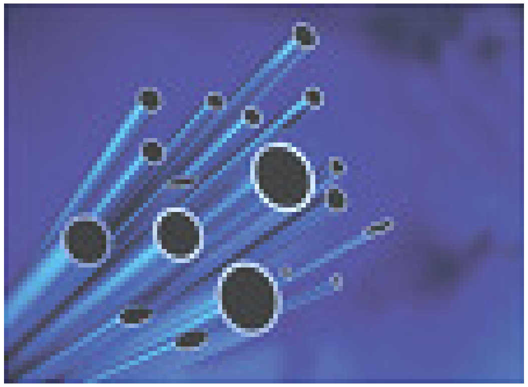
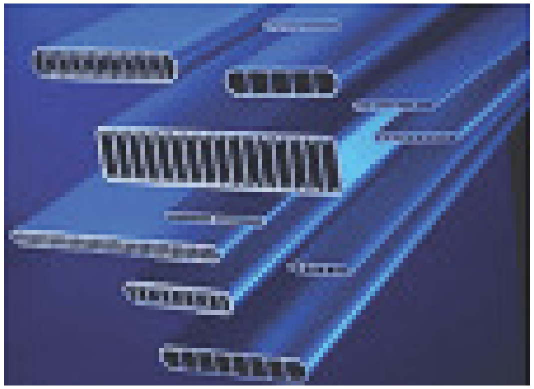
High thermal conductivity

- Aluminium's thermal conductivity is 3-4 times that of steel and more than 100 times that of plastics
- Enables better heat dissipation through the outer skin of a nacelle and therefore allows smaller cooler sizes

- Aluminium is also extensively used in heat exchangers, both as tubes and for fins





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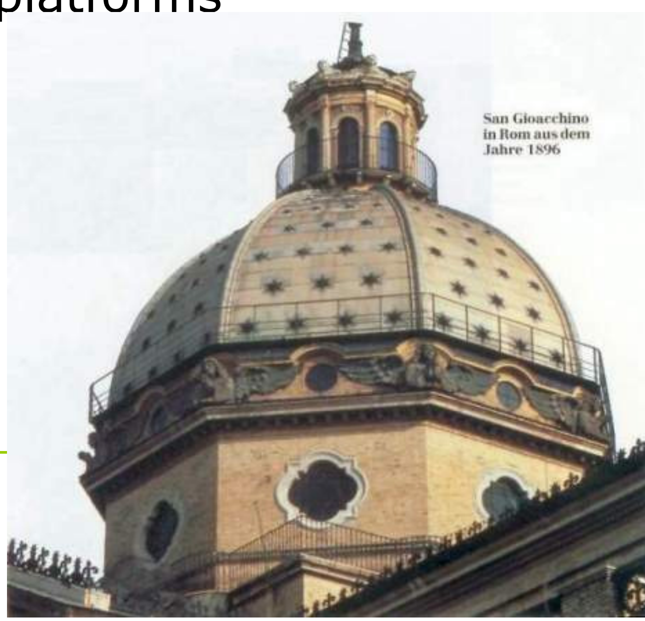
Recyclability

- Aluminium can be infinitely recycled without a loss in quality with a saving of 95% of energy compared to its primary production
- Aluminium keeps a commercial value along its whole lifetime; e.g. the „scrap value" is typically in the range of 1.000-1.500 EUR/tonne (Note: as of 5 Jan 2011, LME Al scrap price >1800€/tonne).

Longevity

- 75% of all aluminium produced so far is still in use
- Aluminium can be kept unpainted in normal environmental conditions
  - Oldest aluminium roof in the world: San Gioacchino church of 1896
- Aluminium survives harshest marine conditions:
  - Wide use in helicopter decks and living quarters of offshore platforms



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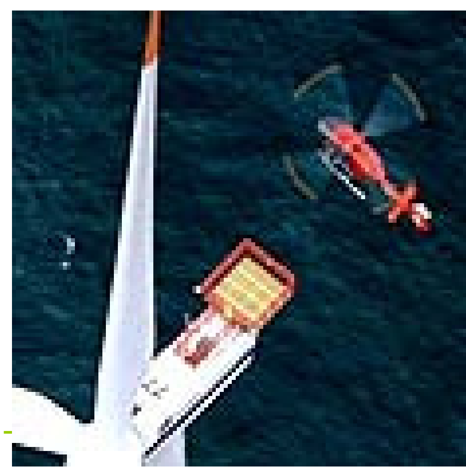
Ease of inspection

As aluminium does not need to be painted and is rust- free, it can easily be inspected with visual means. Any other inspection methods for other metals can also be applied on aluminium.

This is expected to reduce the need for costly and intensive maintenance – especially when used in offshore wind turbines.



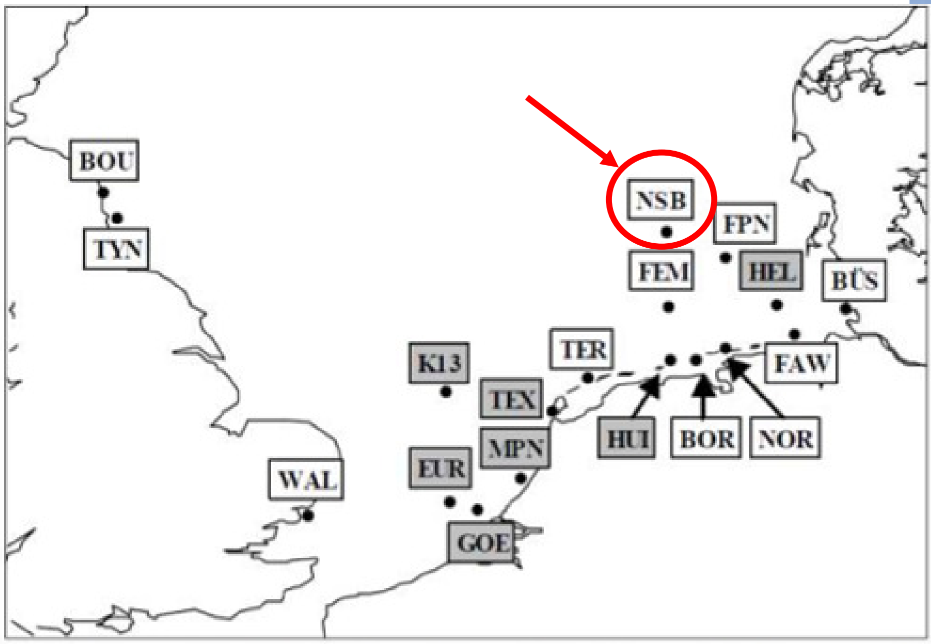

Source: ZDF

Wide range of surface treatments

- Due to its natural oxide layer, an aluminium surface does not corrode and does not need to be painted for surface protection
- For aesthetical reasons and to gain a certain appearance, an aluminium surface can be:
  - Sand- or shot-blasted
  - Painted
  - Brushed or polished
  - Anodized

North Sea Buoy II

- Container with measuring equipment
  - Made of painted aluminium
  - Mounted on top of the buoy during operation



- NSB II is part of a network of meteorological measurement stations in the North Sea

North Sea Buoy II

- NSB II has been operated in the open sea for 32 years with no maintenance other than occasional cleaning
  - Maintenance was necessary in June 2010 due to collision damage
  - Buoy was cleaned with 80 bar high pressure water jet
  - NSB II is in operation again

North Sea Buoy II
Technical survey in 2005

- **No substantial wall thickness reduction** on any part of the buoy
- **No cracks** in base material or weld seams
- **Weldability** identical to new material
- **Joints with stainless steel screws** (1.4571) fully intact without galvanic isolation

Result:
No objection against
another 10 years
of operation

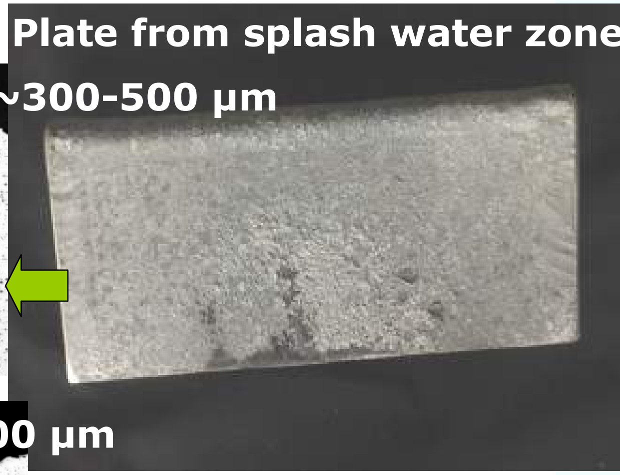
Ergebnis:	Gegen den weiteren Einsatz der Boje in den nächsten 10 Jahren bestehen keine Bedenken.
Anlage:	Zum Bericht: eine Foto-CD-Serie mit 48 Bildern (2 CDs).

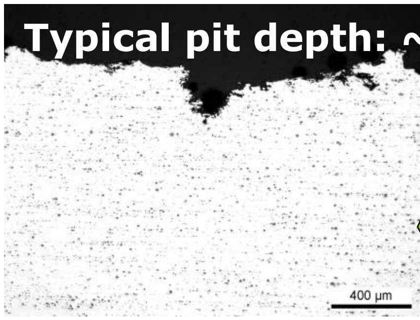
21031 Hamburg, den 14. Juli 2005

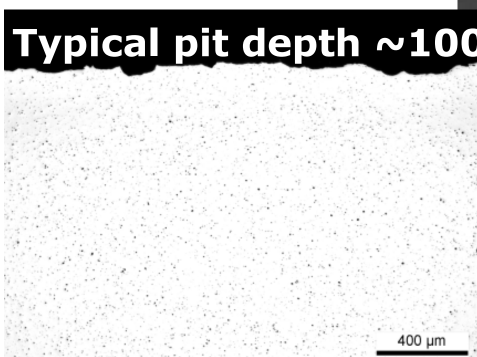
- H.P. Rüde -

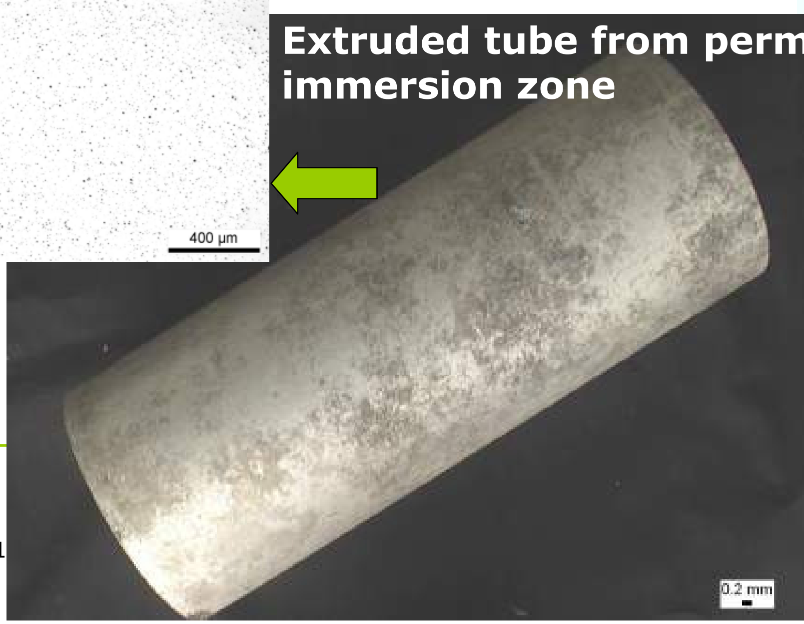
North Sea Buoy II

- Investigation of samples at Hydro R&D after 32 years in service









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Galvanic Corrosion
Outdoor exposure trial on Helgoland

Practical potential series in seawater pH 7.5 [mV]

Stainless 1.4571	+ 220
Silver	+ 149
Copper	+ 10
Stainless 1.4301	- 145
Lead	- 259
Unalloyed steel	- 580
Aluminium	- 670
Zinc	- 806

Stainless 1.4571 X6CrNiMoTi17-12-2	Al MgSi

- Samples:
  friction stir welded rods

Unalloyed steel	Al MgSi

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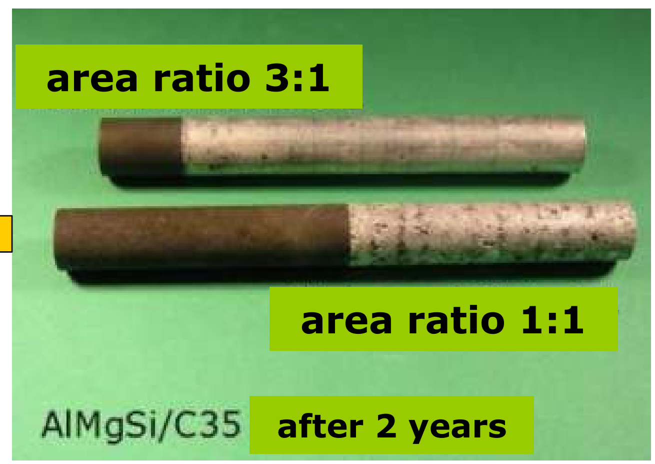

Source: Prof. Dr. B. Arnold, IWS Hamburg

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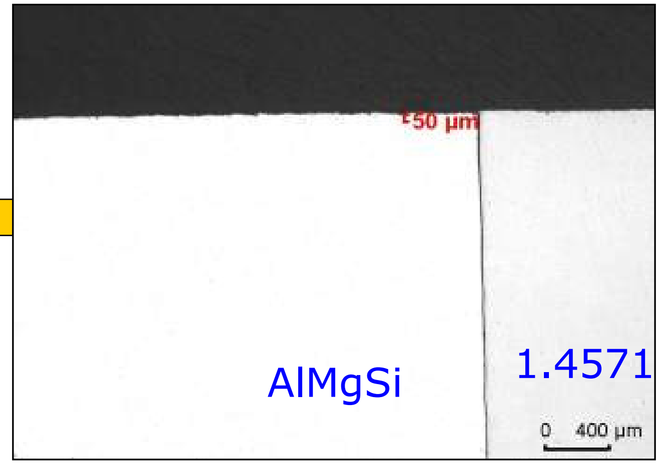
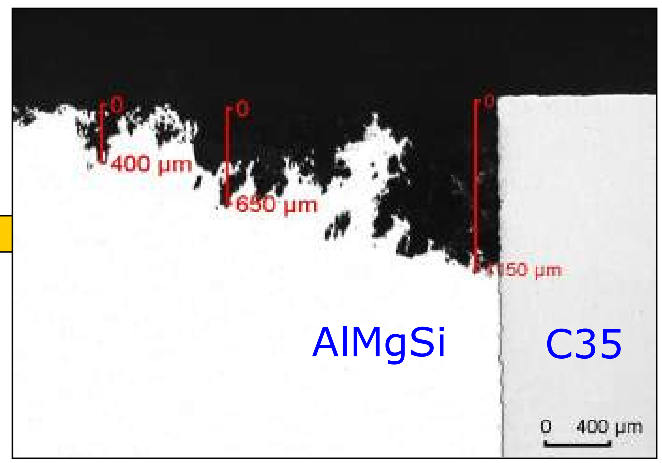


- No galvanic corrosion



- Significant galvanic corrosion

Source: Prof. Dr. B. Arnold, IWS Hamburg

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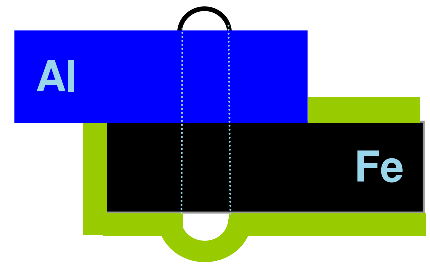
Galvanic Corrosion
Conclusions

- Al alloys are compatible with seawater proof stainless steel (with Mo)

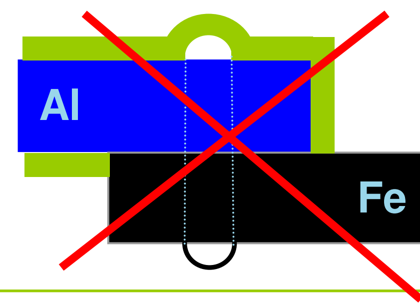
- If Al alloys are coupled with
  - unalloyed steel, or
  - stainless steel without Mo

  the cathode (steel) should be coated
  to effectively avoid galvanic corrosion



- The smaller the cathodic (steel) surface is with respect to the Al surface, the smaller is the galvanic corrosion rate

  ⇨ Do not coat the anode only!
  (coating defects will cause strong local corrosion)



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Lille Frigg Protection Cover after removal

Steel structure with protection cover at top of aluminium extrusions

Lille Frigg Protection Cover after removal

Aluminium top cover of aluminium extrusions

Lille Frigg Protection Cover after removal

Hinge for aluminium protection cover and steel structure

Lille Frigg Protection Cover

For corrosion protection, galvanic anodes are used. The need for galvanic anodes is ~10% of what is needed for steel structures.

Summary

- Lightweight
  - Typical weight savings of 50% for both mechanical and electrical applications
- Built-in fire protection
  - Inherent lightning protection
- Ease of inspection
  - Unpainted surfaces for simplified visual inspection
- High thermal conductivity
  - Further weight reductions through reduced cooling requirements
- Recyclability
  - End-of-use value helps to offset decommissioning costs
- Wide range of surface treatments
- Combination of steel and aluminium possible through appropriate design and surface coating of steel.

An opportunity for the Wind Industry?

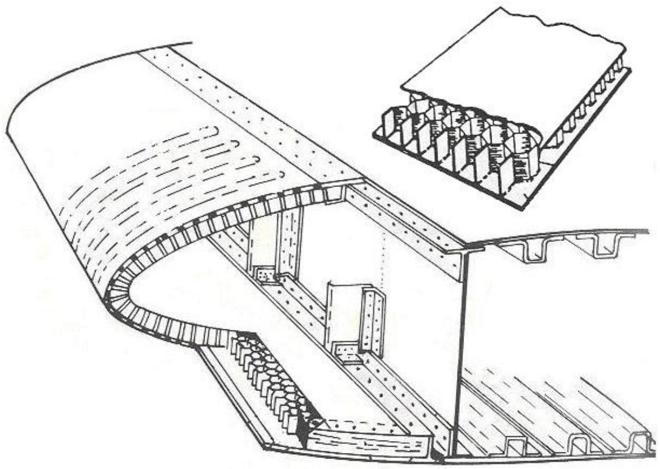
A major issue regarding life cycle costs of wind turbines, is durability and end of life scrapping of fibreglass/CFRP rotor blades.

It has been suggested by several turbine manufacturers that an Al solution would be desirable.

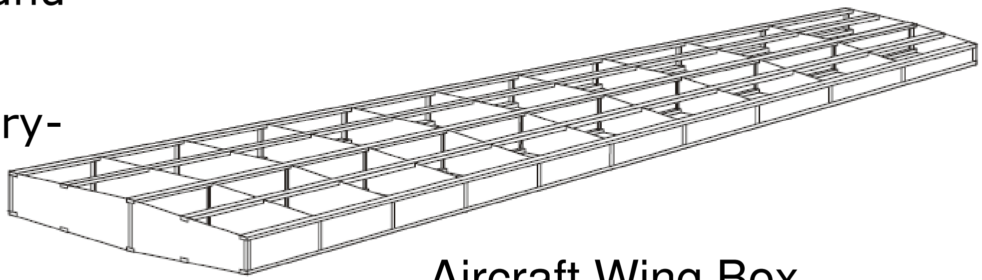
Experience from the aerospace industries suggests that this would be possible.

However, the development and testing of a full scale blade is a major investment and would require industry-wide interest and support.

A solution would be to form an industry-wide consortium, including Hydro Aluminium as partner.



Sandwich core structure for aircraft wings



Aircraft Wing Box

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www.hydro.com

Thank you for your attention

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