Fatigue resistance of Al-Cu-Li alloys – effect of environment

Jean-Christophe Ehrström
Olivier Andreau
Christine Baudoux (Institut Pprime, ENSMA)

Constellium Technology Center, Voreppe, France

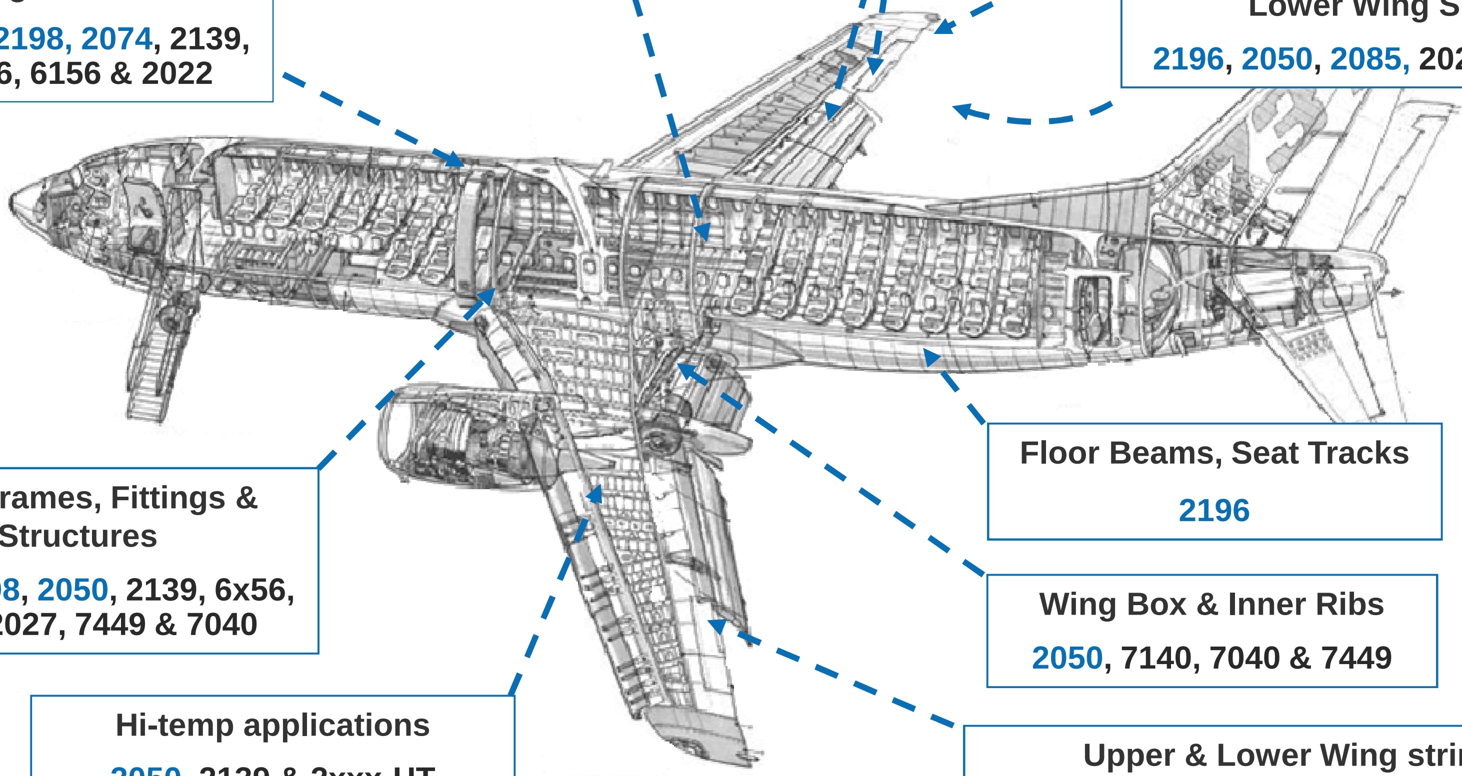
Constellium

Contents

- General introduction on Al-Cu-Li alloys → AIRWARE®
- Fatigue crack growth rate of Al-Cu-Li alloys
  - Overall behaviour very attractive
  - Al-Cu-Li alloy fit in the framework of « Poitiers », J. Petit et al.
- Fatigue performance of Al-Cu-Li alloys
  - Conventional samples
  - Technological specimens
- Specific study: effect of environment on endurance fatigue
  - With or without notch
  - Air or vacuum
- Conclusion

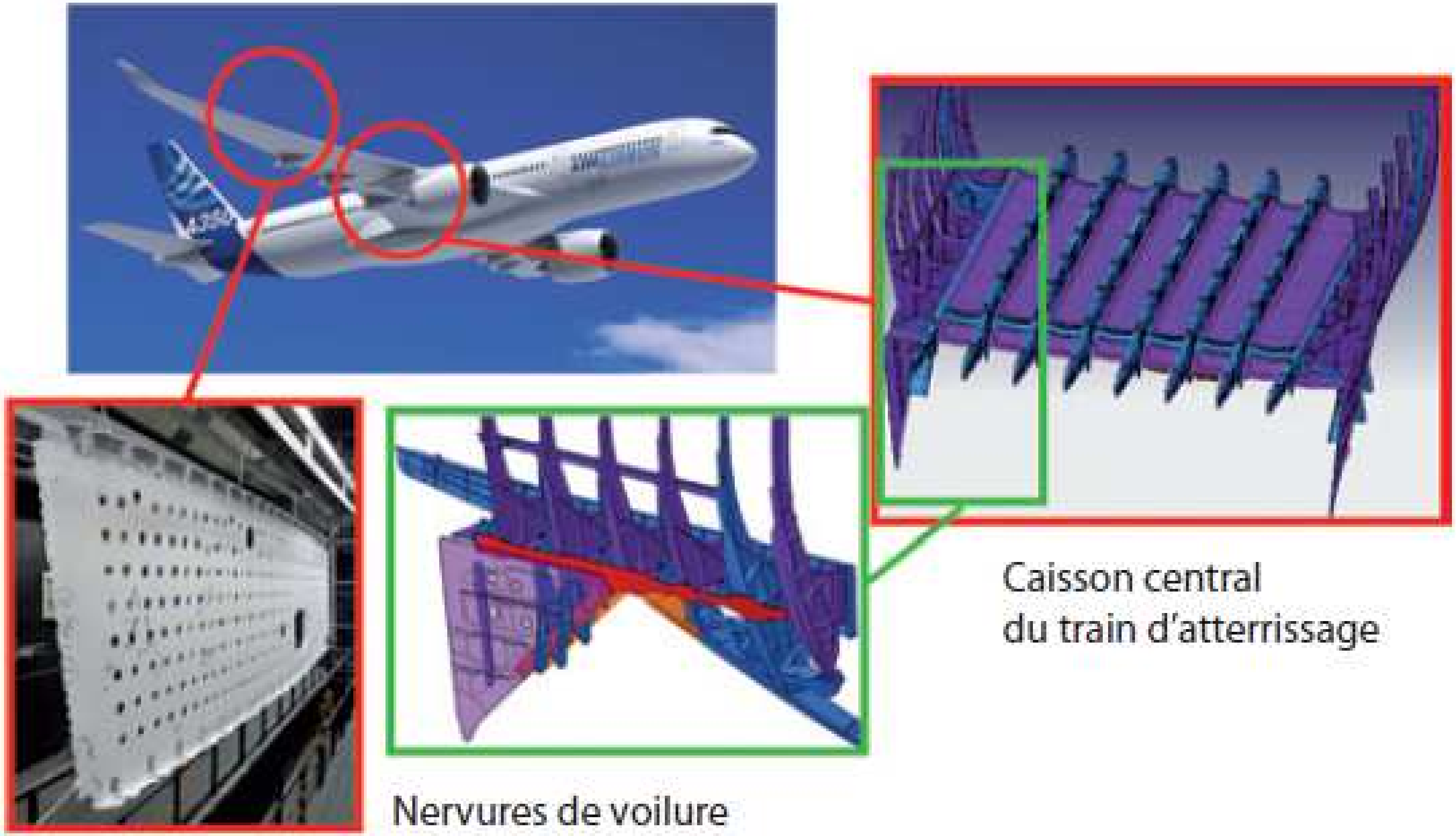
Airware® alloys can be used in the whole aircraft structure

Alloys in Blue designate AIRWARE® = trade mark for Constellium's Al-Cu-Li alloys



2050 industrially applied for thick structures

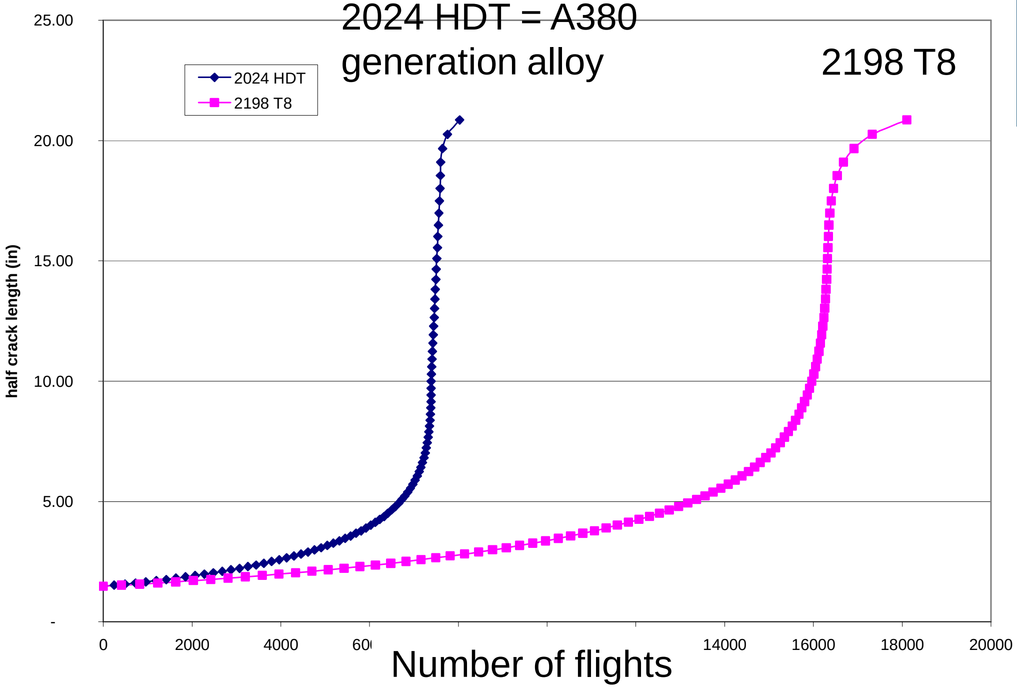
A350 ribs is a key market

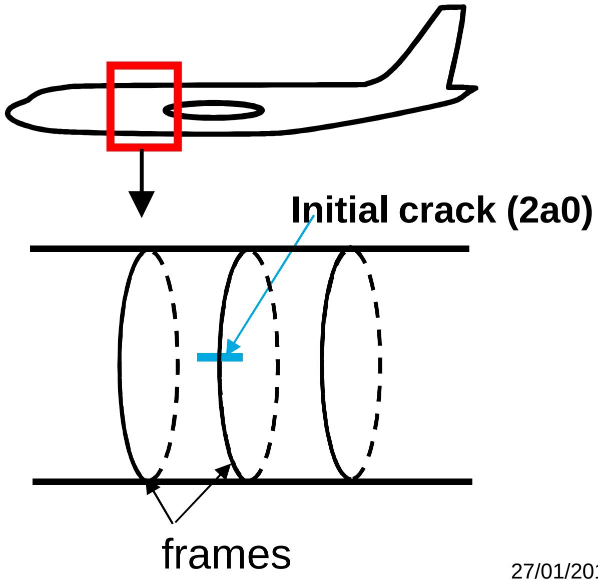


2198 damage tolerance → high performance fuselage

2198 T8 = alloy of C-series fuselage

Longitudinal crack length (in)



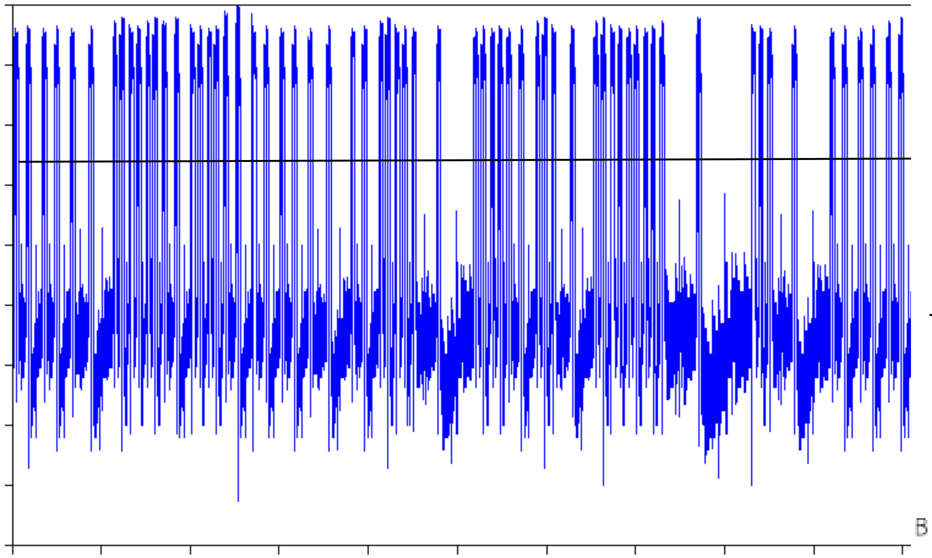


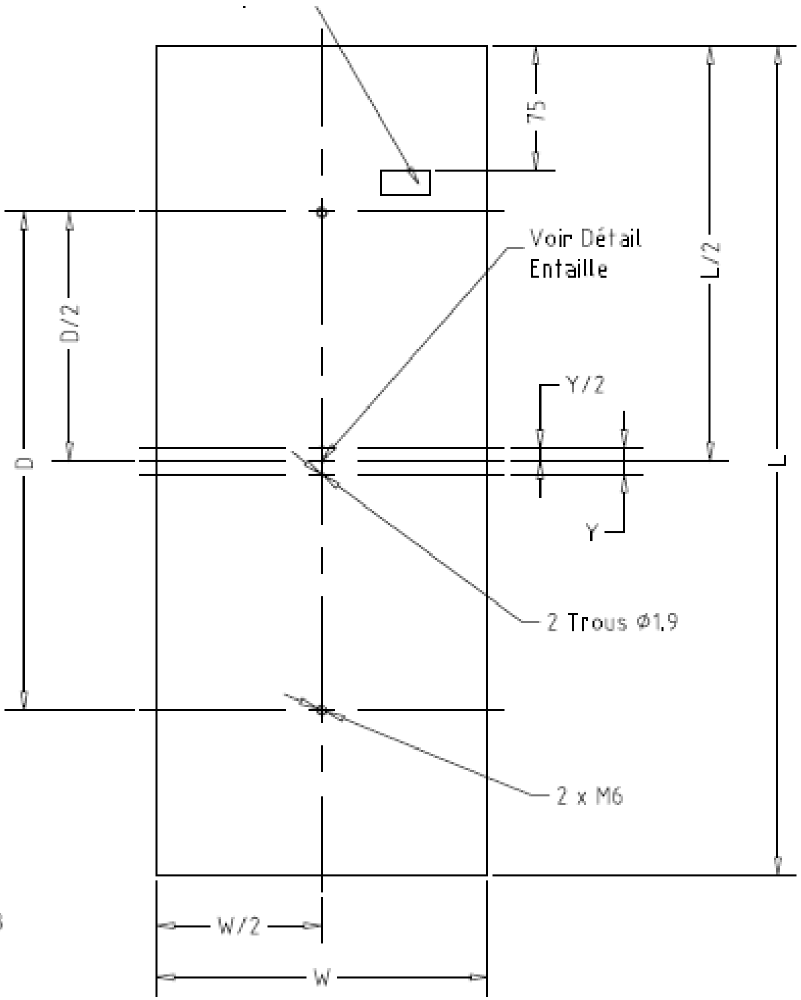
Contents

- General introduction on Al-Cu-Li alloys → AIRWARE®
- Fatigue crack growth rate of Al-Cu-Li alloys
  - Overall behaviour very attractive
  - Al-Cu-Li alloy fit in the framework of « Poitiers », J. Petit et al.
- Fatigue performance of Al-Cu-Li alloys
  - Conventional samples
  - Technological specimens
- Specific study: effect of environment on endurance fatigue
  - With or without notch
  - Air or vacuum
- Conclusion

Method: fatigue crack propagation in wing panels

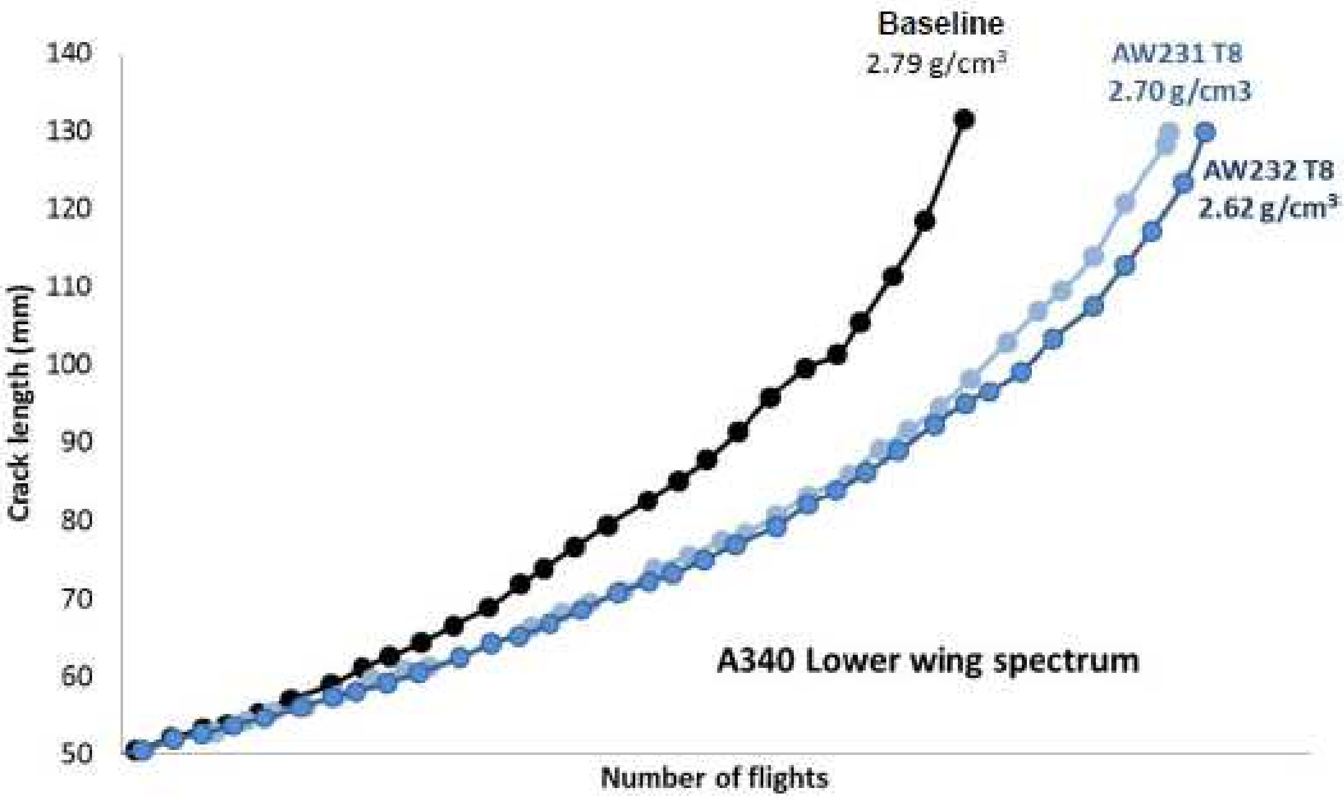
Long range spectrum





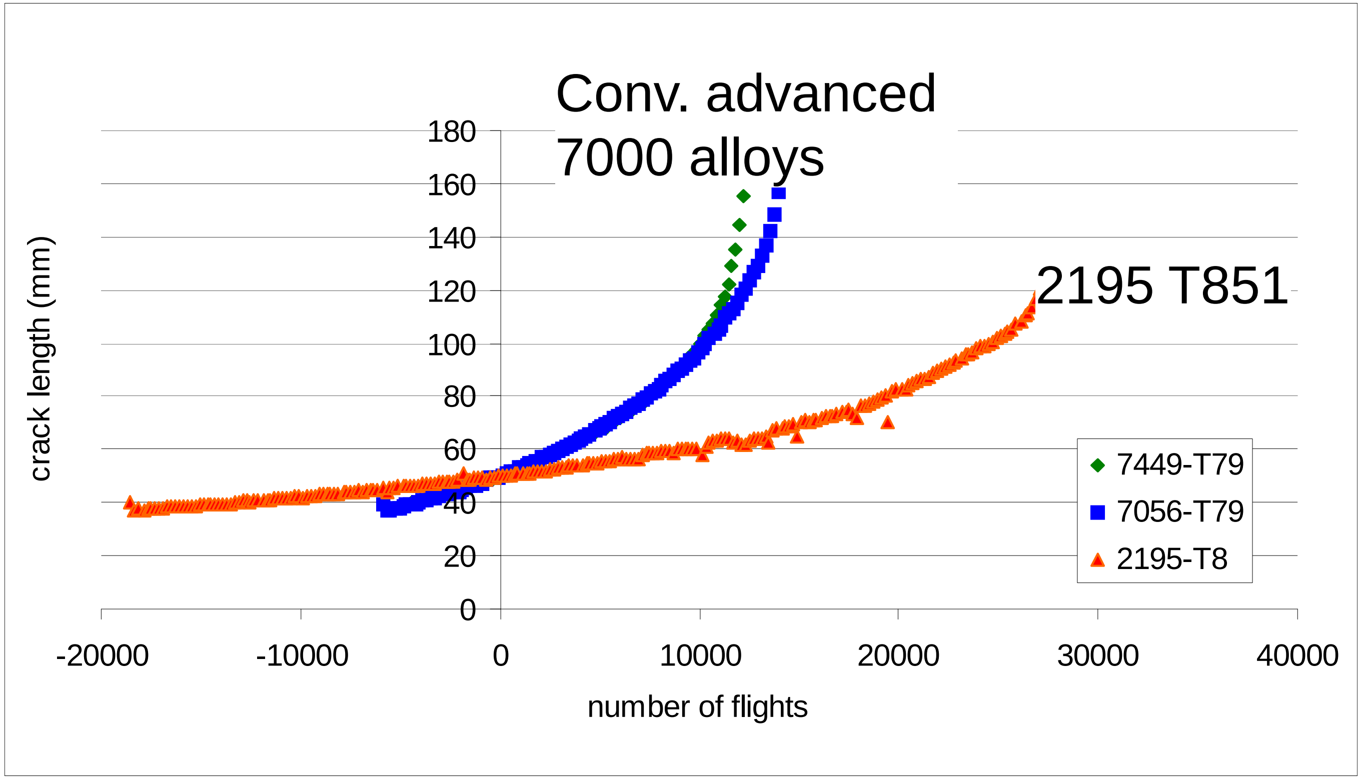
Lower wing Al-Cu-Li alloys performing better than A380 generation alloys (2027, 2024HDT > 2024)

Gain de densité de 5 – 6%



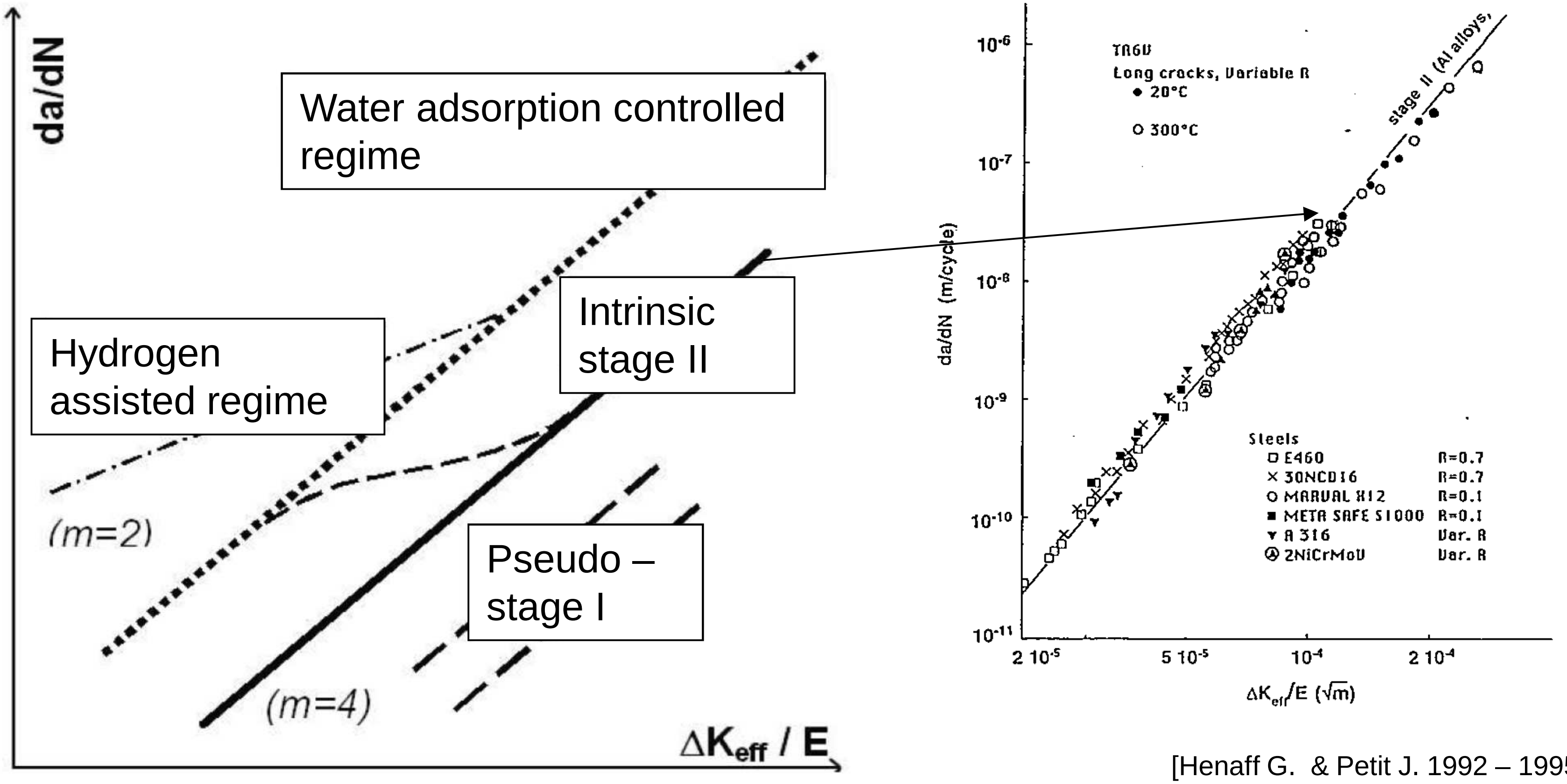
For high strength top wing alloys, FCG under spectrum is improved by a factor 2

- All alloys have similar yield stress



FCG in metals can be described with 4 basic regimes

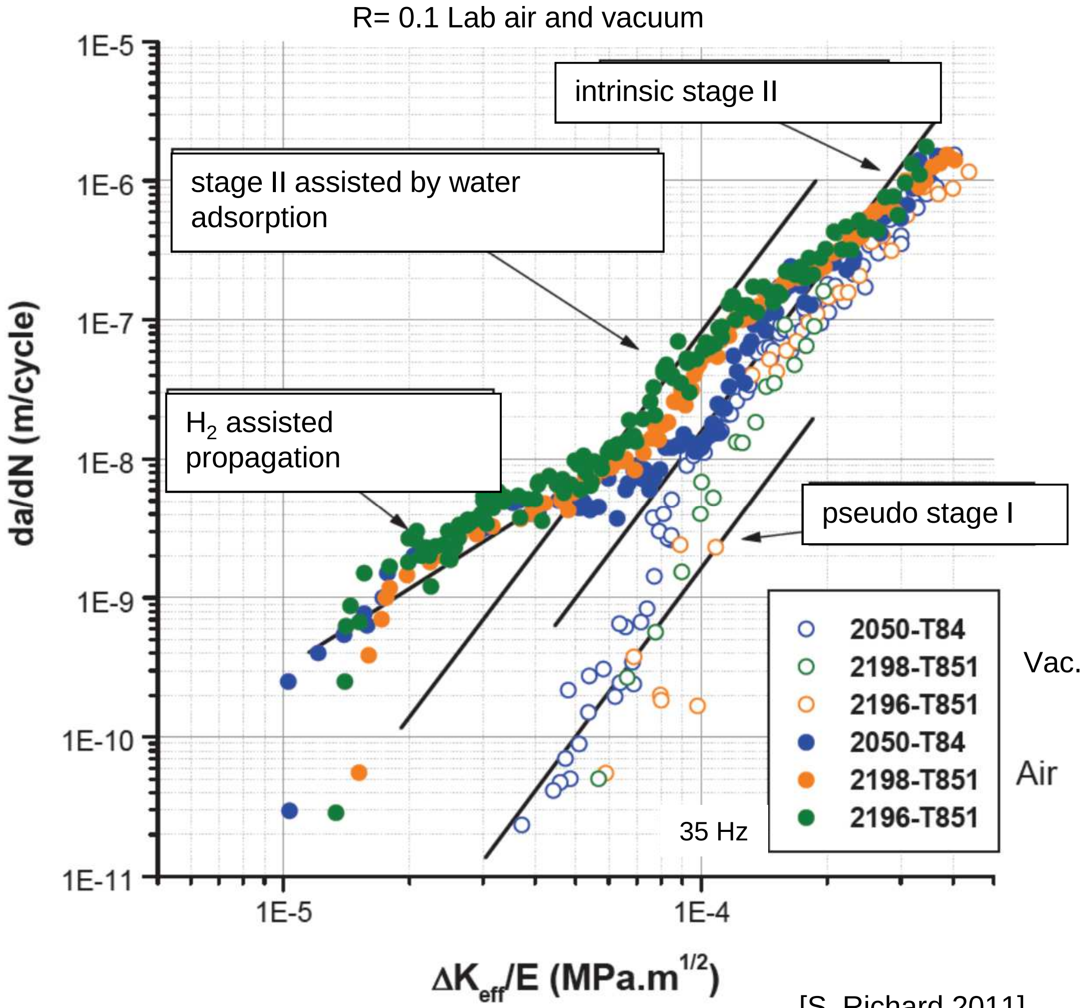
- FCG curves for different Al alloys and other metals (steel, Ti) can be reduced to master curves (e.g.. stage II)
- Effective stress intensity factor (divided by E) is the main parameter



[Henaff G. & Petit J. 1992 – 1995]

The 4 regimes positioning apply to AIRWARE®

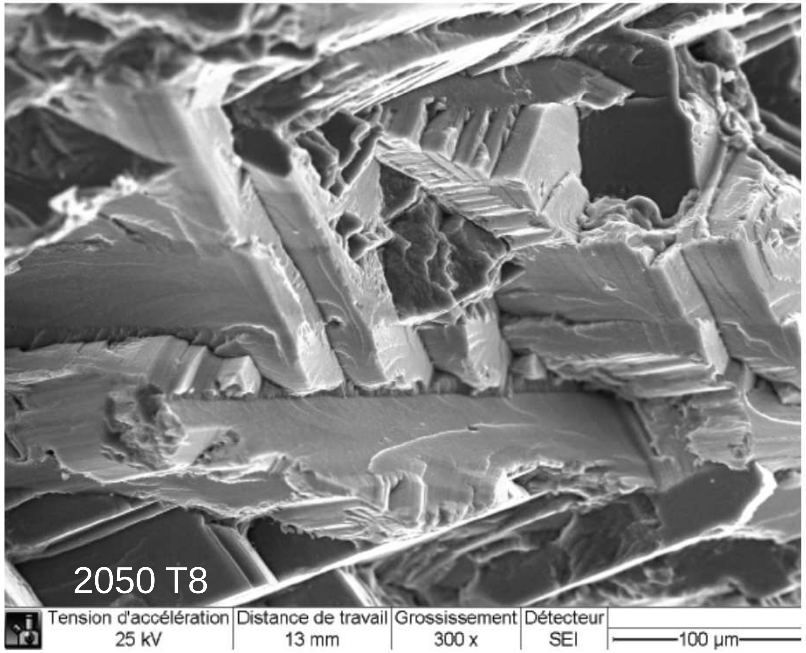
- In ΔK_{eff} plots, all 3 alloys (sheet, plate, low and higher Li contents) behave similarly
- Environment effect amounts to x100 at ΔK_{eff}= 3 MPa.m$^{1/2}$
- No environment effect at ΔK_{eff}> 15 MPa.m$^{1/2}$

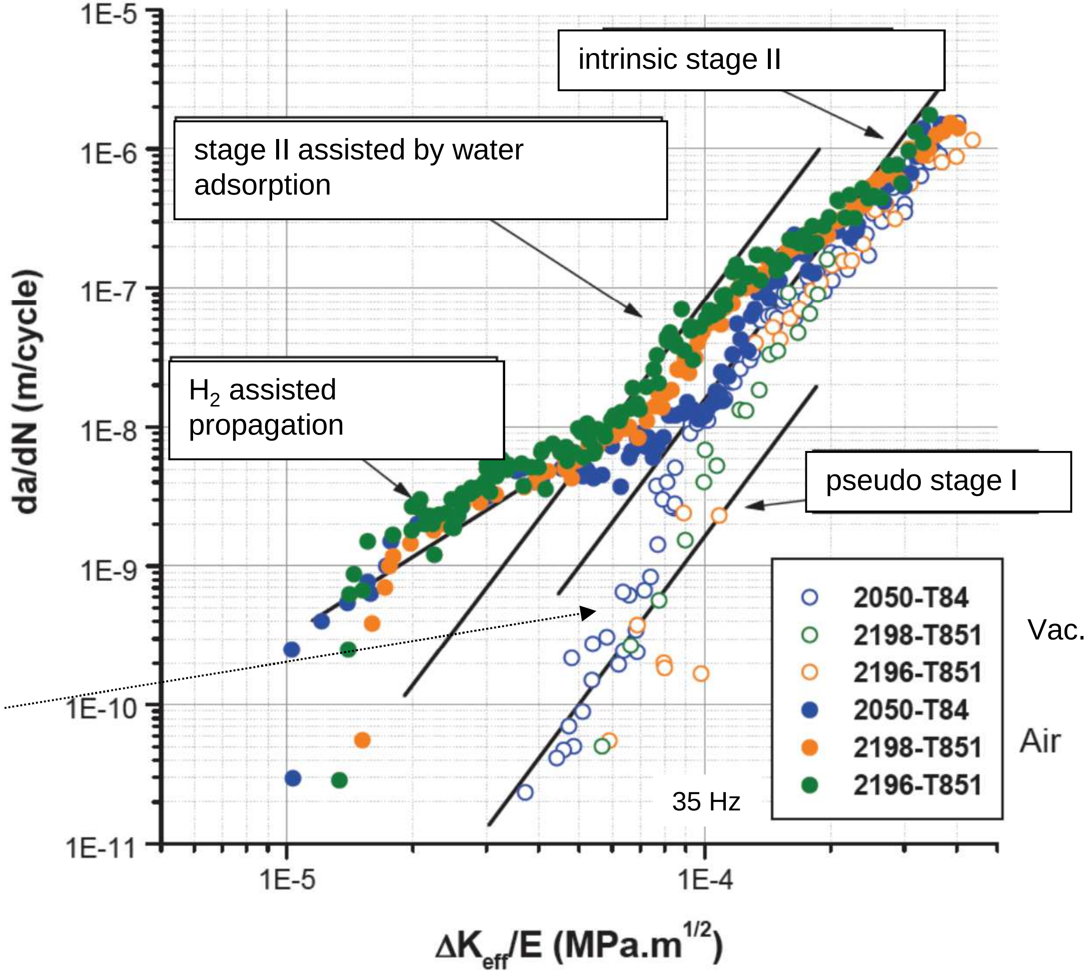


[S. Richard 2011]

Pseudo-stage I observed under vacuum

- Crystallographic fracture surface at $\Delta K_{eff} < 7$ MPa.m$^{1/2$}

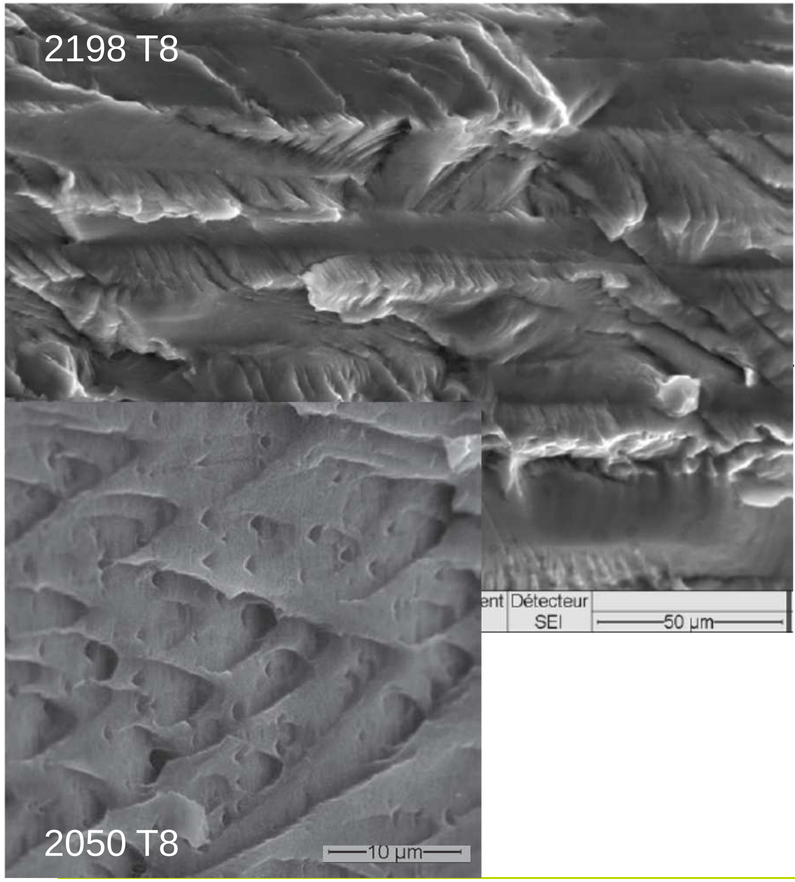


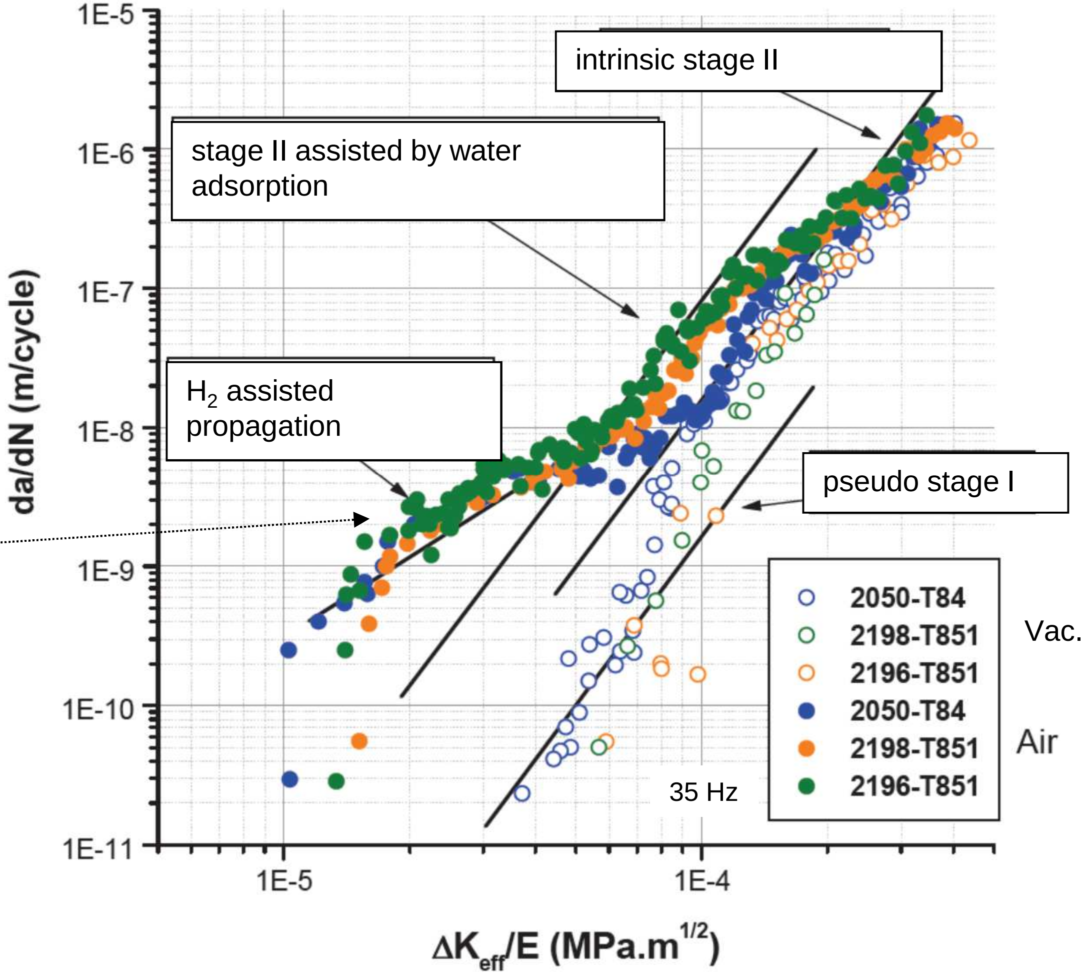


[S. Richard 2011]

H_2 assisted fracture → chevrons + smooth zones

- Chevrons associated to cracking of {111} planes

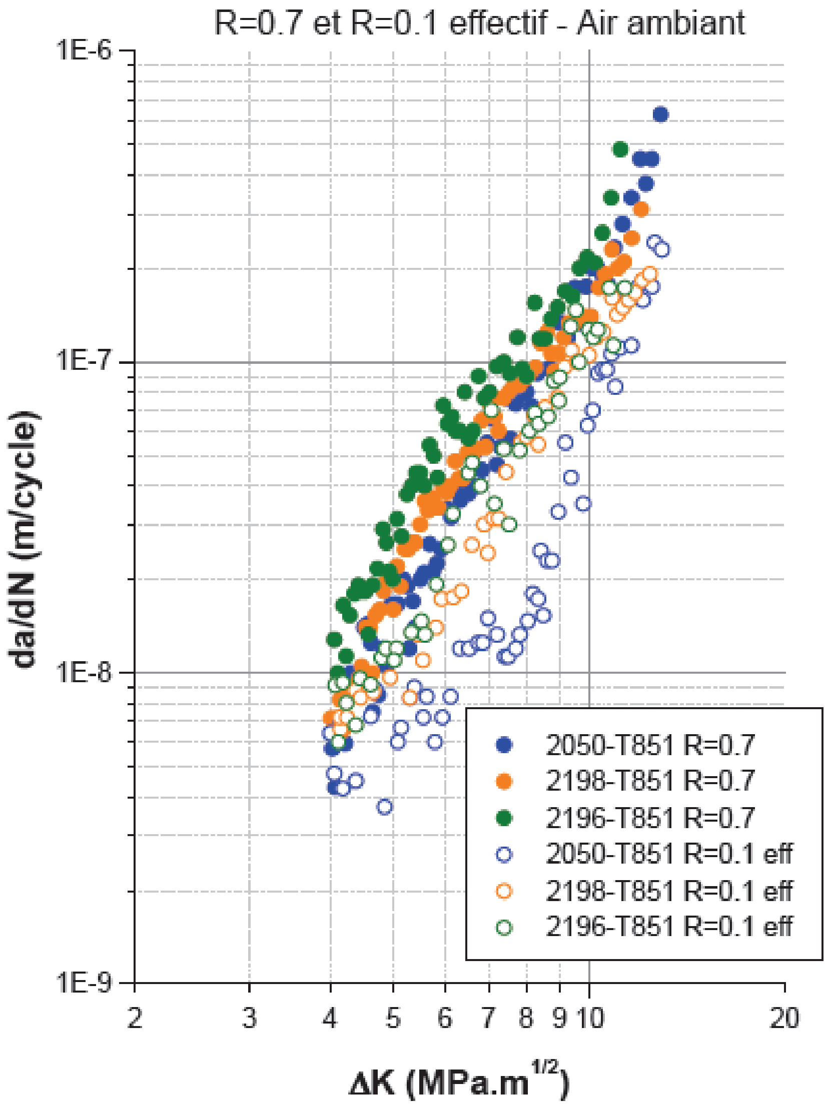




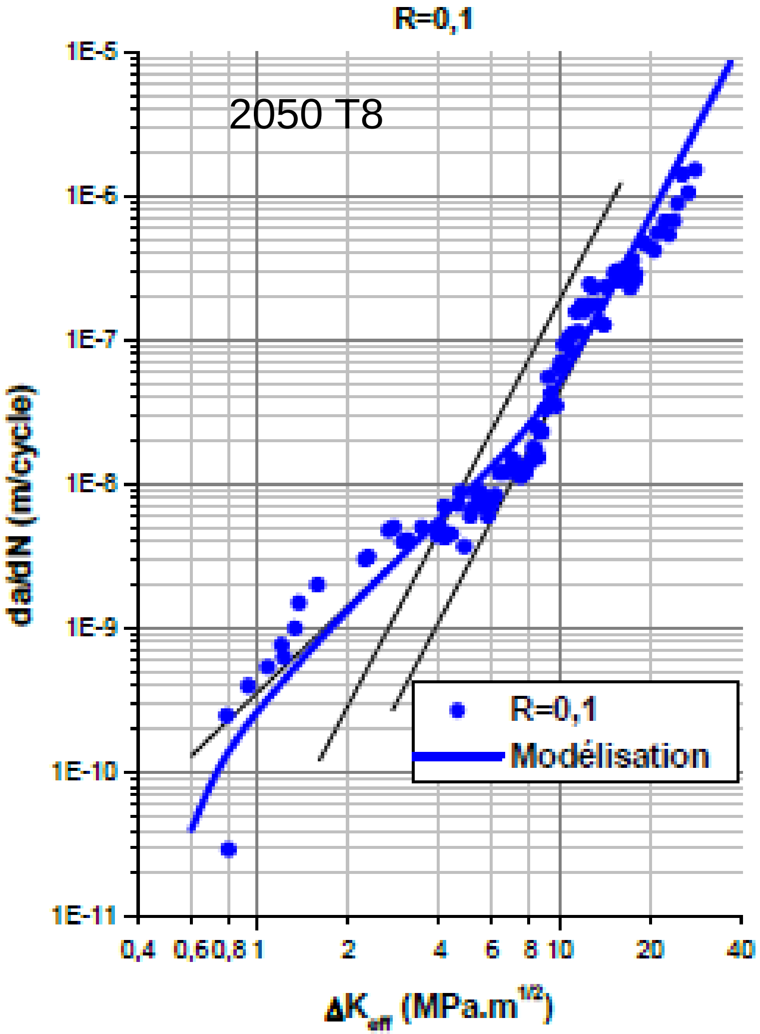
[S. Richard 2011]

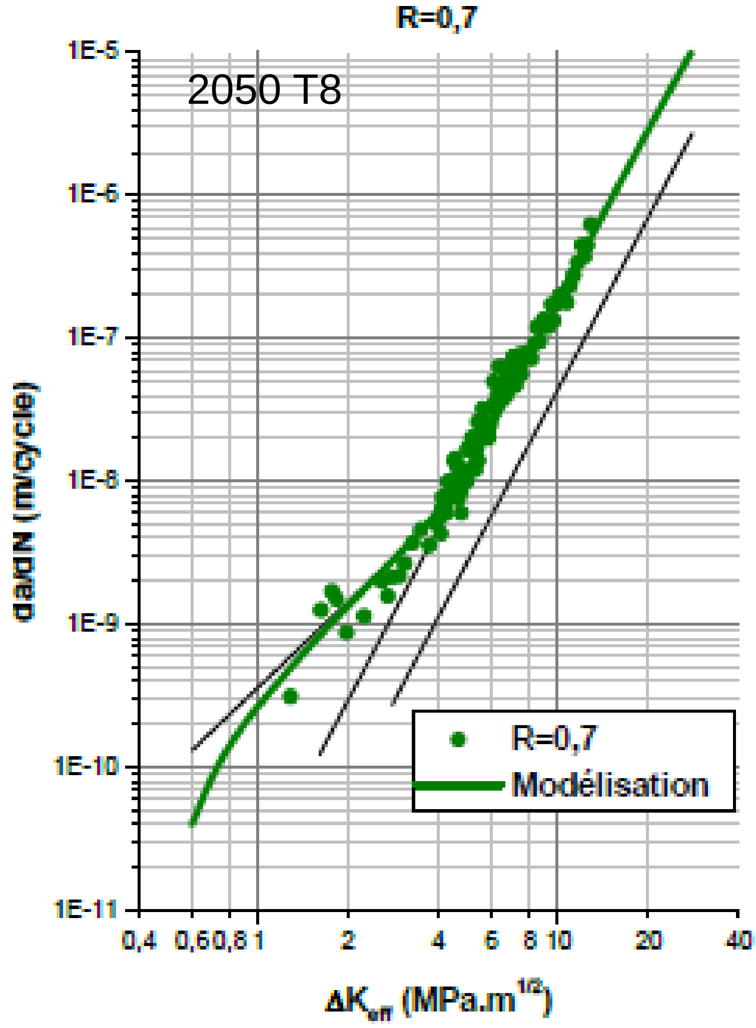
Closure does not fully explain R effect

R=0.7 → H_2O can access crack tip

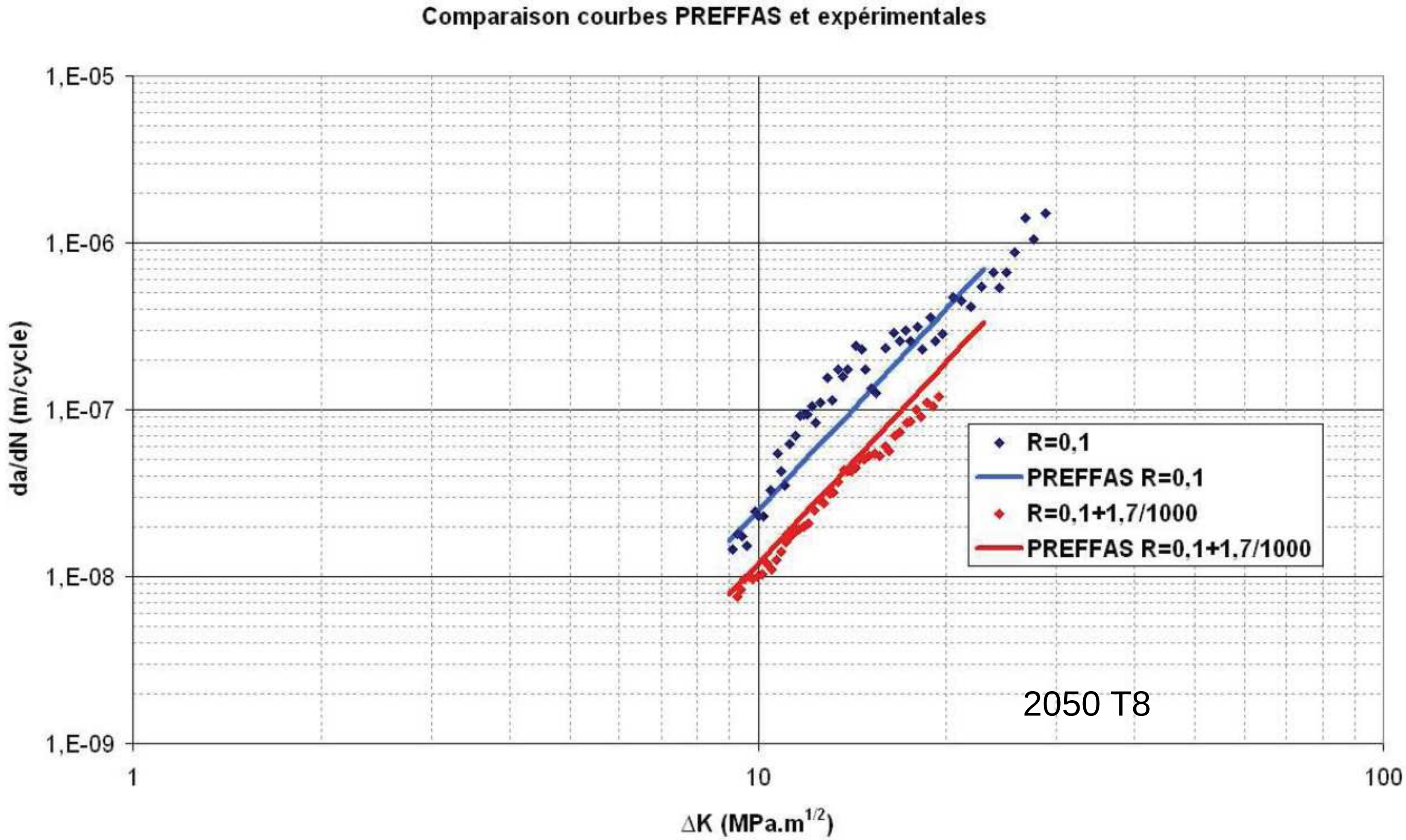


An exposure based model fits with the data





The exposure based model introduced in PREFFAS allows predicting overload effect



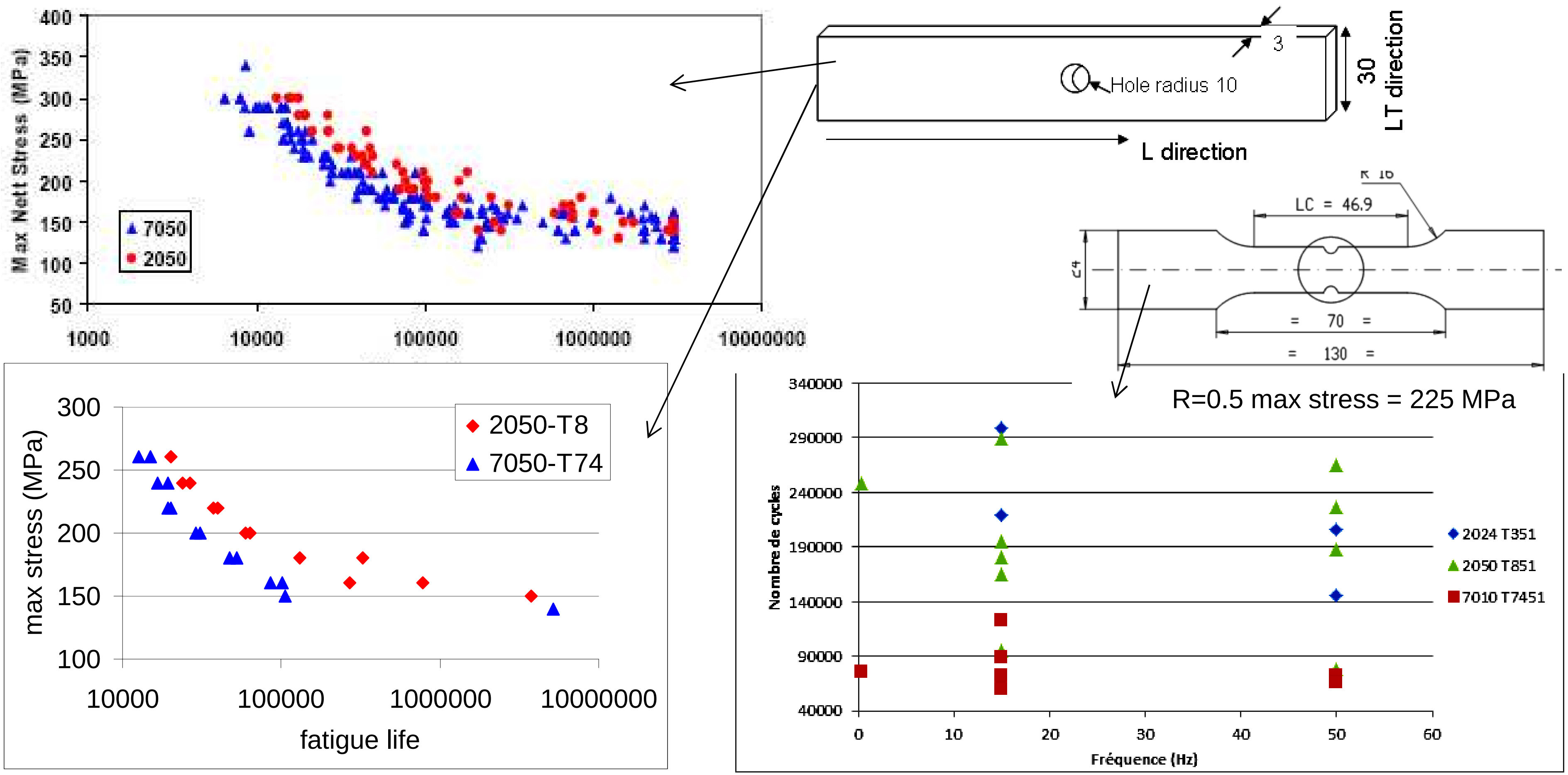
Contents

- General introduction on Al-Cu-Li alloys → AIRWARE®
- Fatigue crack growth rate of Al-Cu-Li alloys
  - Overall behaviour very attractive
  - Al-Cu-Li alloy fit in the framework of « Poitiers », J. Petit et al.
- Fatigue performance of Al-Cu-Li alloys
  - Conventional samples
  - Technological specimens
- Specific study: effect of environment on endurance fatigue With or without notch
  - Air or vacuum
- Conclusion

Open hole fatigue: 2050 > 7050 or 7010

In many studies, 2050 shown to have better resistance than 7000 alloys

OH Fatigue - 2050 vs 7050 - Kt2,3, T-L, R0,1, t/2 - Th=75-125mm

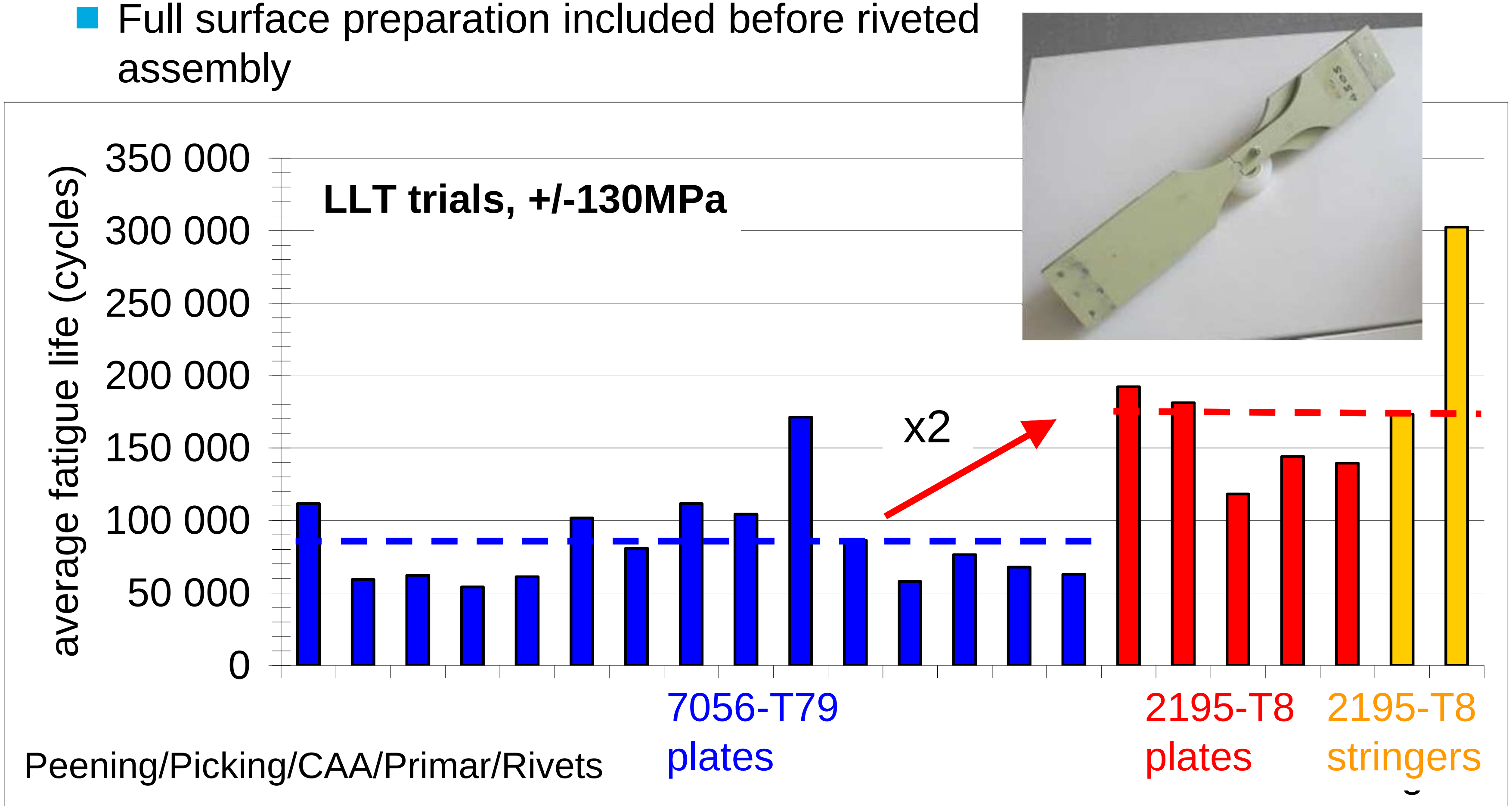


Low Load Transfer fatigue testing: Constant Amplitude

AIRWARE® products have increased lifetime compared to 7xxx alloys

AIRWARE® alloys have 2 times longer fatigue life compared to 7xxx alloys in a low load transfer assembly fatigue configuration

- Full surface preparation included before riveted assembly

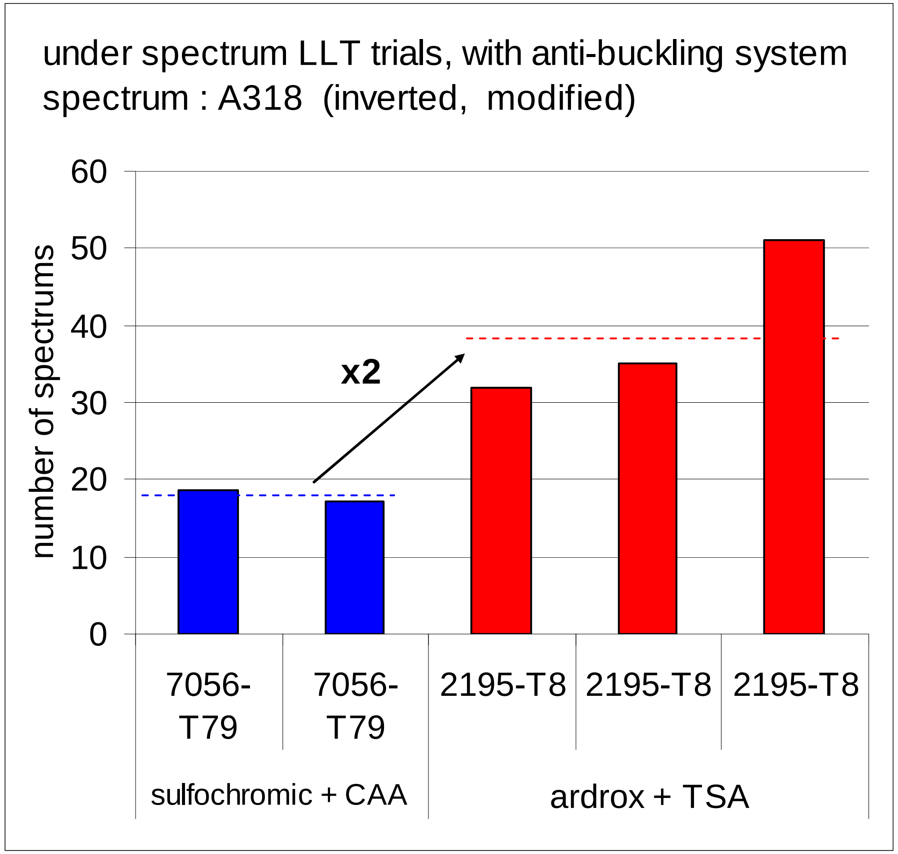


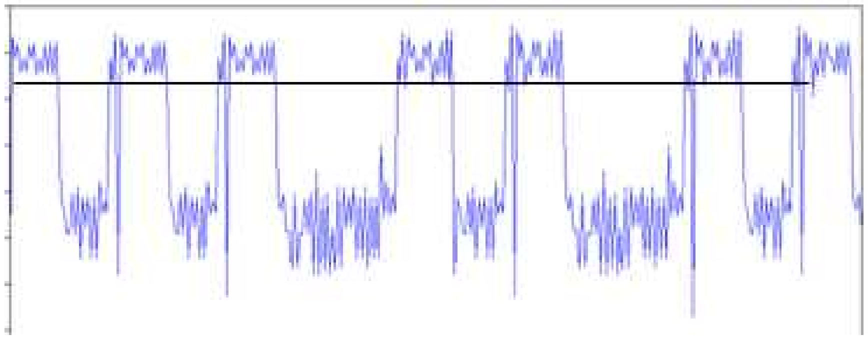
Low Load Transfer fatigue testing: Variable Amplitude

AIRWARE® products have increased lifetime compared to 7xxx alloys

AIRWARE® alloys have 2 times longer fatigue life compared to 7xxx alloys: This gain is confirmed for Chromium free surface treatment

- Specimen preparation: Ardrox + TSA

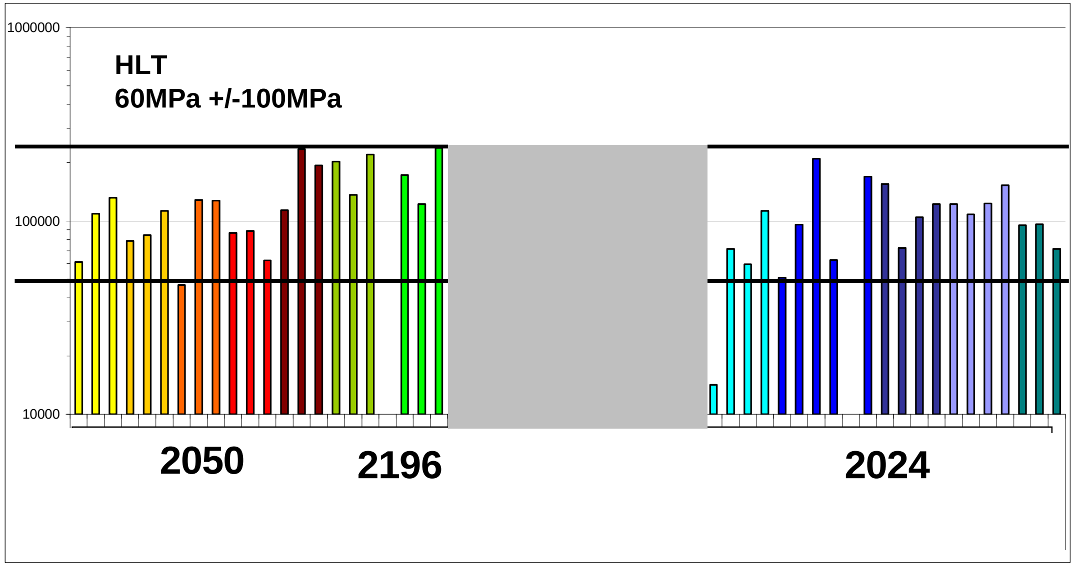


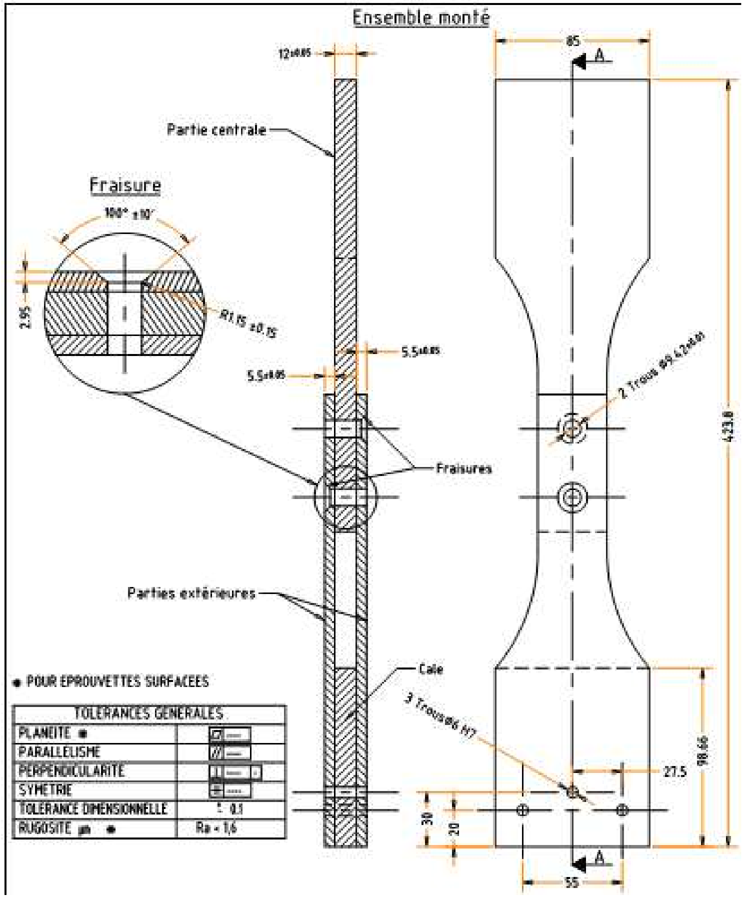


High Load Transfer fatigue testing
AIRWARE® 2050 has typical 2xxx alloys type behaviour

AIRWARE® 2050 has a high fatigue performance in an assembled test configuration including the full surface preparation process route.

- Specimens preparation:
  - Shot peening
  - Pickling + Chromic Acid Anodizing
  - Coating with primer
  - Titanium rivet



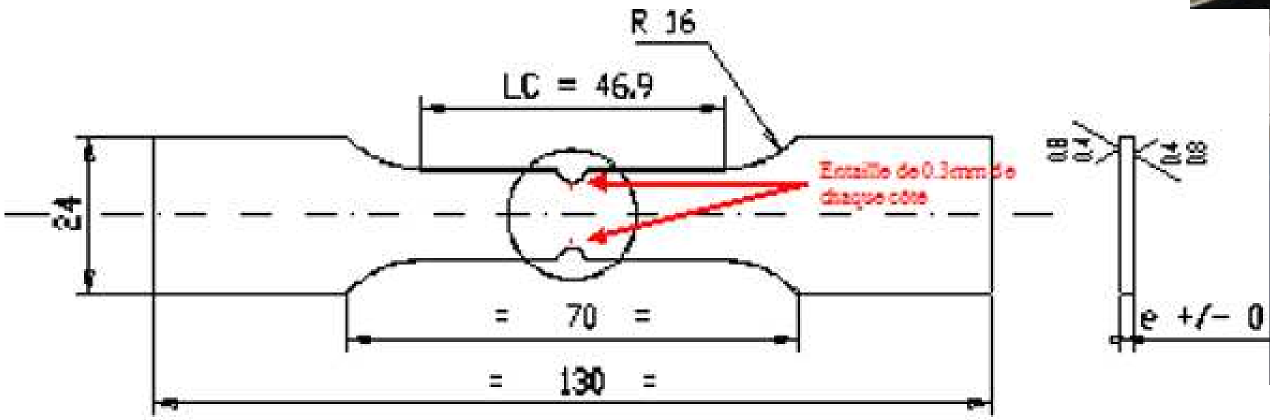


Contents

- General introduction on Al-Cu-Li alloys → AIRWARE®
- Fatigue crack growth rate of Al-Cu-Li alloys
  - Overall behaviour very attractive
  - Al-Cu-Li alloy fit in the framework of « Poitiers », J. Petit et al.
- Fatigue performance of Al-Cu-Li alloys
  - Conventional samples
  - Technological specimens
- Specific study: effect of environment on endurance fatigue With or without notch
  - Air or vacuum
- Conclusion

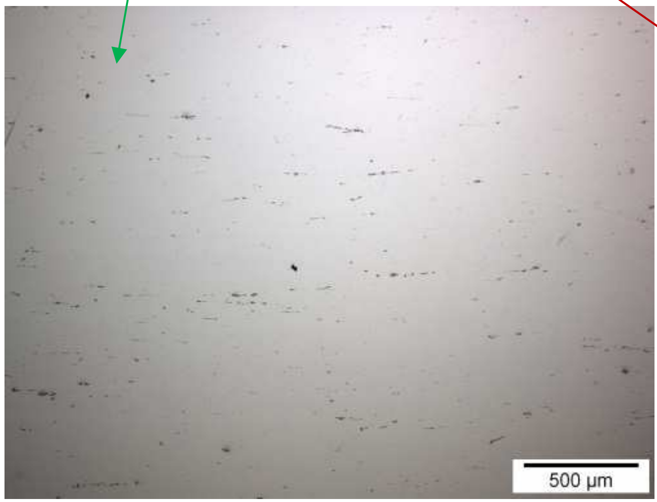
Tests selected to identify intrinsic behaviour

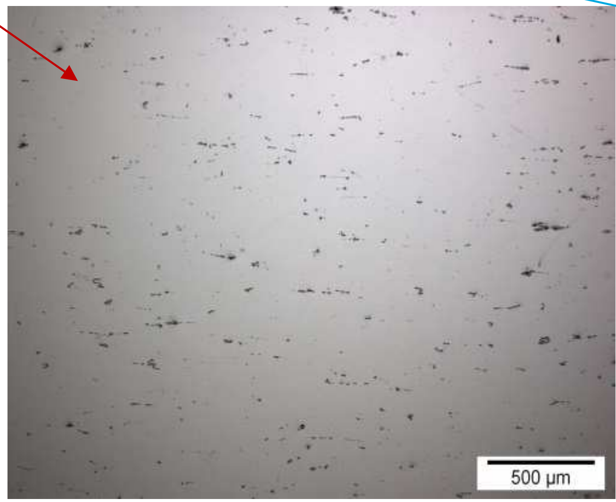
- Sample with and without a small slot at notch root
  - Kt=2.15
- R=0.5 → no closure
- Vacuum (<2.10^{-5} mBar), air at f= 0.3 Hz, 15 Hz and 50 Hz

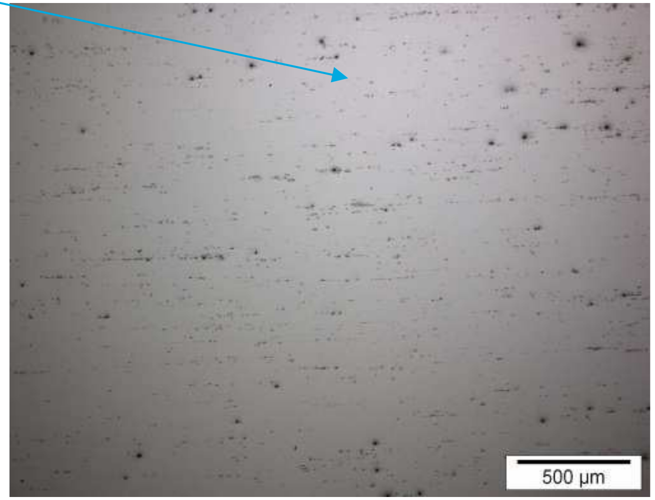


Materials investigated

	Si	Fe	Cu	Mn	Mg	Zn	Ti	Zr	Ag	Li
2050	*0.08 max*	*0.10 max*	*3.2-3.9*	*0.20-0.50*	*0.20-0.6*	-	*0.10 max*	*0.06-0.14*	*0.20-0.7*	*0.7-1.3*
7010	*0.12 max*	*0.15 max*	*1.5-2.0*	-	*2.1-2.6*	*5.6-6.7*	*0.06 max*	*0.10-0.16*	-	-
2024	*0.50 max*	*0.50 max*	*3.8-4.9*	*0.30-0.9*	*1.2-1.8*	-	*0.15 max*	-	-	-





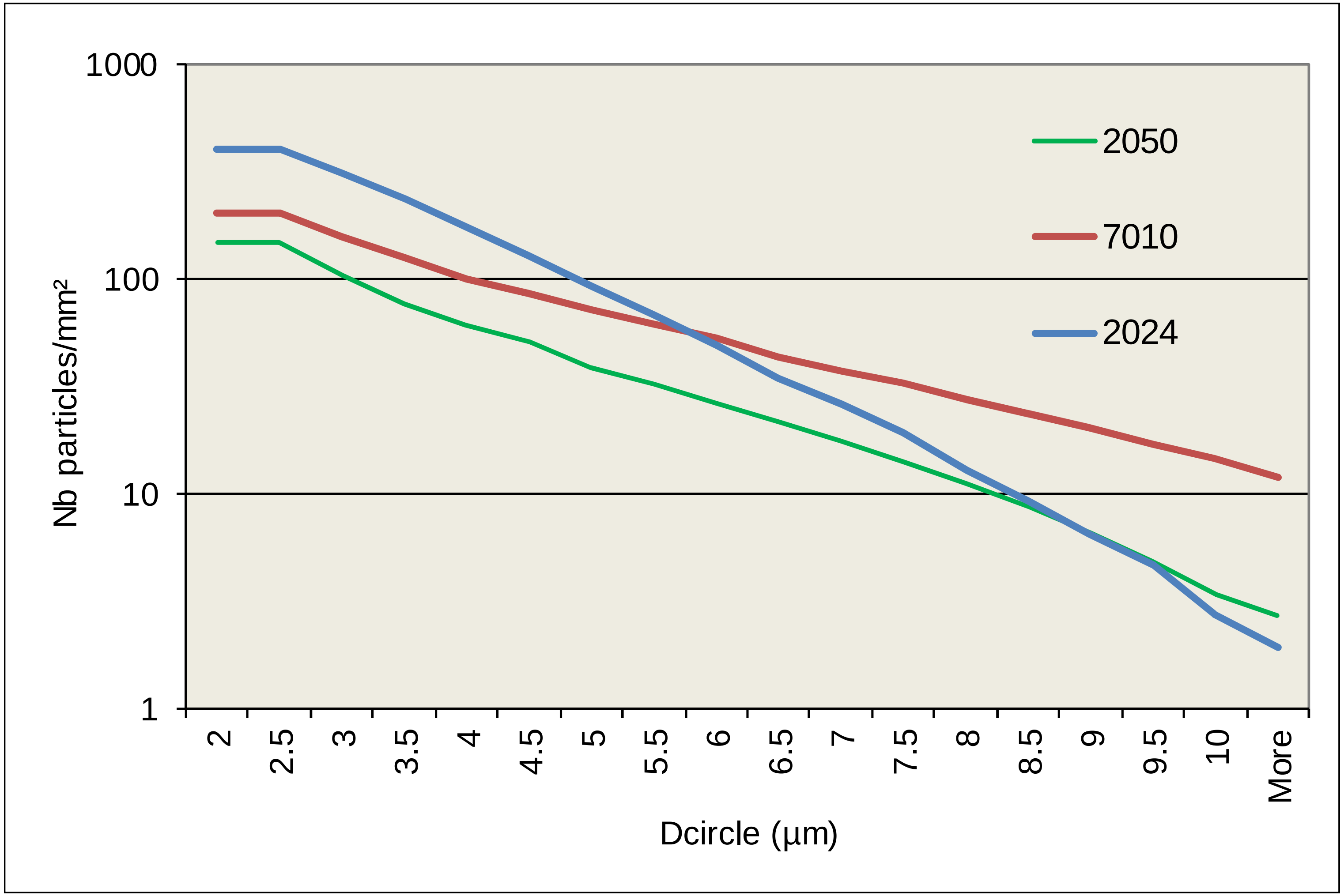


2050 T8 90 mm

7010 T74 110 mm

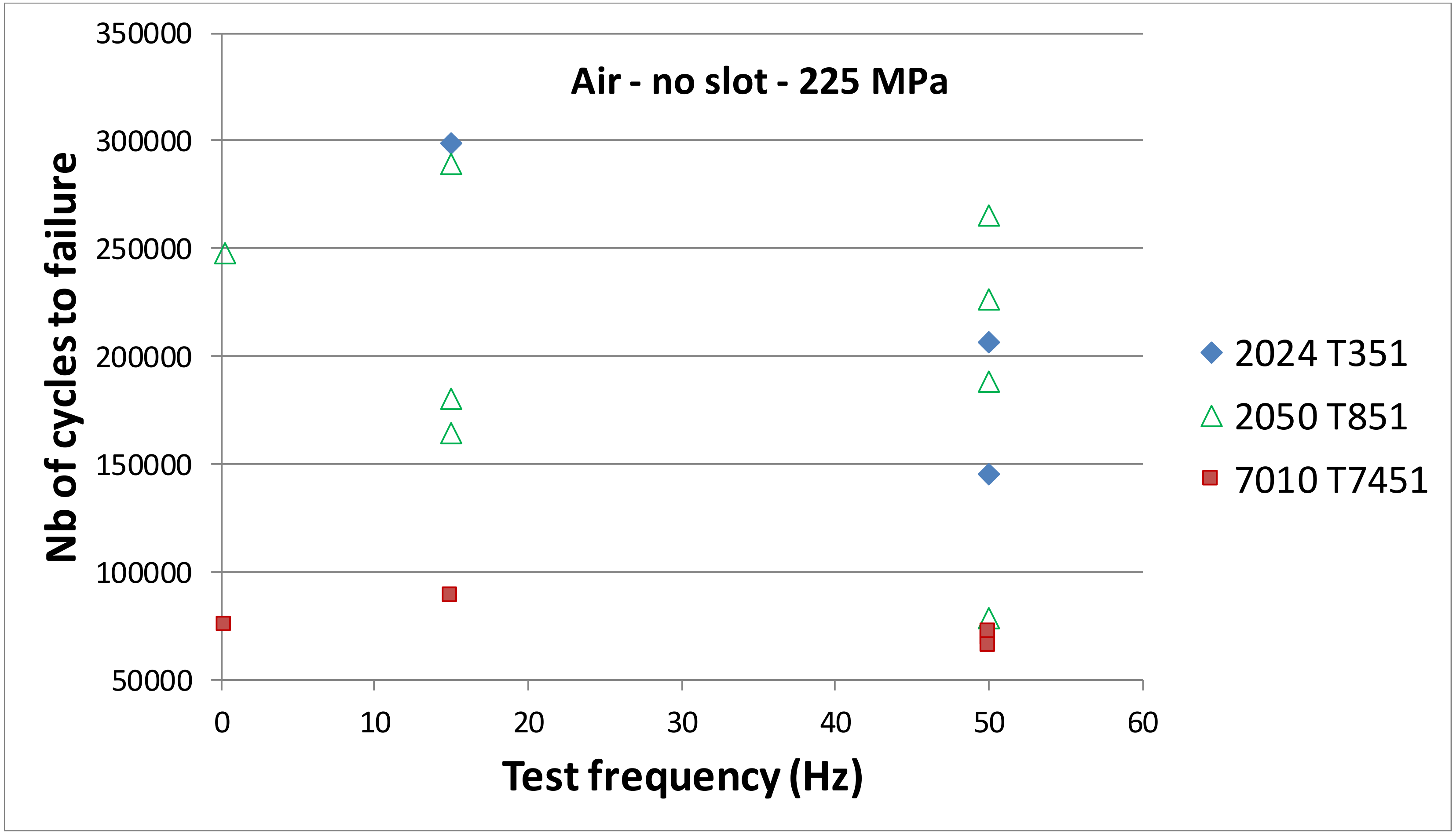
2024 T3 30 mm

2050: less constituents > 7 microns than 7010

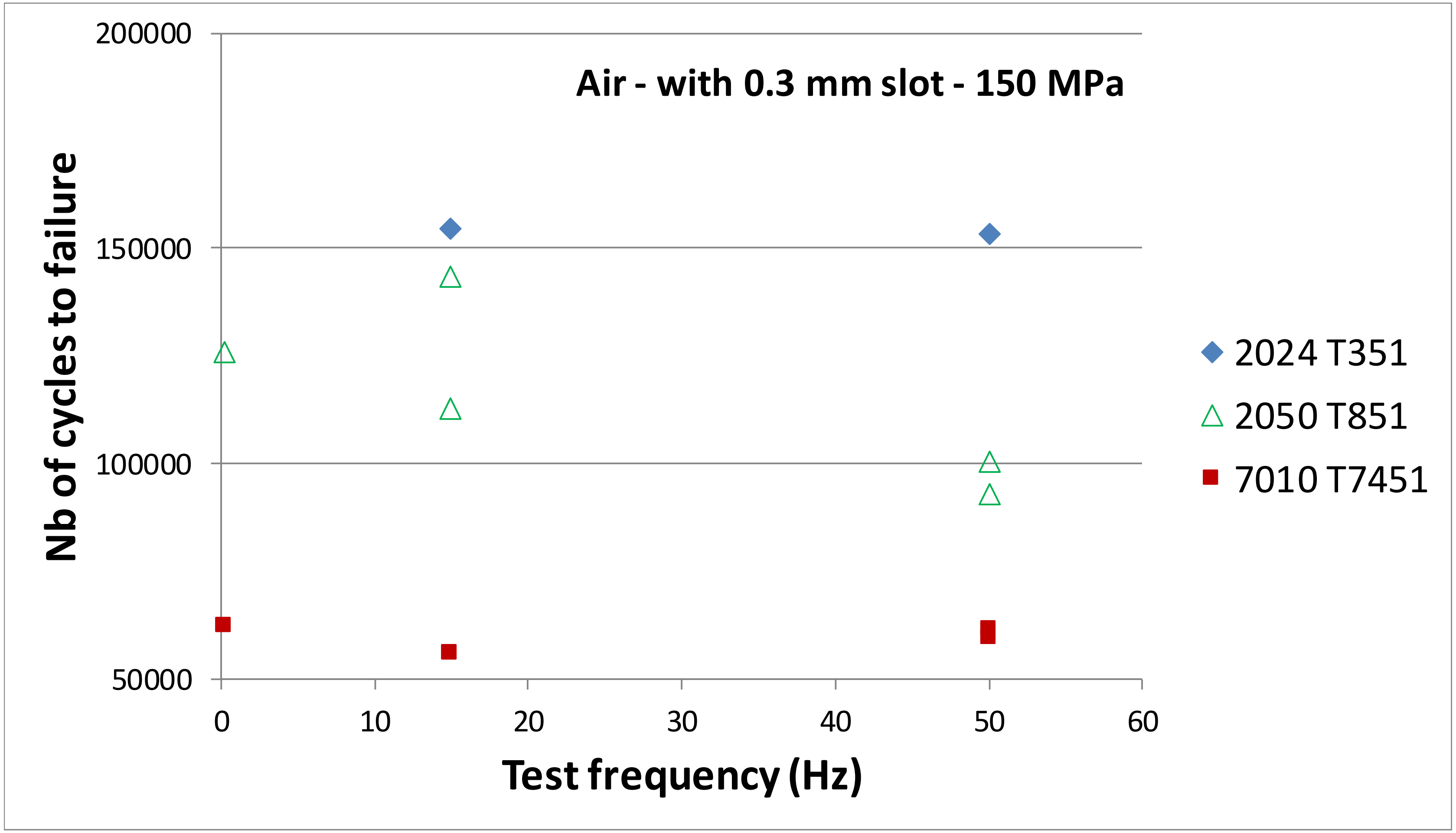


Air, no slot: 2050 ~ 2024 > 7010

- No frequency effect



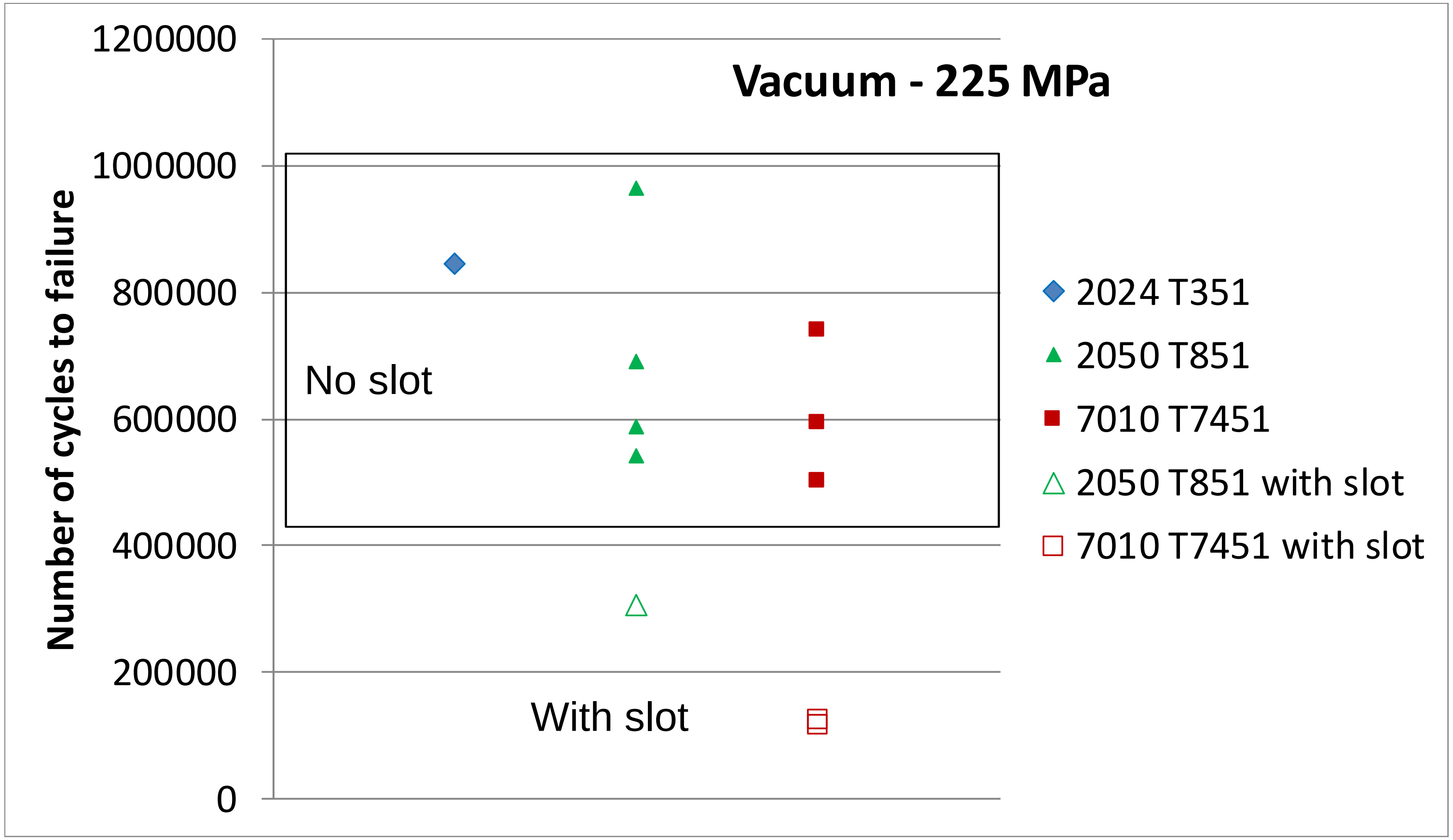
Air, with the slot: 2024 > 2050 > 7010



- No frequency effect

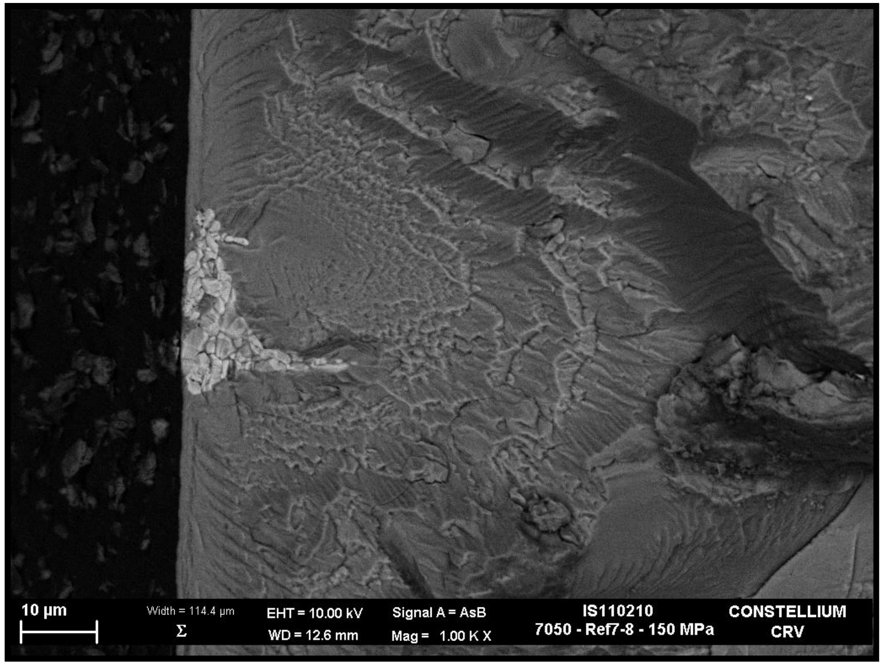
Vacuum, no slot: smaller difference between alloys

- No frequency effect

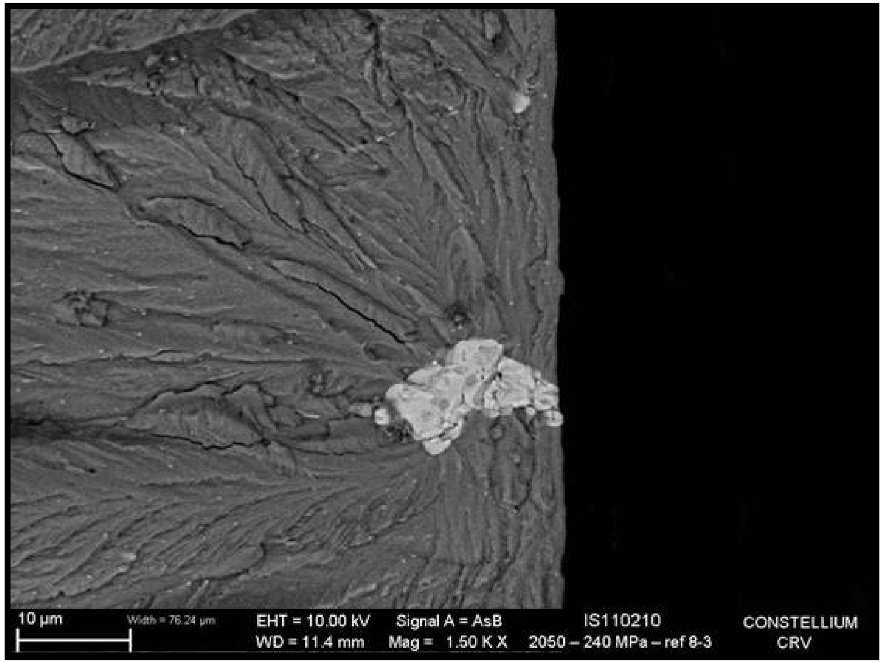


Most initiation occurs on constituent particles for 7050 (similar to 7010) and 2050

- Analysis of crack initiation by FEG-SEM (after failure)
- → Detection of the origin of fatigue failure
- → in most cases : presence of insoluble constituent particle



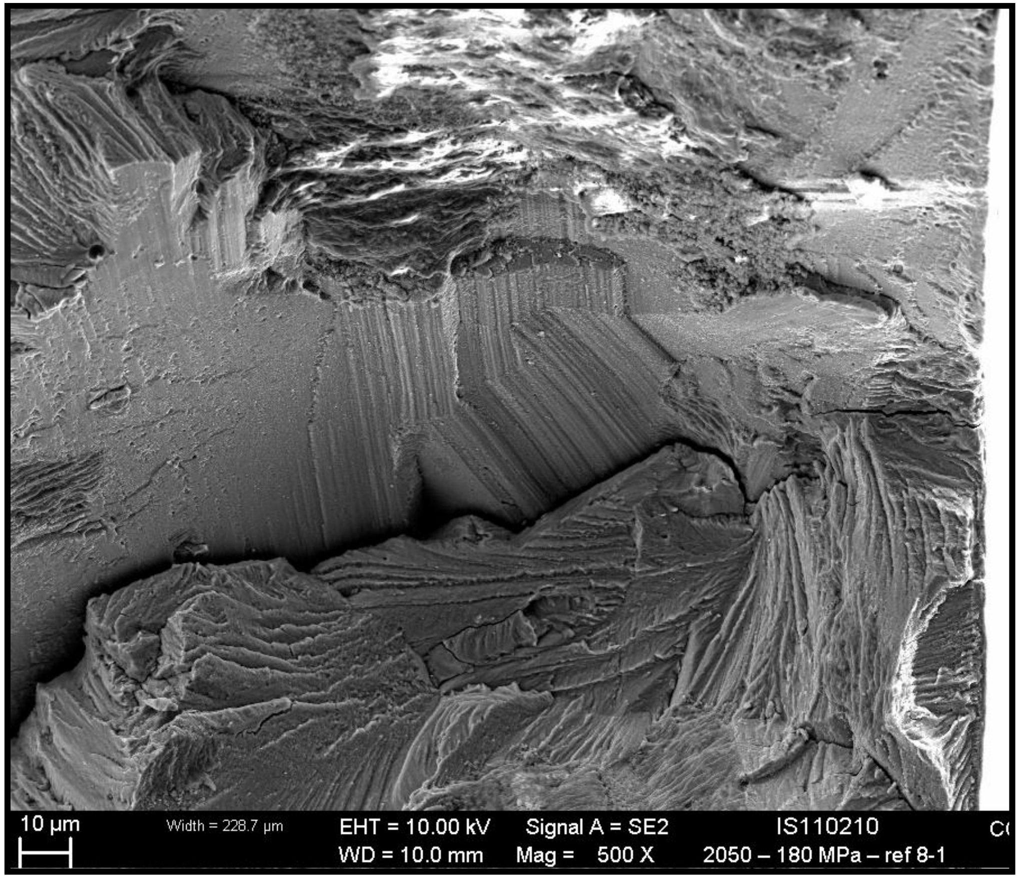
alloy 7050, 150MPa, 105986 cycles
Al_7Cu_2Fe



alloy 2050, 220MPa, 32000 cycles
(Al, Cu, Fe, Mn) particle

Some initiation occurs on slip bands, for 2050-T8 only

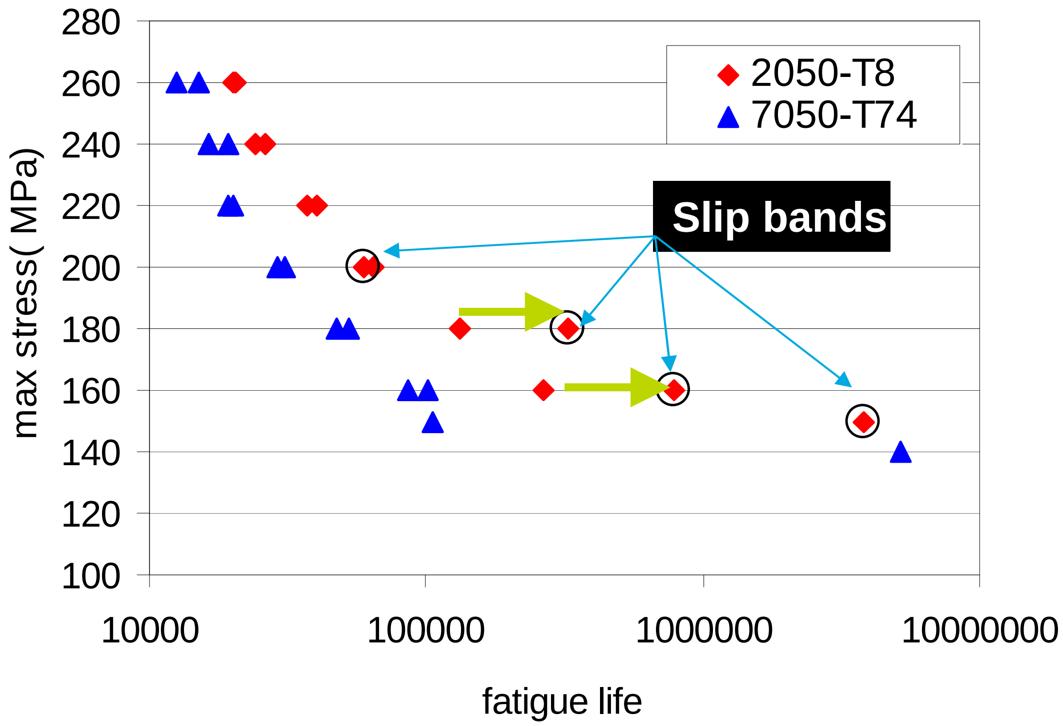
- Analysis of crack initiation by FEG-SEM (after failure)
  - At low stress level:
    - No constituent particle
    - Slip bands are present



Alloy 2050, 180MPa, 327960 cycles

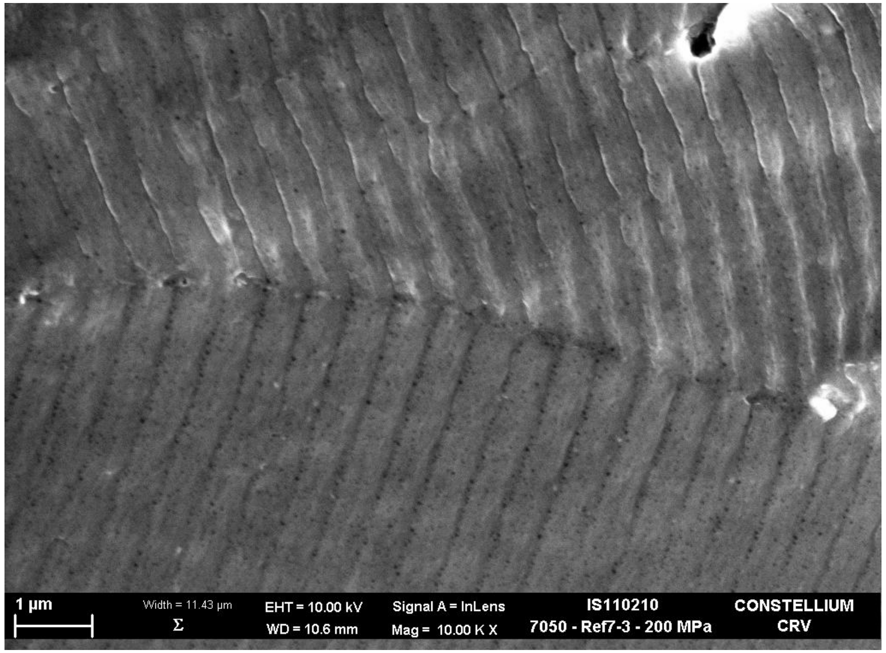
Initiation on slip bands corresponds to low stress level and high fatigue life

- FEG-SEM of fatigue initiation
  - Initiation on slip bands obtained only for 2050, for stress levels≤200MPa
  - The fatigue life is higher when initiation occurs on slip bands compared to initiation on constituent particles

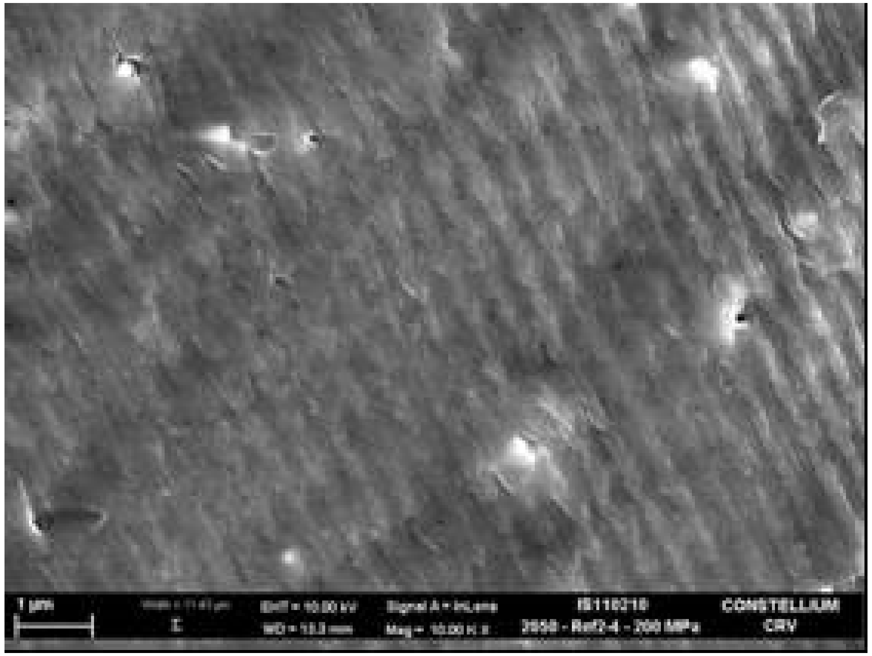


Inter-striation distance is higher for 7050 than for 2050

- Measure of inter-striation by FEG-SEM on failed samples at 1mm from the hole
- 1 striation = 1 cycle



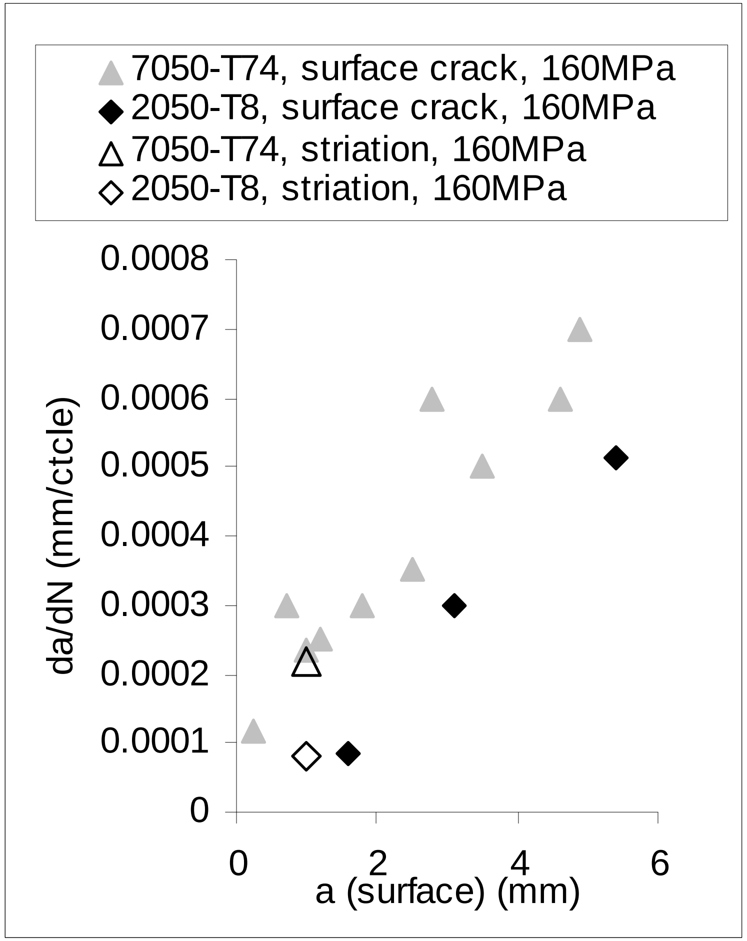
7050, 200MPa



2050, 200MPa

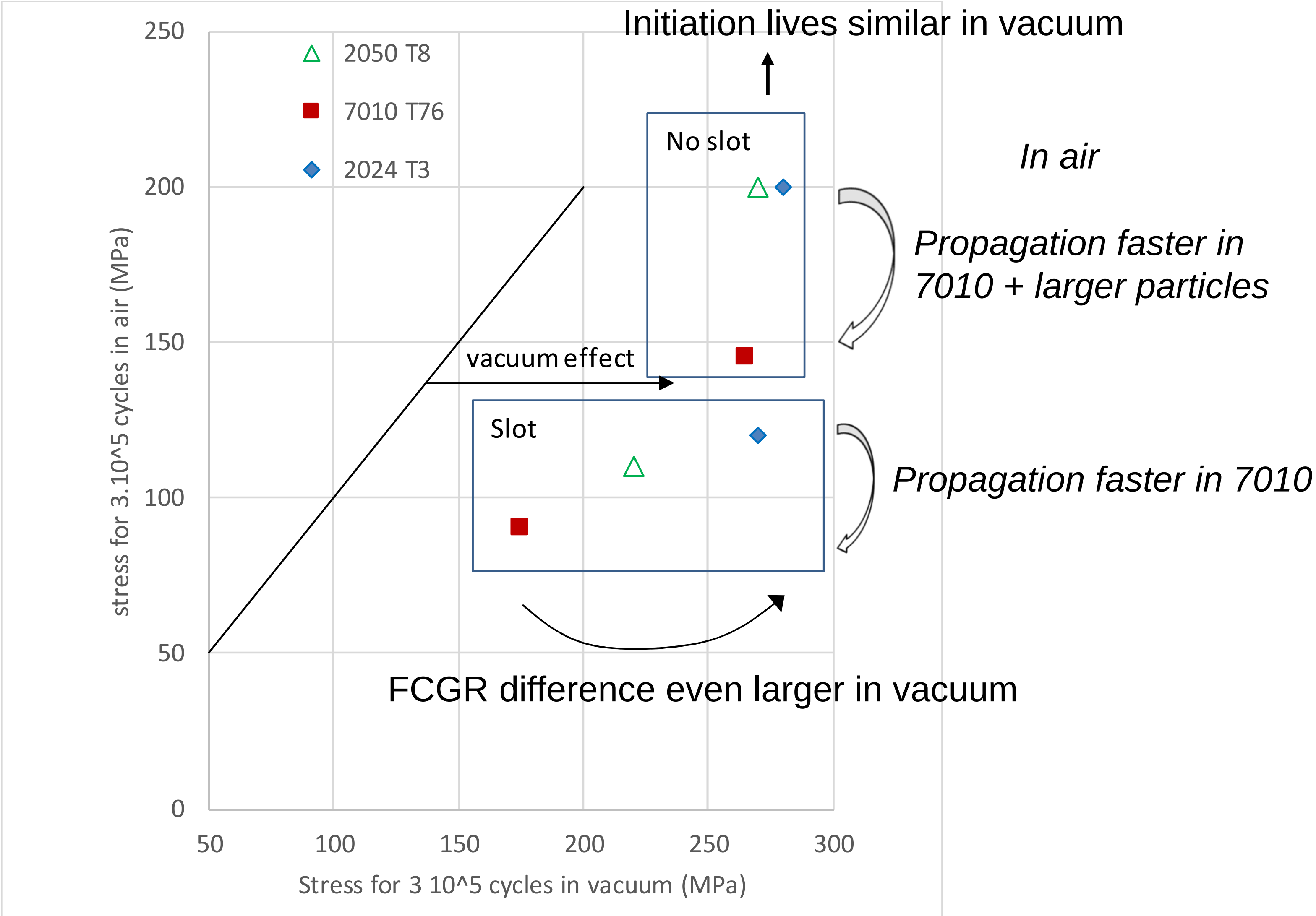
Striation distance is consistent with surface crack growth rate (→ slower rate for 2050)

- da/dN obtained by:
  - Measurement of small cracks by microscopy <u>on the surface</u>
  - Inter-striation distance on fractographs <u>in the bulk</u>
- For both methods:
  - da/dN (2050)<da/dN (7050)



Note: presentation as a function of <u>a</u> rather than ΔK avoids theoretical issues with K definition of small cracks in open hole specimens

2050 performance: slower FCGR, (smaller constituents)



Conclusion

- Al-Cu-Li alloys offer can fulfill the requirements on the whole aircraft
- Very high strength, higher than 7000 can be combined with 2000 type fatigue and damage tolerance properties
- Some very high damage tolerance versions show better DT than best conventional
- The effect of environment is significant and needed to understand the propagation behaviour
- Better fatigue properties than 7000 are mainly due to FCG improvement