Corrosion behaviour of a self-pierce rivet joint of carbon-fibre reinforced plastic-laminate and EN AW-6060-T6 subjected to laboratory and outdoor exposure tests



CFK-Valley Stade Convention 2013

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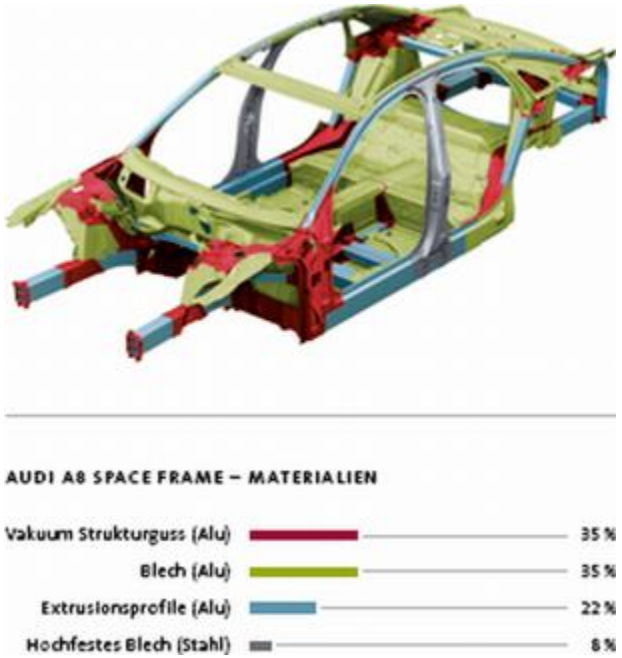
Outline

- Light-weight design concept
- Joining by riveting
- Corrosion
- Experimental
  - Indoor and Outdoor exposure
- Results
- Conclusion



Source: Audi

Light-weight design concept

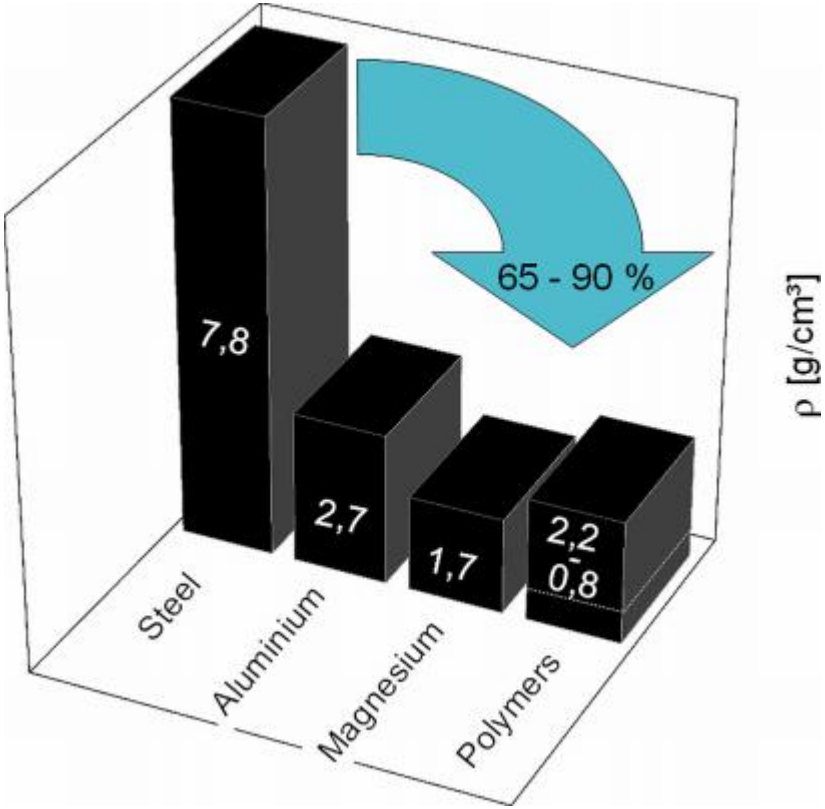
Weight reduction → replacement of steel → CO_2 reduction

Alternatives:

Aluminium

Magnesium

Polymers



→ Good atmospheric corrosion behaviour

→ Multi-Material design needs appropriate joining technologies

Corrosion

Atmospheric corrosion is influenced by:

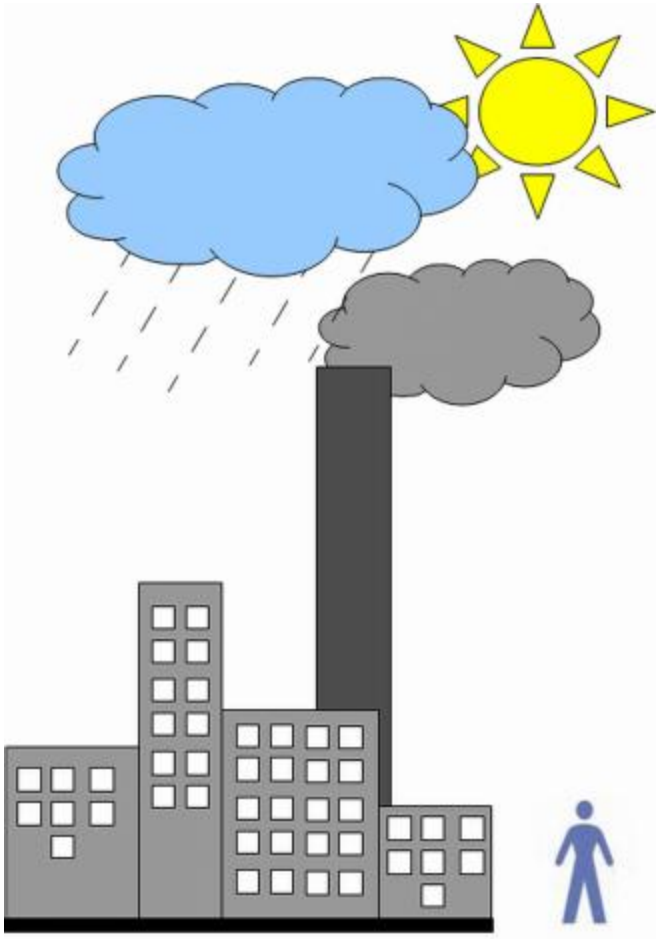
- Relative humidity
- Fly-ash
- Temperature
- Gases
- Solved salts
- Human factors

…

Good behaviour of intrinsic corrosion

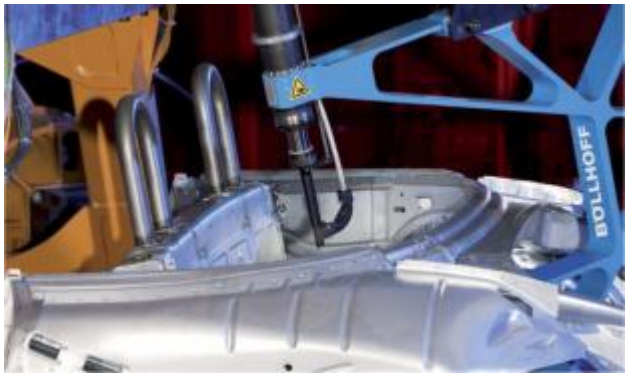
but problems when joined

→ Galvanic Corrosion, Crevice Corrosion



Corrosive effects

Joining by riveting



Source: Wilhelm Böllhoff GmbH & Co. KG

Advantages

- No heat introduction
- No pre-drilled holes
- High dynamic tensile strength
- Force- and form-fit
- Appropriate for hybrid-compounds

Disadvantages

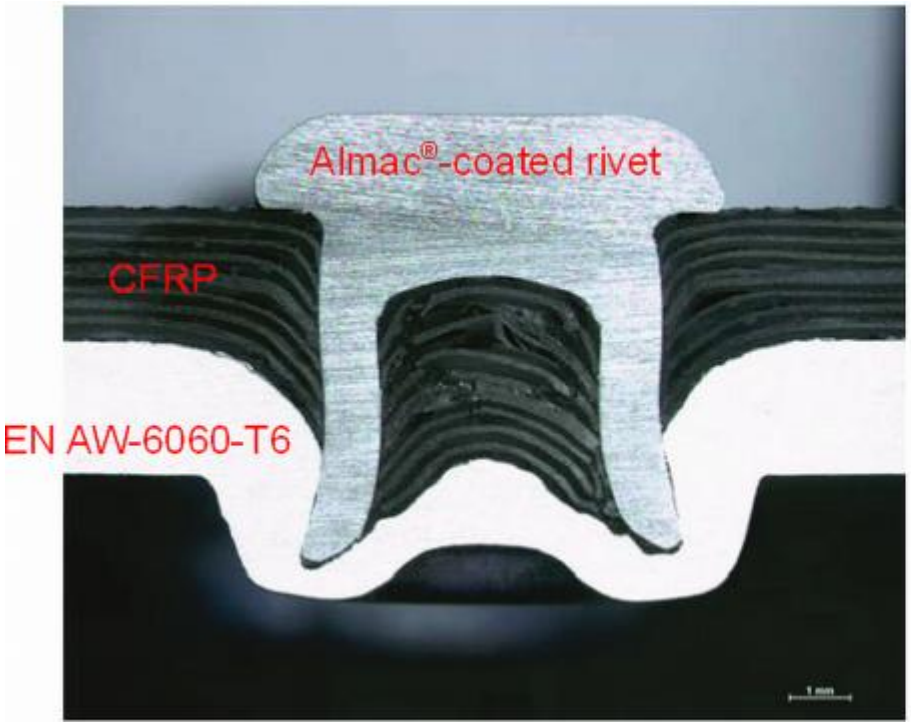
- Access to both sides
- High force load
- Galvanic corrosion

Joining by riveting

DFG-AiF Cluster Project KOMMA

- Investigation of 2 rivet joints in

  → Interaction of corrosion and mechanical load



Self-piercing rivet joint
CFRP/Al

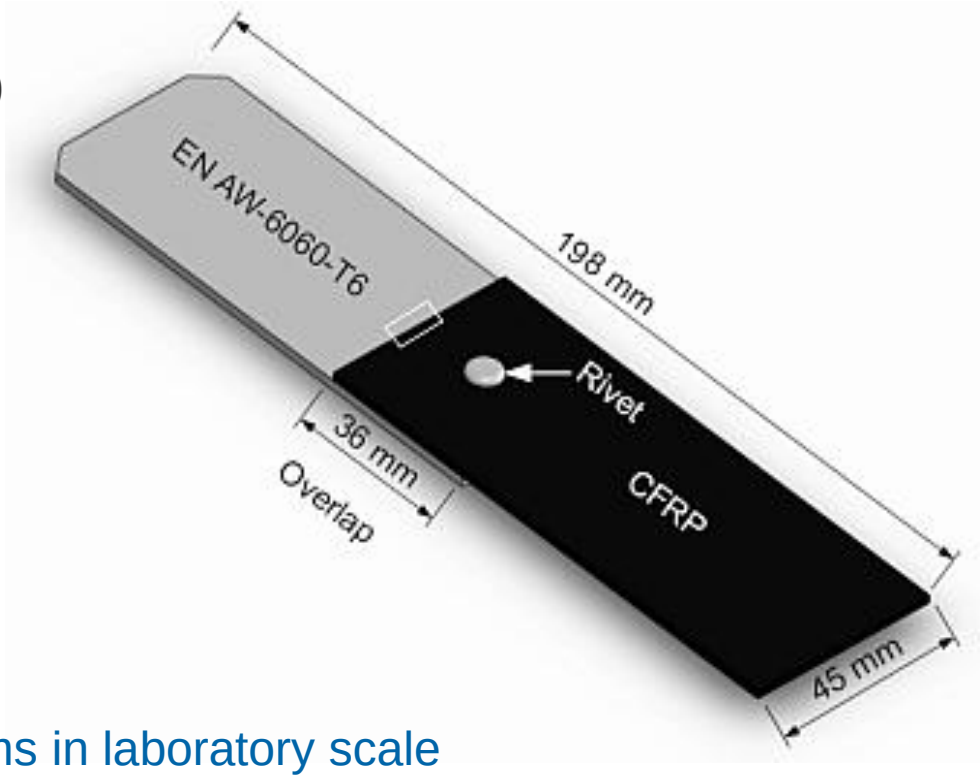
Blind rivet joint
Steel/Al

Experimental

Self-piercing rivet joint

- Extruded sheet of EN AW-6060-T6
- CFRP-laminate (T700SC/RIM935)
- Almac®-coated self-pierce rivet

Electric conductivity between EN AW-6060-T6 and CFRP-laminate due to joining process



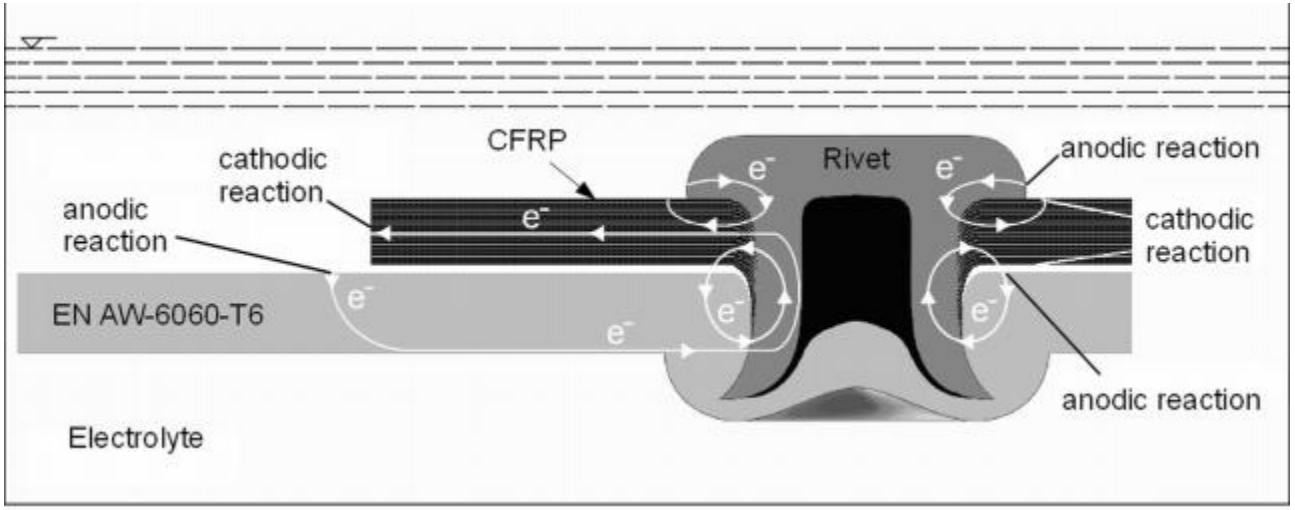
Investigation of corrosion mechanisms in laboratory scale

→ But how to transfer the results to real corrosion behaviour?

Experimental

Galvanic Corrosion

- in contact to an electrolyte a galvanic element is formed
- CFRP is the cathode
- EN AW-6060-T6 and rivet are the anodes



Test conditions

Indoor

Climatic conditions defined by controller

Outdoor

Source: Institute for Corrosion Protection Dresden GmbH

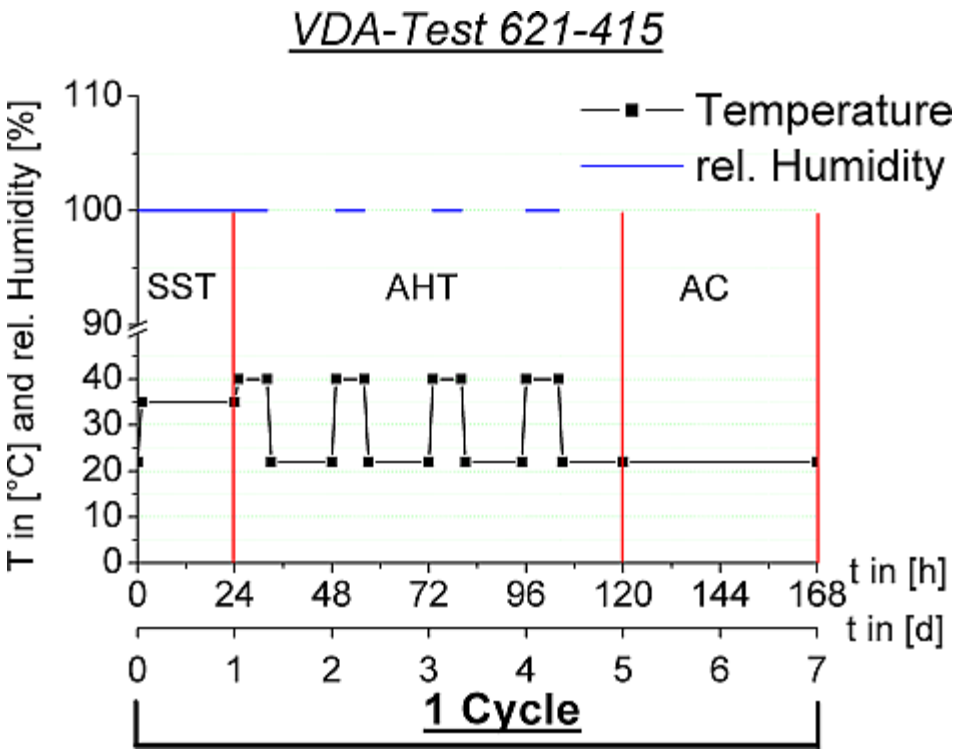
Climatic conditions defined by environment and controller

Experimental

Indoor – VDA 621-415

- 24h salt spray test (SST)
- 96h alternating humidity and air temperature test (AHT)
- 48h ambient climate test (AC)

Preferred test for investigation of subsurface corrosion of organically-coated materials



Experimental

Outdoor – VDA 621-414

- Climatic conditions of Dresden
- Corrosion category C2/C3
- Weekly sprayed with 3wt% sodium chloride solution

Source: www.wetterdienst.de

Source: Institute for Corrosion Protection Dresden GmbH

Results

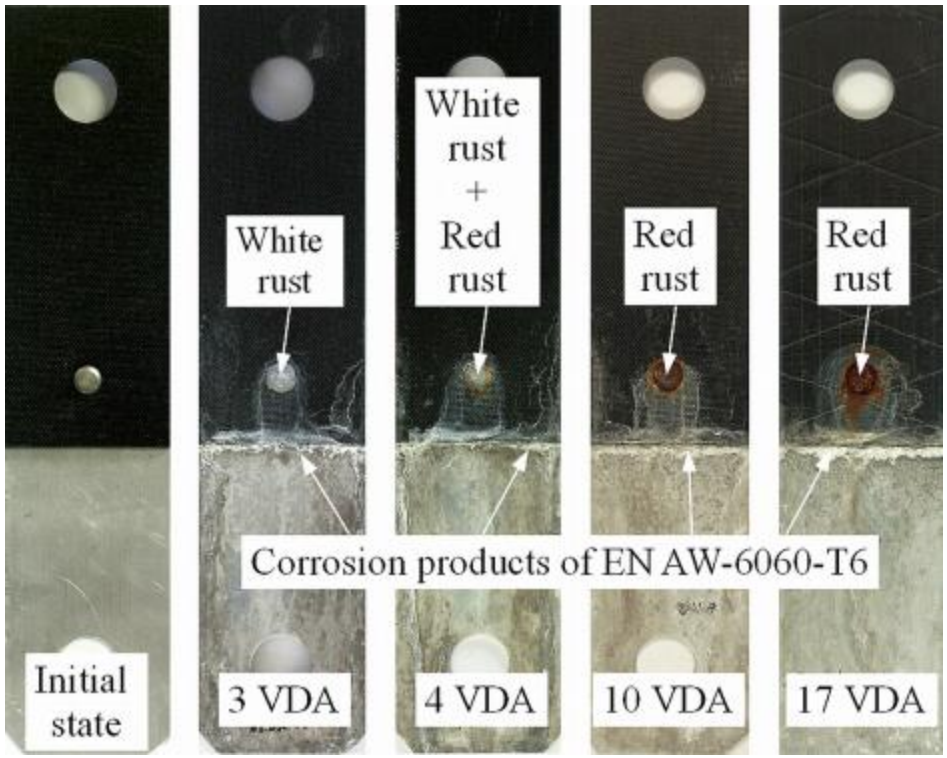
Indoor – VDA 621-415

Cycle 1
- white rust at rivet head
- heavy formation of corrosion products at the overlap

Cycle 4
- white and red rust at rivet head

Cycle 10
- completely dissolved Almac®-coating

Cycle 17
- increased formation of corrosion products at the overlap



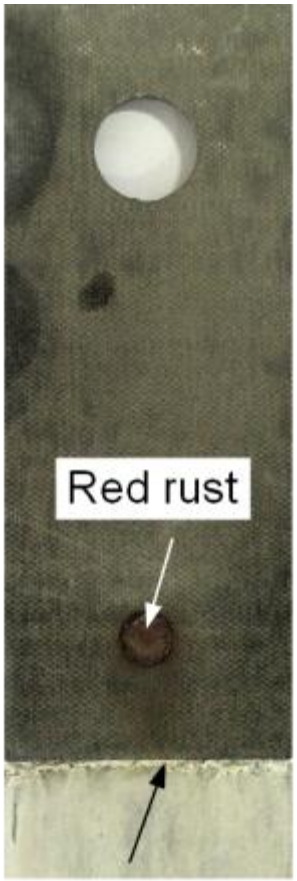
Results

Outdoor – VDA 621-414

- red rust at rivet head
- heavy formation of corrosion products at the overlap

→similar corrosion behaviour in comparison to indoor testing

⇒ VDA 621-415 is comparable to VDA 621-414



Corrosion products of EN AW-6060-T6

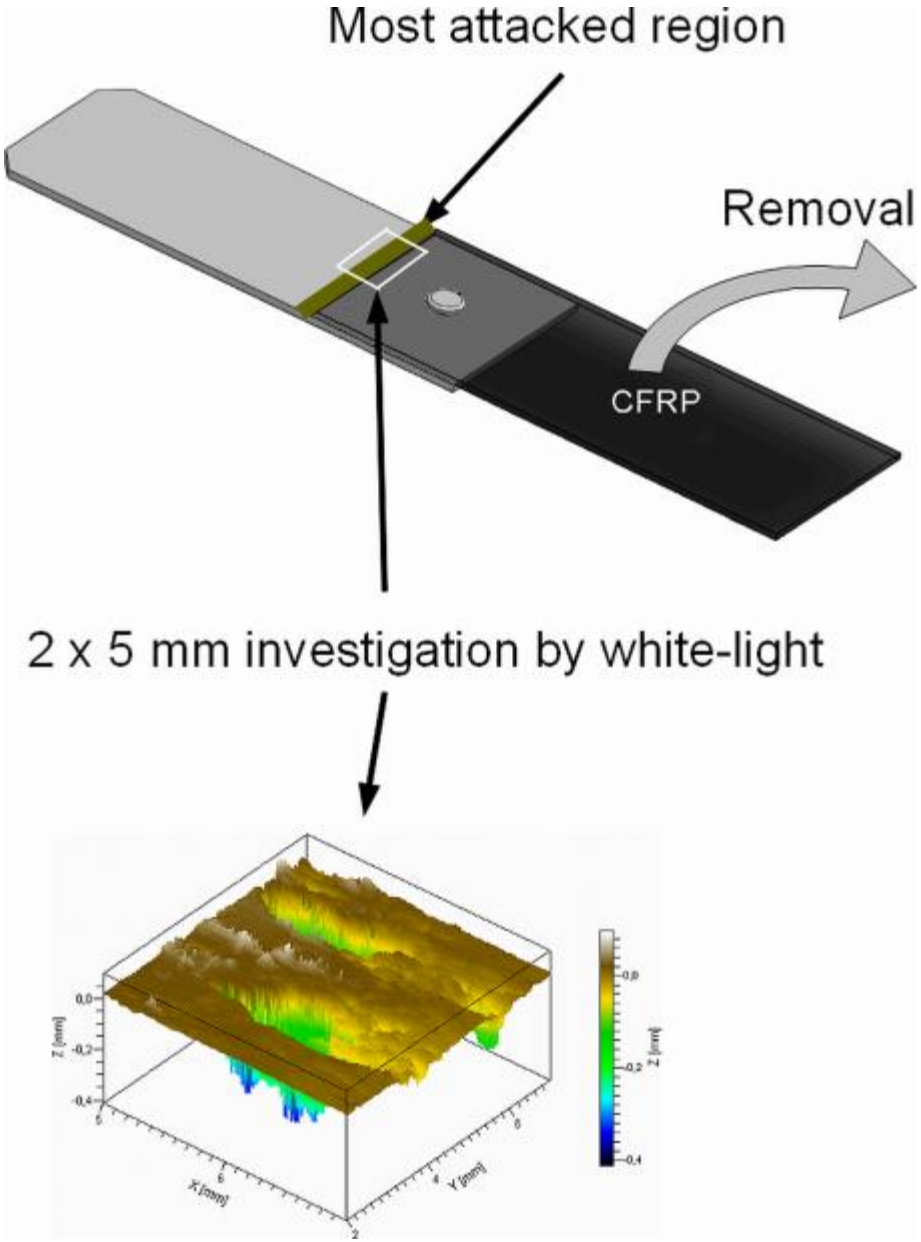
Results

Surface scan

- removal of CFRP
- most attacked region at the EN AW-6060-T6 at the overlap
- investigation by white-light interferometry

Indoor: every cycle

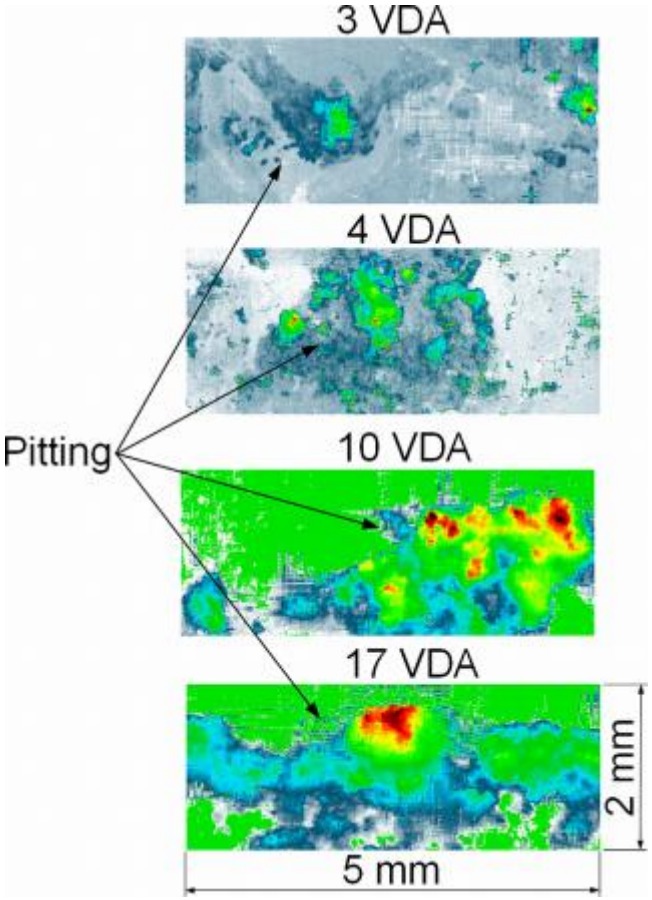
Outdoor: after one year



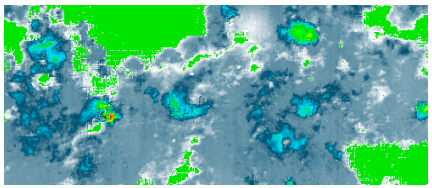
Results

Surface scan

- Similar corrosion damage
- 1 year outdoor is more aggressive than 4 cycles indoor



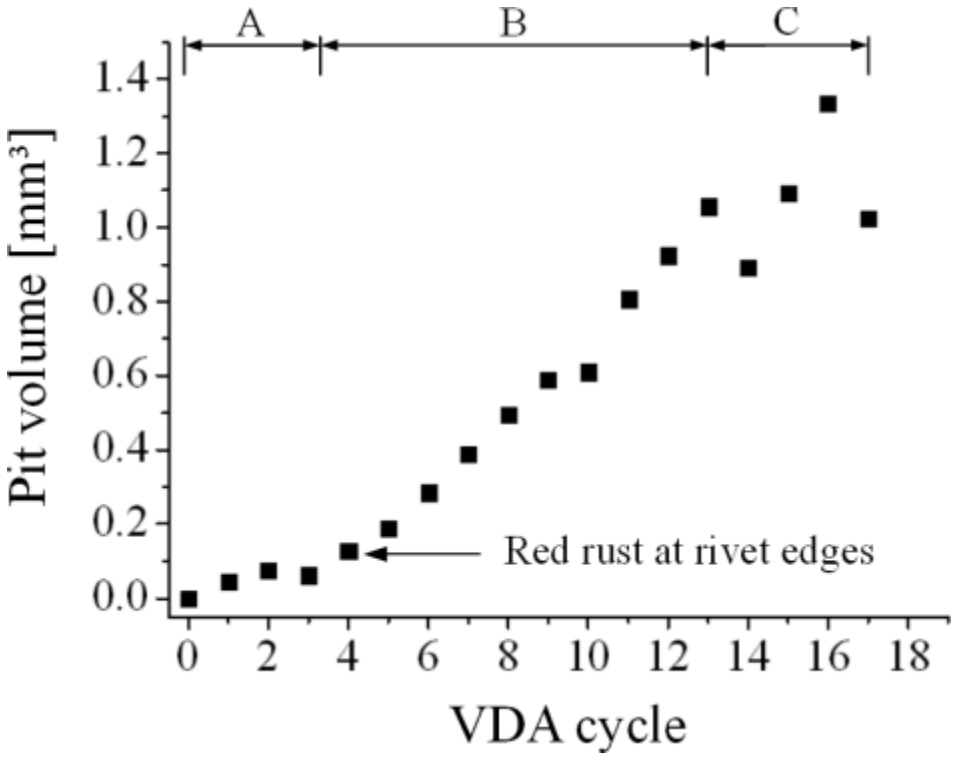
Indoor



Outdoor

Pit volume

- Determination of the pit volume after each cycle of VDA 621-415
- Dividing in Region A, B and C
- complete dissolution of the Almac® coating



(mean of 3 samples)

Results

Indoor – VDA 621-415

Region A: corrosion is low

→ Pitting corrosion,

z ~ 0.15µm

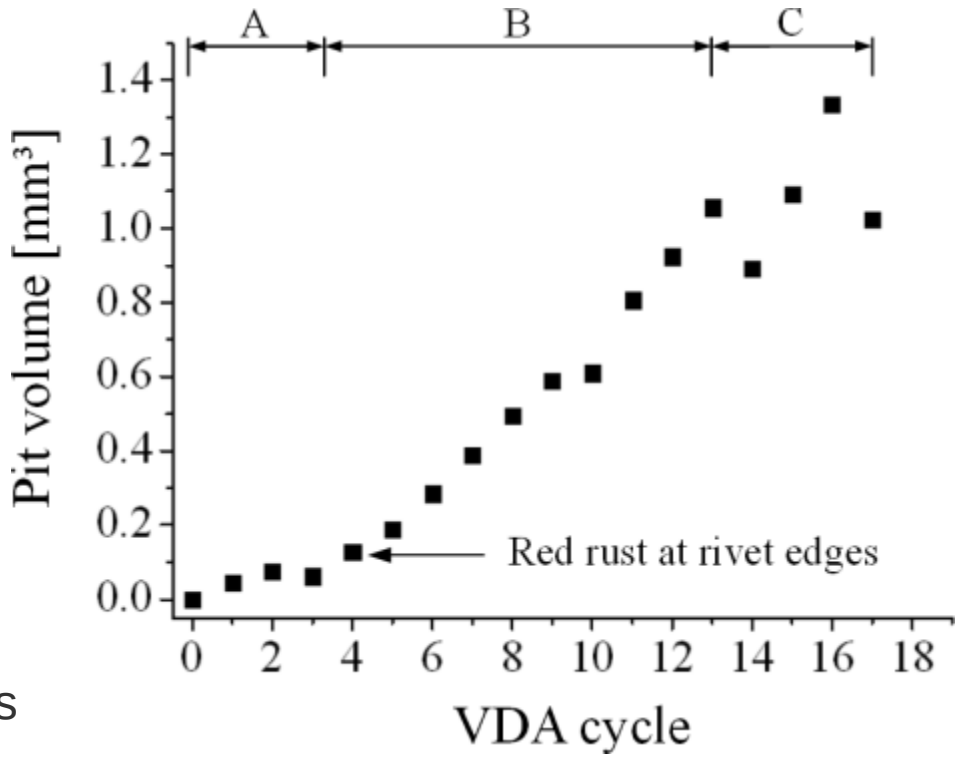
Region B: corrosion is high

→ Pitting corrosion,

z ~ 0.2µm → z ~ 0.5µm

Region C: corrosion rate decreases

→ z ~ 0.6µm



Corrosion attack as well in lateral direction → Pits coalesce

Results

Comparison of indoor and outdoor

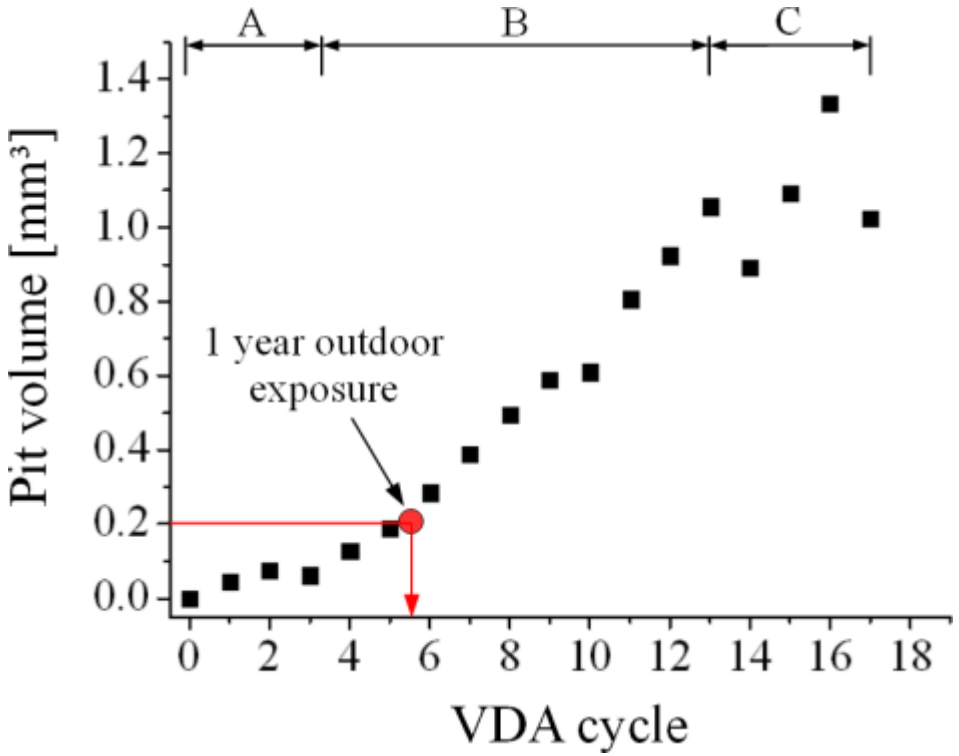
Corrosion attack was more

aggressive than 4 cycles indoor,

z ~ 0.25µm

Pit volume is equivalent

to 5 – 6 cycles indoor exposure



1 year outdoor = 5 - 6 cycles indoor

Results

Similar corrosion behaviour at indoor and outdoor testing

→ Test results are comparable to each other

→ 1 cycle VDA 621-415 = 1 week

→ 1 year outdoor exposure = 5 – 6 VDA 621-415

⇒ Corrosion behaviour at 1 year outdoor exposure is received in

5 – 6 weeks indoor exposure

⇒ significant reduction of test duration

Test-duration: Indoor = $\frac{1}{9}$ Outdoor

⇒ Time saving of 90%

Conclusion

- Investigation of the corrosion behaviour of a self-piercing rivet joint

  EN AW-6060-T6 / CFRP-laminate / Almac®-coated rivet

- Rivet supplies electric conduction between

  EN AW-6060-T6 and CFRP

→ Formation of a galvanic element in the presence of an electrolyte

Anodes: EN AW-6060-T6, Almac®-coated rivet

Cathode: CFRP-laminate

Conclusion

- Investigation of the corrosion behaviour by 17 cycles of VDA 621-415 and 1 year VDA 621-414

→ Corrosion damage is similar

→ Test results are comparable to each other

- Determination of the pit volume in the most attacked region of EN AW-6060-T6
- 1 year VDA 621-414 = 5 – 6 cycles of VDA 621-415

⇒ Significant reduction of test duration