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Accelerated evaluation of the susceptibility of aluminium alloys to corrosion fatigue in de-icers using varying load waveforms

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Background and Aim of the Investigations

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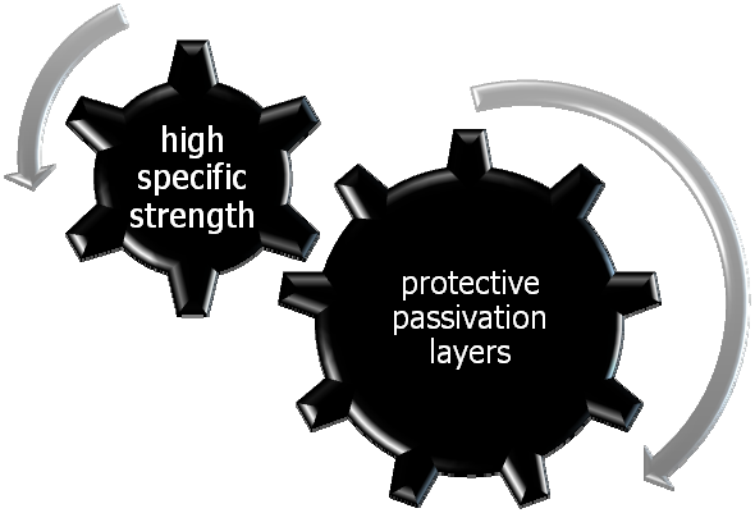
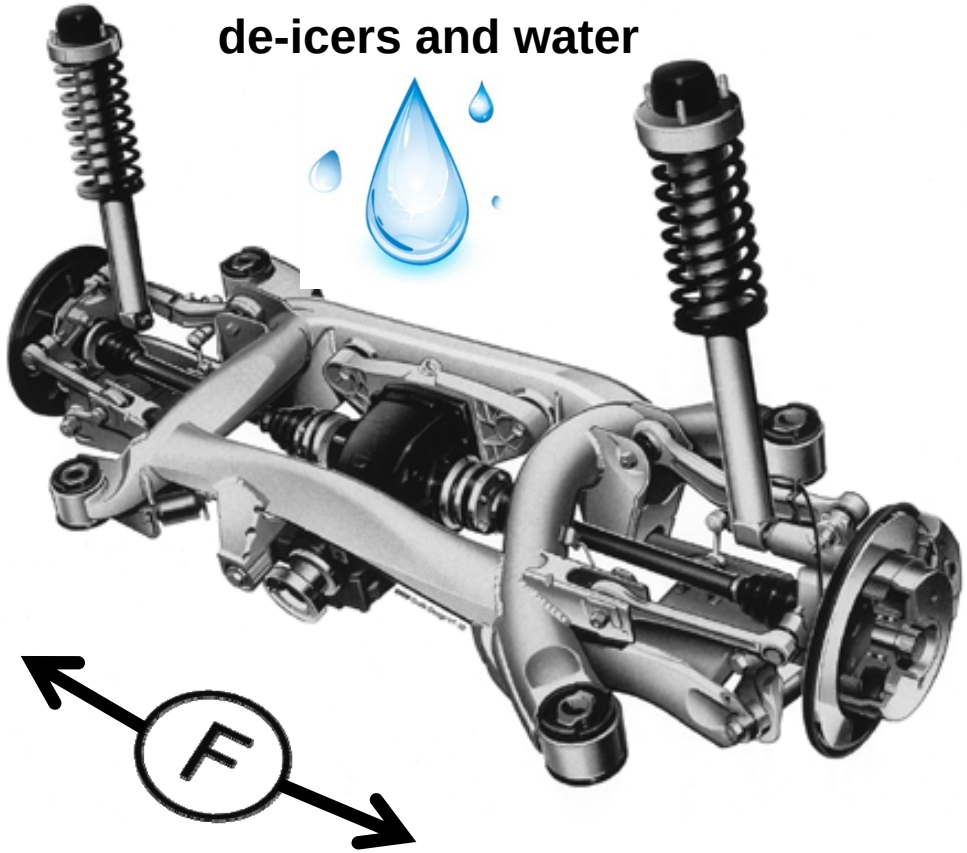




Quelle: BMW

Interaction of corrosive and mechanical loads during material qualification?

Material and Specimens

alloy: EN AW-5018 (AlMg3,5Mn) used for rear axle carriers

sensitization level of susceptibility to intergranular corrosion (IC):

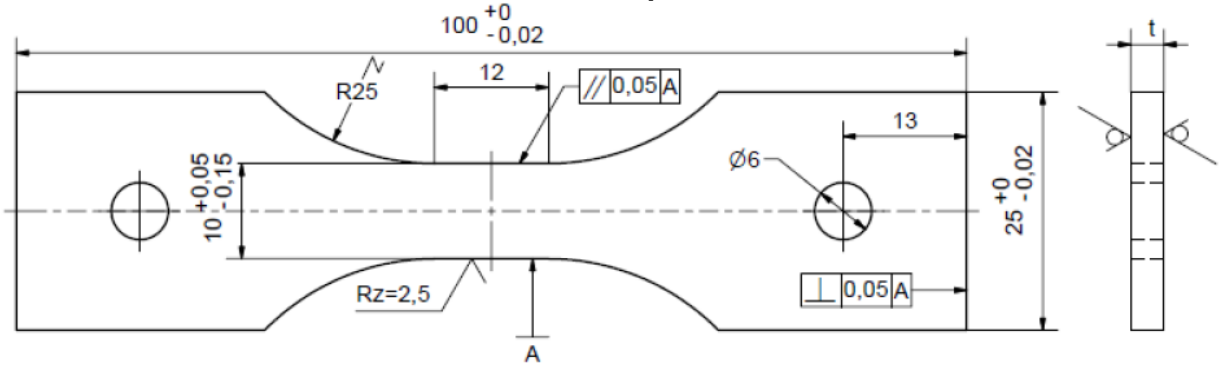
- ➢achieved by a defined heat treatment at 130 °C
- ➢accelerated precipitation of the ignoble Al_5Mg_8 along the grain boundaries
- ➢susceptibility to IC

•Temper O: Material condition according to component state: Rolled and soft annealed

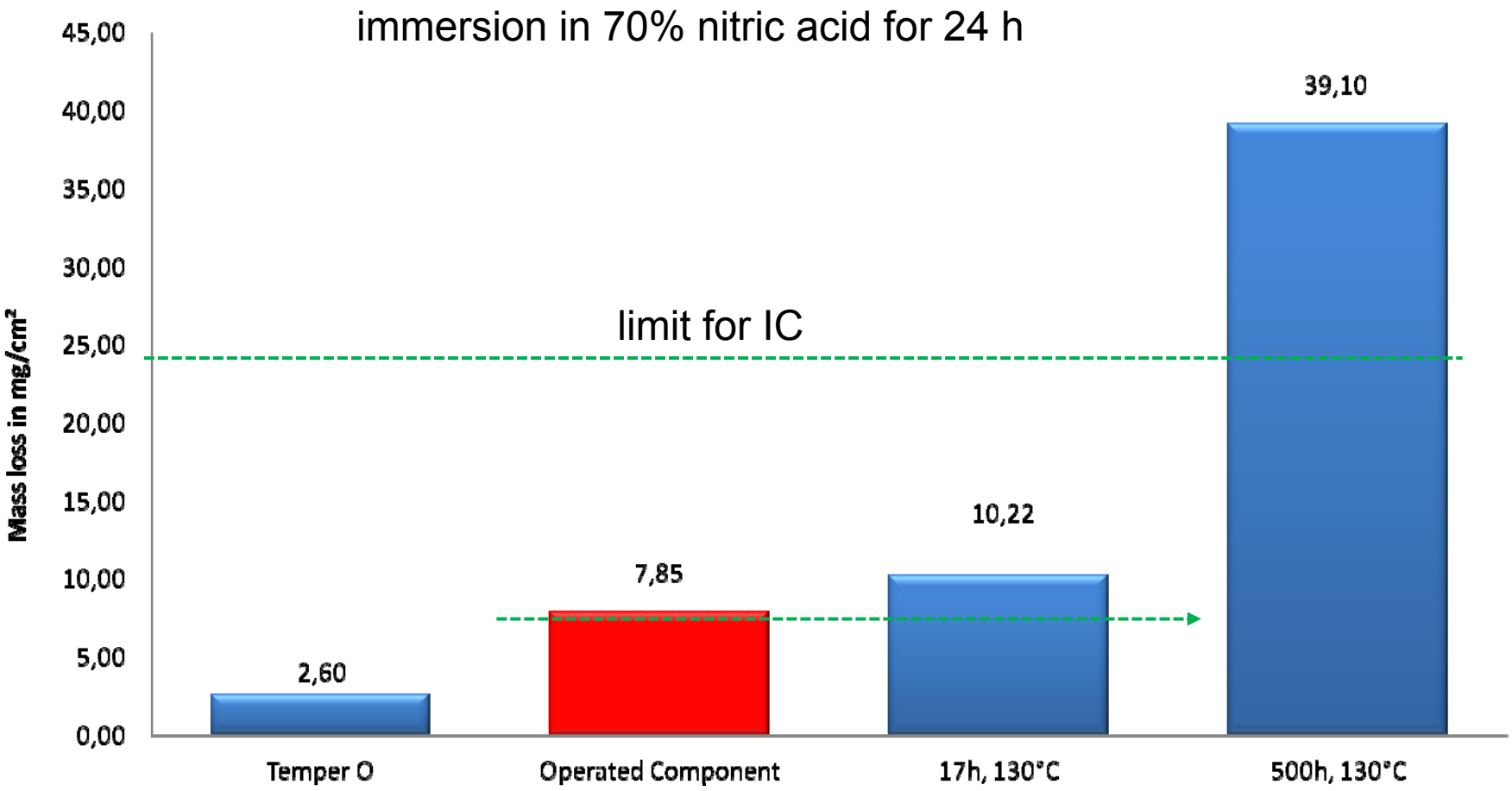
•Sensitised (17 h/130 °C): Corresponding to material state after planned operating time

•Sensitised (500 h/130 °C): Critical condition, should not be used

specimen: surface condition similar to component



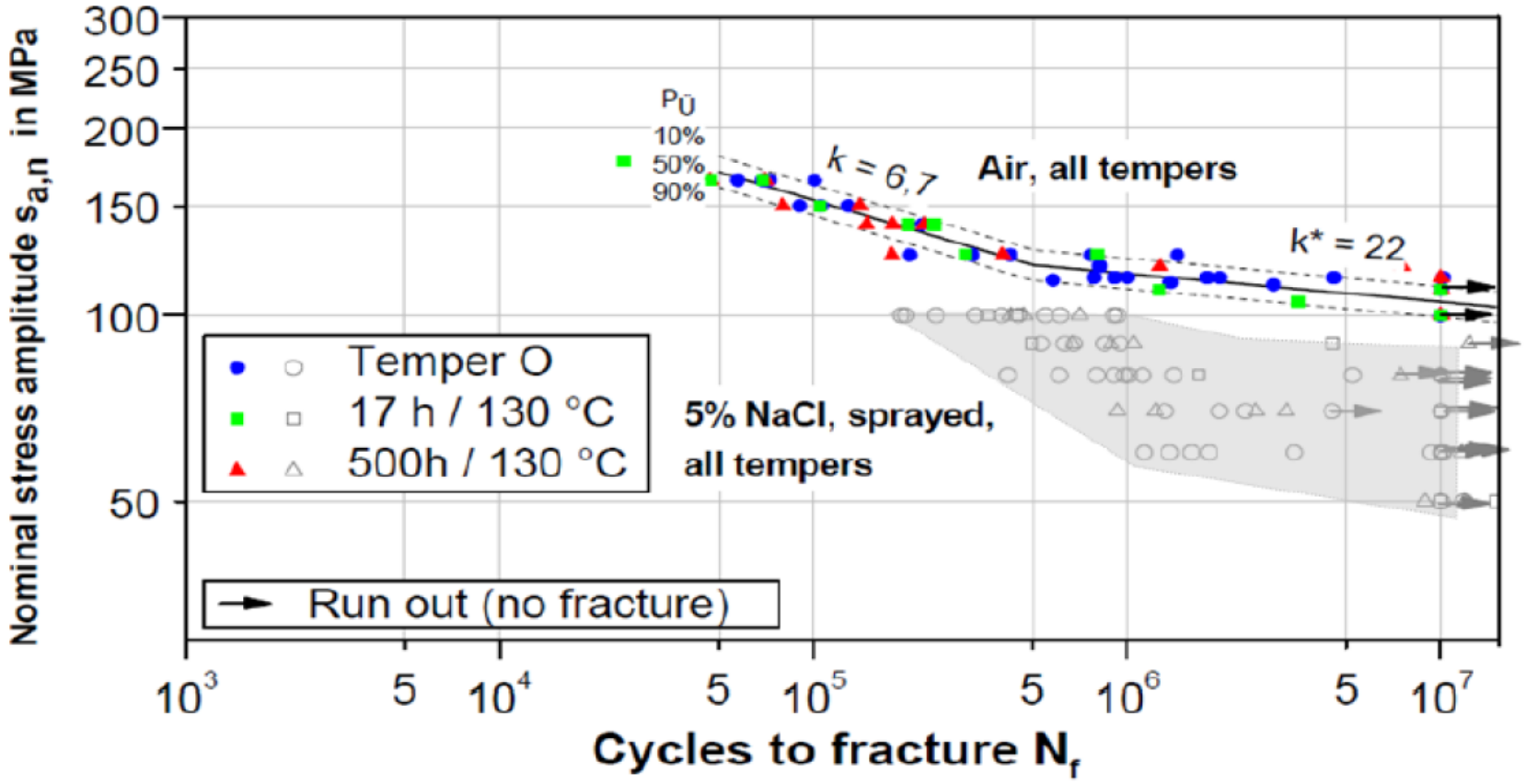
Standard Corrosion Testing ASTM G67
evaluation of the corrosion behavior



an increased tendency to IC with longer heat treatment exposure times

Standard Corrosion Fatigue Testing

Intermittent spraying (5% NaCl - 5min, 20min)



The three distinct different sensitization states show no clear influence on corrosion fatigue properties due to the enveloping large scatter band.

Influences on Corrosion Fatigue Behaviour

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Corrosion fatigue experiments are also used for material selection, however, the conventional test approach (5% NaCl, 5min/20min) does not reveal any influence of different sensitization levels for corrosion.

Coincidence, scatter, errors in test setup?

➔Analysis of specific mechanical load parameters on corrosion fatigue behavior

- ➔ frequency
- ➔ stress ratio
- ➔ load level
- ➔ environment
- ➔ …
- ➔ **load waveform**

Interaction between passivition state and crack propagation rate

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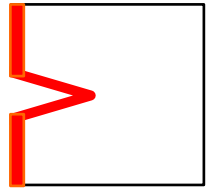
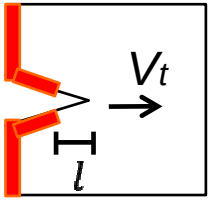
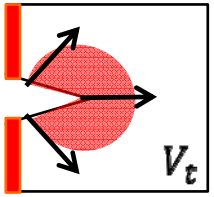
	• strain rate $\dot{\epsilon} < V_{repass}$ • limited corrosion damage
	• strain rate $\dot{\epsilon} > V_{Repass}$ • partly passiviating conditions • crack propagation rate partially controlled by strain rate at the crack tip $\frac{dl}{dt} = V_t = \frac{M \cdot Q_f}{z \cdot \rho \cdot F \cdot t}$ $t = \frac{\epsilon_f}{\dot{\epsilon}}$ → [illegible]
	• intensified dissolution • e.g. aggressive solution , limited resistance, strain rate>> V_{Repass} • active surface, no repassivation during crack opening • maximum volume dissolved • crack propagation rate controlled by the duration of crack opening $\frac{dl}{dt} = V_t = \frac{M \cdot Q_f}{z \cdot \rho \cdot F \cdot t}$ $i_{max} = \frac{Q_f}{t}$ → [illegible]

V_t : crack propagation rate

ϵ_f: fracture strain of the passivized layer

l: length of the crack

$\dot{\epsilon}$: strain rate at the crack tip

Comparison of Corrosion Fatigue Test Conditions

Sinusoidal and Rectangular Waveforms

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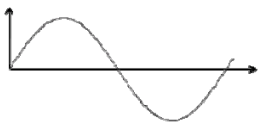
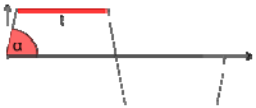
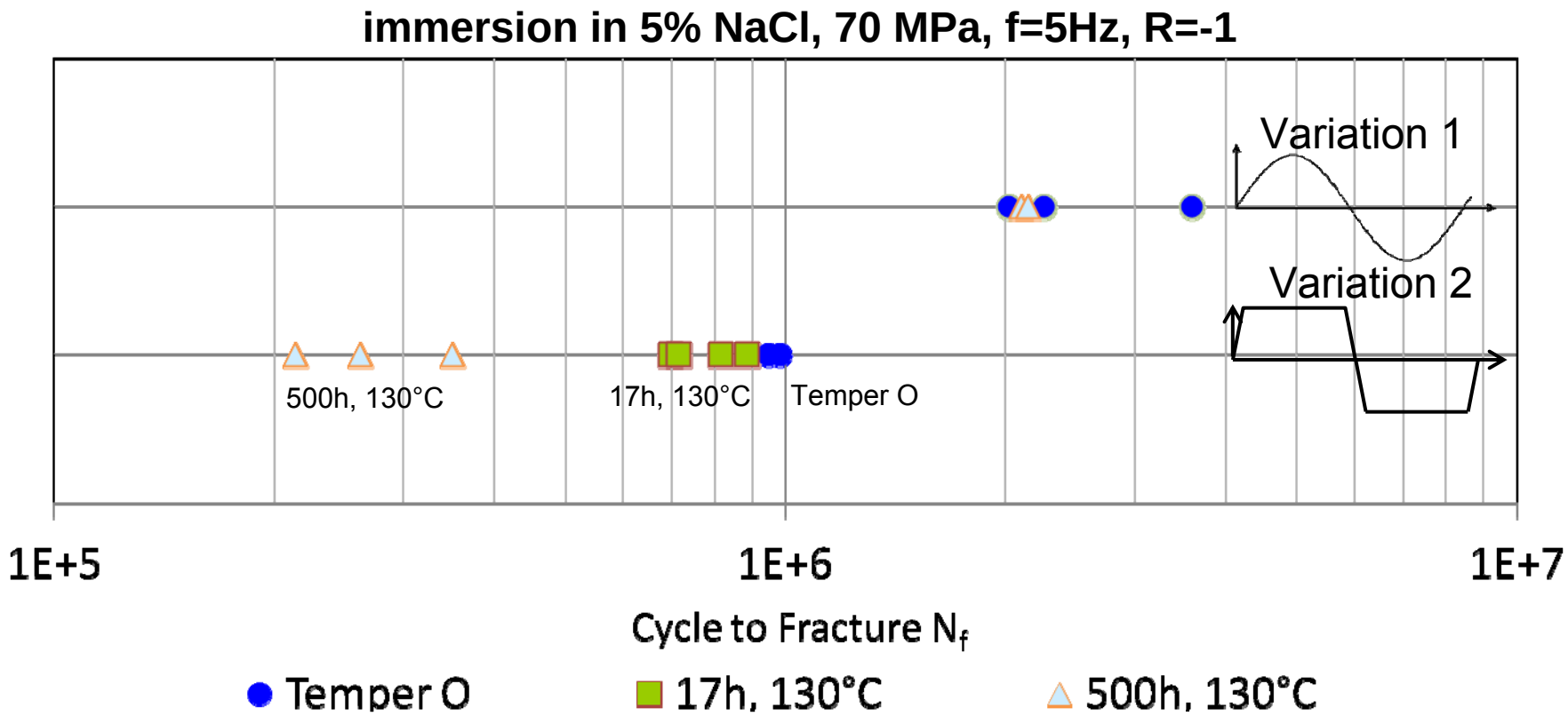
waveform	load [Mpa]	frequency f [1/s]	strain rate [1/s]	dwell period t [s]	corrosive load
	70	5	$\dot{\epsilon} = 0{,}002 \cdot \pi \cdot f \cdot \cos(t\pi f)$ $\dot{\epsilon} = 0\text{-}0{,}031$	t = 0	immersion in 5% NaCl
	70	5	$\dot{\epsilon} = \dot{F}/2415$ $\dot{F}$=1000 kN/s $\dot{\epsilon} = 0{,}41$	t = 0,0952 t = 47% period T	immersion in 5% NaCl

- In order to develop a differentiating evaluation method for the qualification of aluminum alloys in case of constant amplitude loading as well as to determine the impact of the waveform a rectangular waveform was used to magnify the impact of strain rate.
- Both the strain rate ˙ and the dwell period of the maximum load in the tension phase within one cycle of the rectangular waveform are greater than during the sinusoidal waveform. Both can be changed.

CF Tests with Different Load Waveforms

Sinusoidal and Rectangular Waveforms



- According to the three levels of IC sensitization an impact of the waveform on corrosion fatigue life can be illustrated for the rectangular waveform.
- With respect to the practicability of a differentiating test, the test procedure is accelerated compared to a corrosion fatigue test with sinusoidal waveform.

Variation of the Waveforms

Modification of the Strain Rate for the Rectangular Waveform

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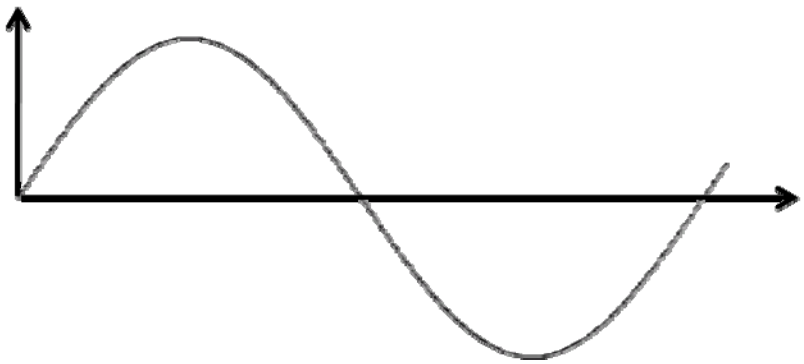
variation 1

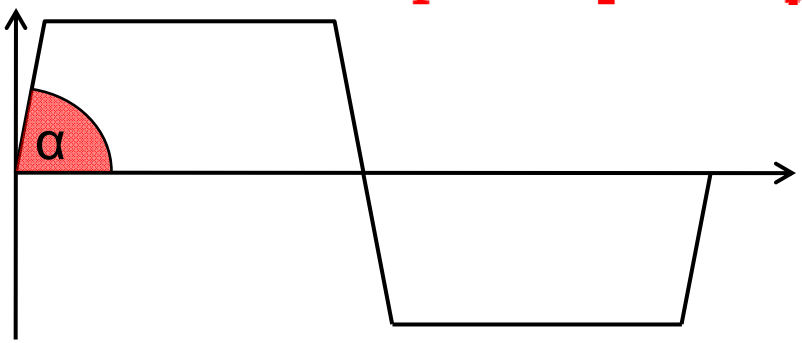
- f=5 Hz
- t = 0
- $\dot{\varepsilon}$ = 0-0,031 1/s



variation 2

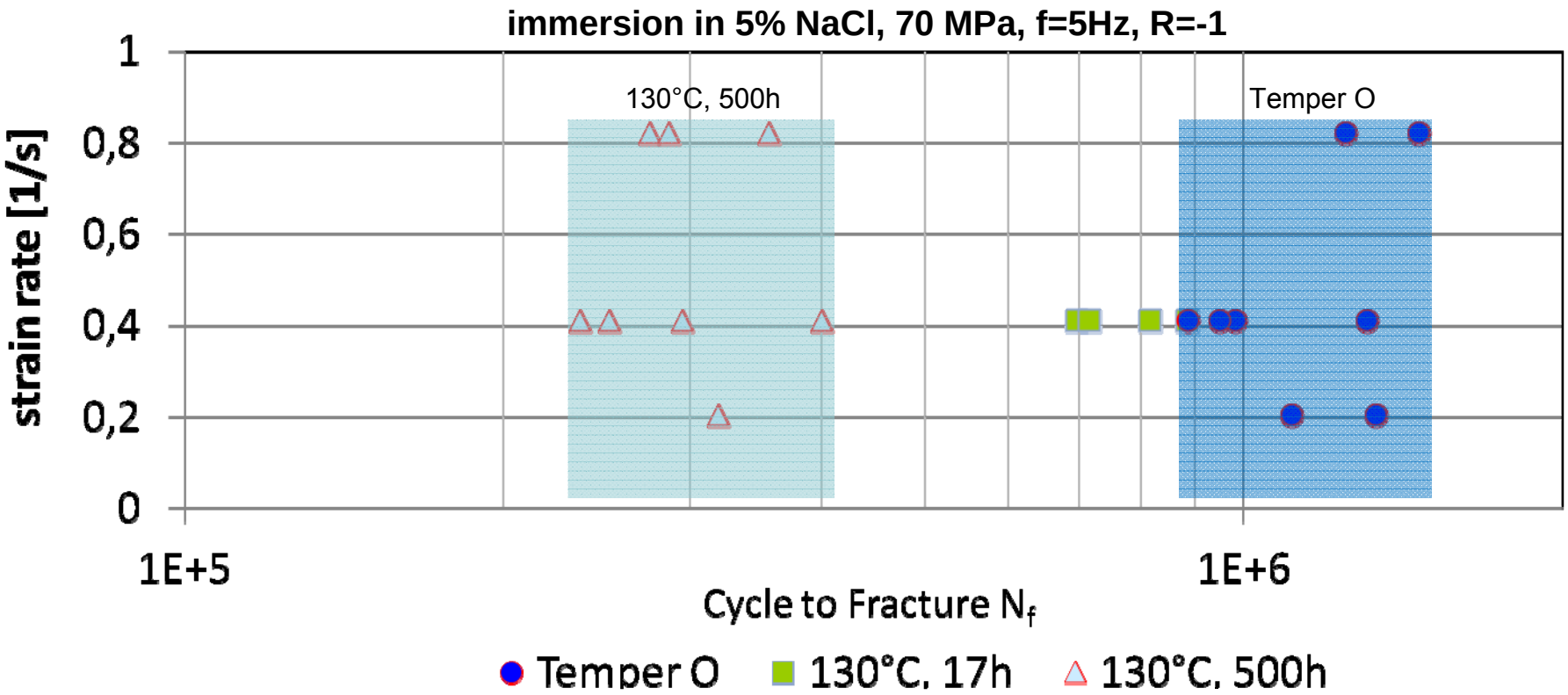
- f=5 Hz
- t≈0,1 s
- $\dot{\varepsilon}_1$ = 0,205 1/s
- $\dot{\varepsilon}_2$ = 0,41 1/s
- $\dot{\varepsilon}_3$ = 0,82 1/s

$\dot{\varepsilon}_1 = 1/2\ \dot{\varepsilon}_2 = 1/4\ \dot{\varepsilon}_3$



CF Tests with Different Load Waveforms

Variation of the Strain Rate



- This result indicates, that the corrosion fatigue damage under the rectangular load waveform of alloy AlMg3,5Mn is apparently not dominated by the strain rate for the conventional test solution (5% NaCl). The damage behavior at the crack tip is controlled by the bare, active condition.
- The dwell period of the maximum load in the tension phase controls the impact on corrosion fatigue behavior.

CF Tests with Different Load Waveforms

Variation of the Dwell Period at S_{max}

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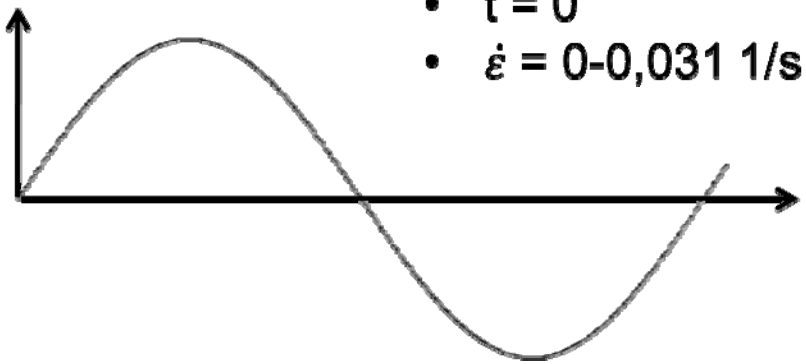
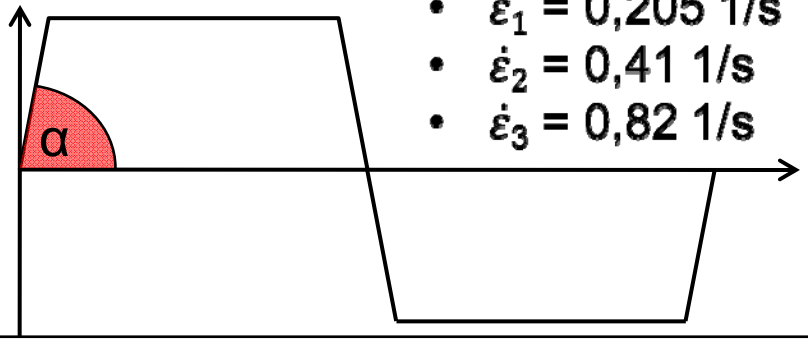
variation 1

- f=5 Hz
- t = 0
- $\dot{\varepsilon}$ = 0-0,031 1/s



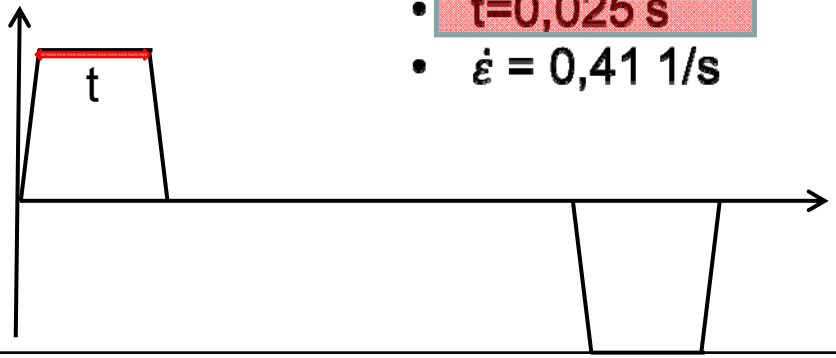
variation 2

- f=5 Hz
- t≈0,1 s
- $\dot{\varepsilon}_1$ = 0,205 1/s
- $\dot{\varepsilon}_2$ = 0,41 1/s
- $\dot{\varepsilon}_3$ = 0,82 1/s



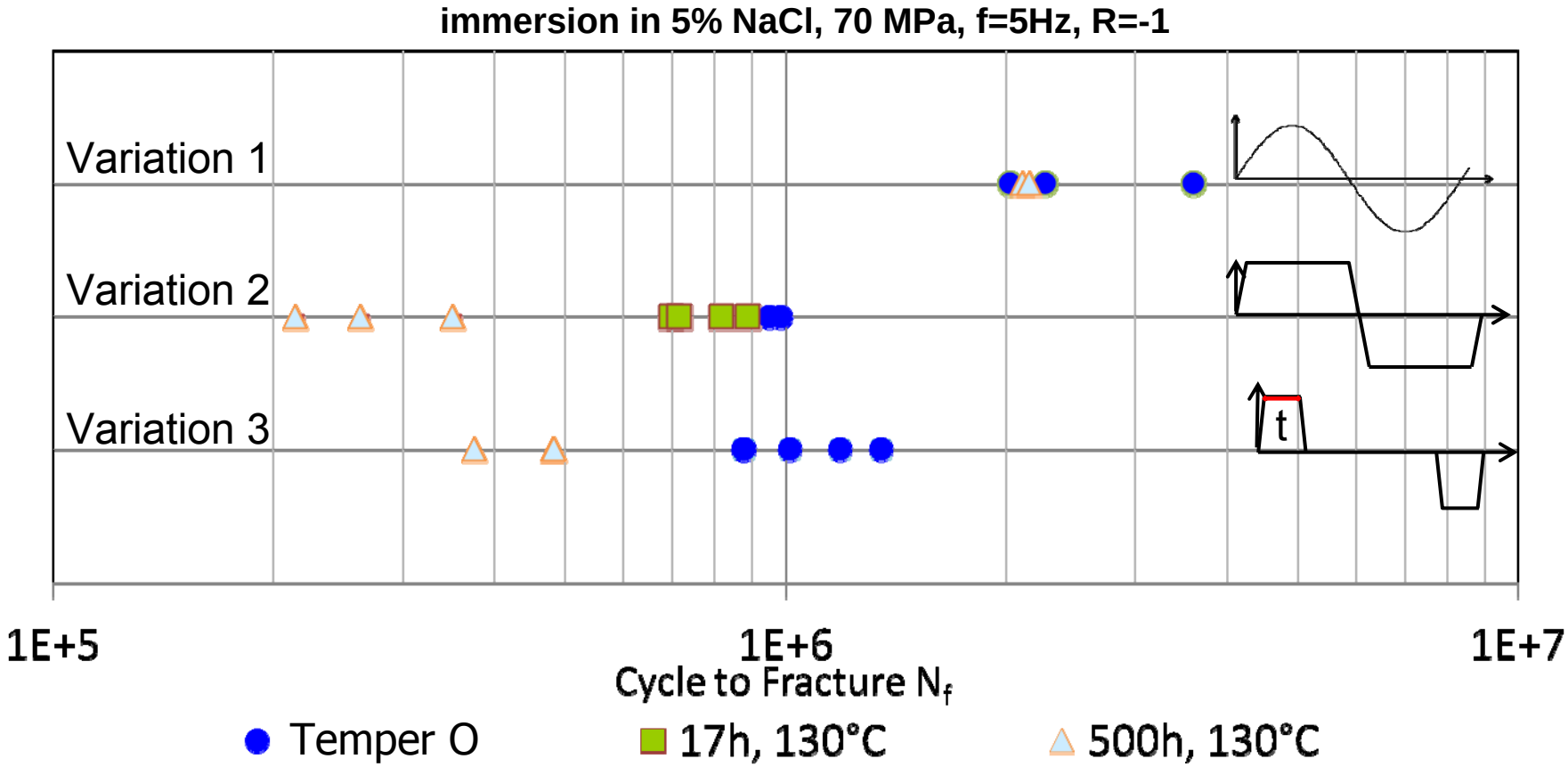
variation 3

- f=5 Hz
- t=0,025 s
- $\dot{\varepsilon}$ = 0,41 1/s



CF Tests with Different Load Waveforms

Variation of the Dwell Period at S_{max}



- The reduction of the dwell period increases corrosion fatigue life significantly.

CF Tests with Different Load Waveforms

Variation of Strain Rate <u>and</u> Dwell Period at S_{max}

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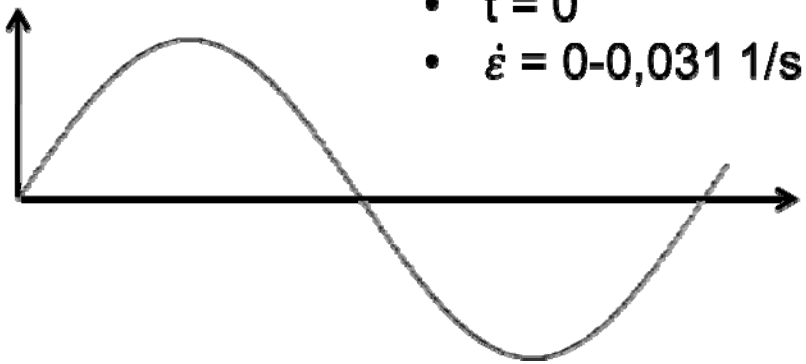
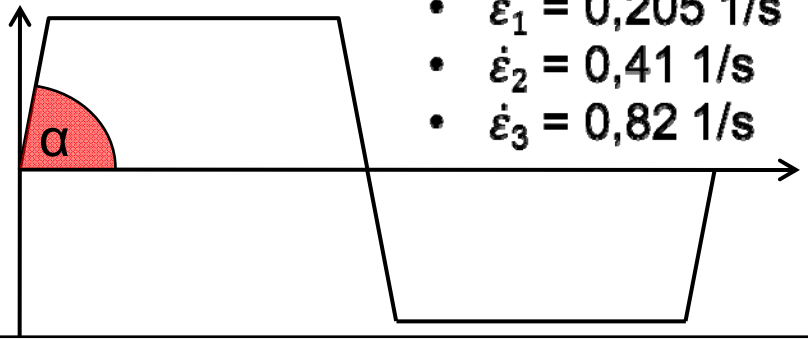
variation 1

- f=5 Hz
- t = 0
- $\dot{\varepsilon}$ = 0-0,031 1/s



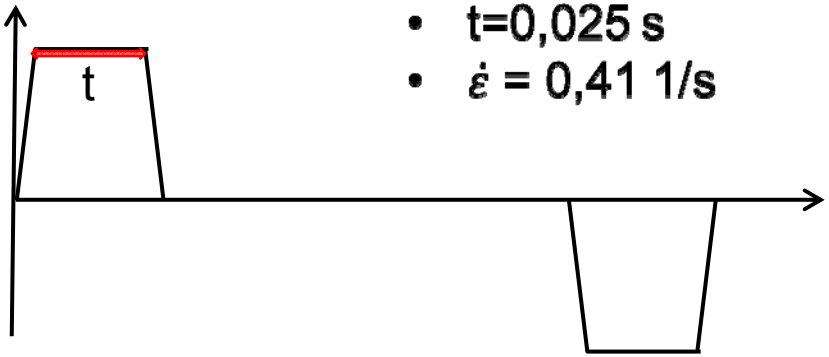
variation 2

- f=5 Hz
- t≈0,1 s
- $\dot{\varepsilon}_1$ = 0,205 1/s
- $\dot{\varepsilon}_2$ = 0,41 1/s
- $\dot{\varepsilon}_3$ = 0,82 1/s



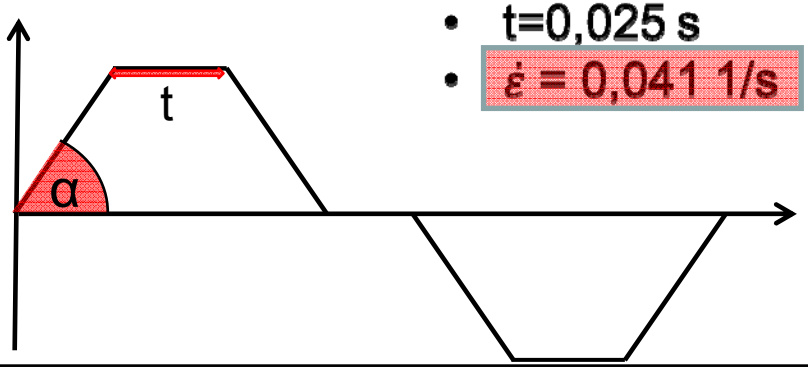
variation 3

- f=5 Hz
- t=0,025 s
- $\dot{\varepsilon}$ = 0,41 1/s



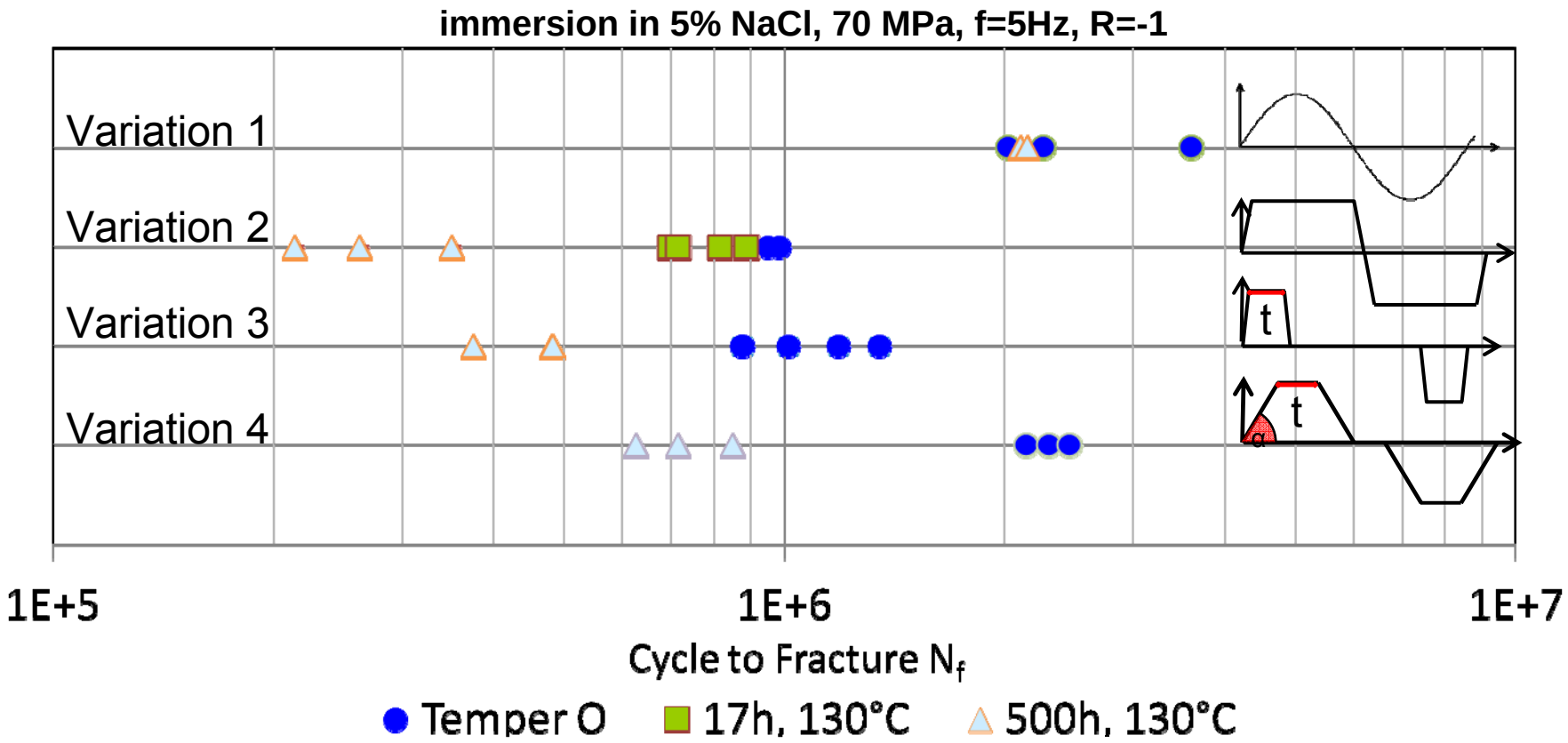
variation 4

- f=5 Hz
- t=0,025 s
- $\dot{\varepsilon}$ = 0,041 1/s



CF Tests with Different Load Waveforms

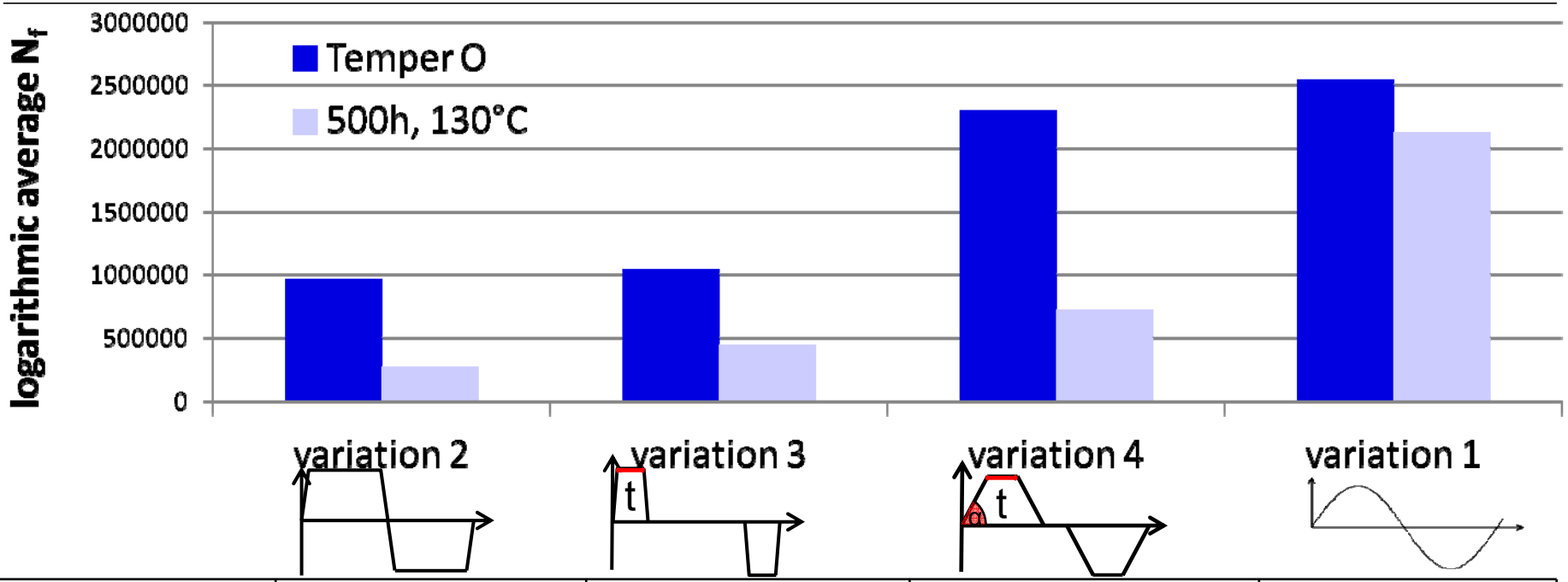
Variation of Strain Rate and Dwell Period at S_{max}



- reduced corrosion fatigue life for the increased strain rate

Summary of the Results

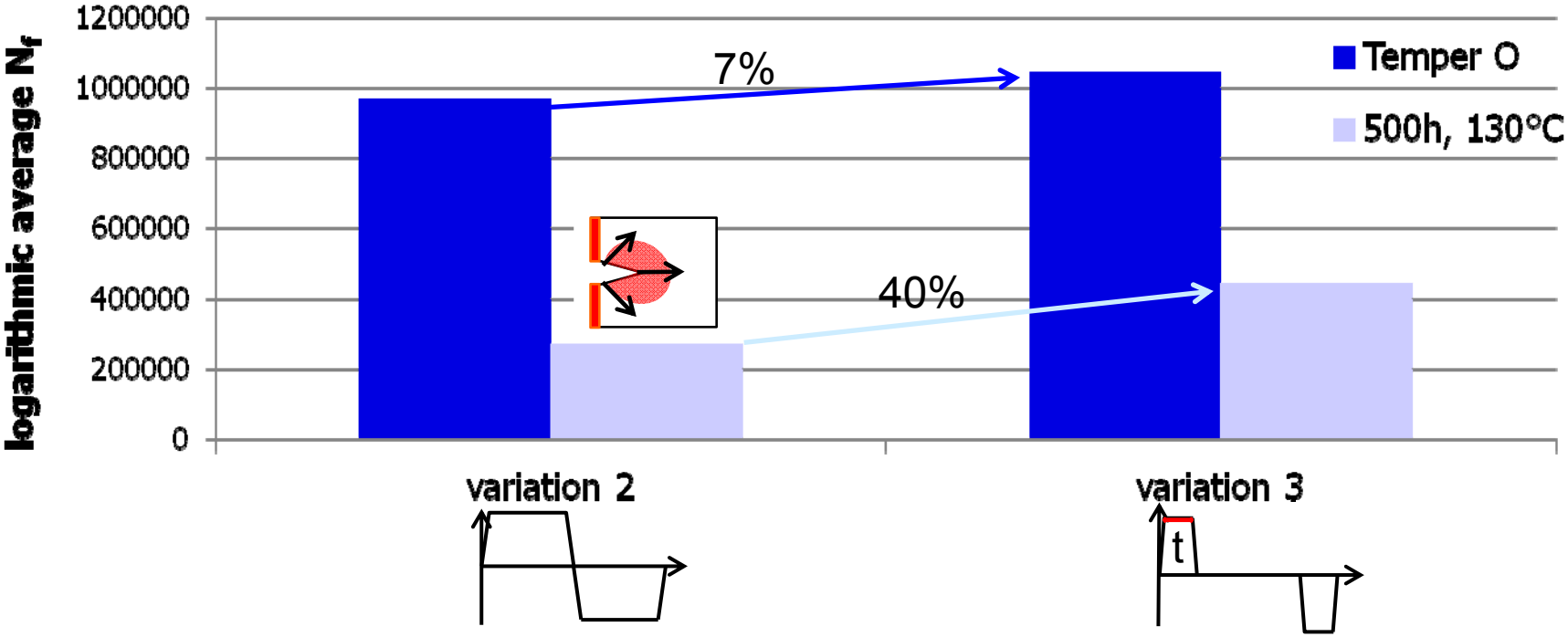
Influence of the Variation of Load Waveforms



strain rate [1/s]	0,205/ 0,41/ 0,82	0,41	0,041	0-0,031
dwell period [s]	ca. 0,1	0,025	0,025	0

In direction the smaller strain rate and shorter dwell period lead to longer fatigue life.

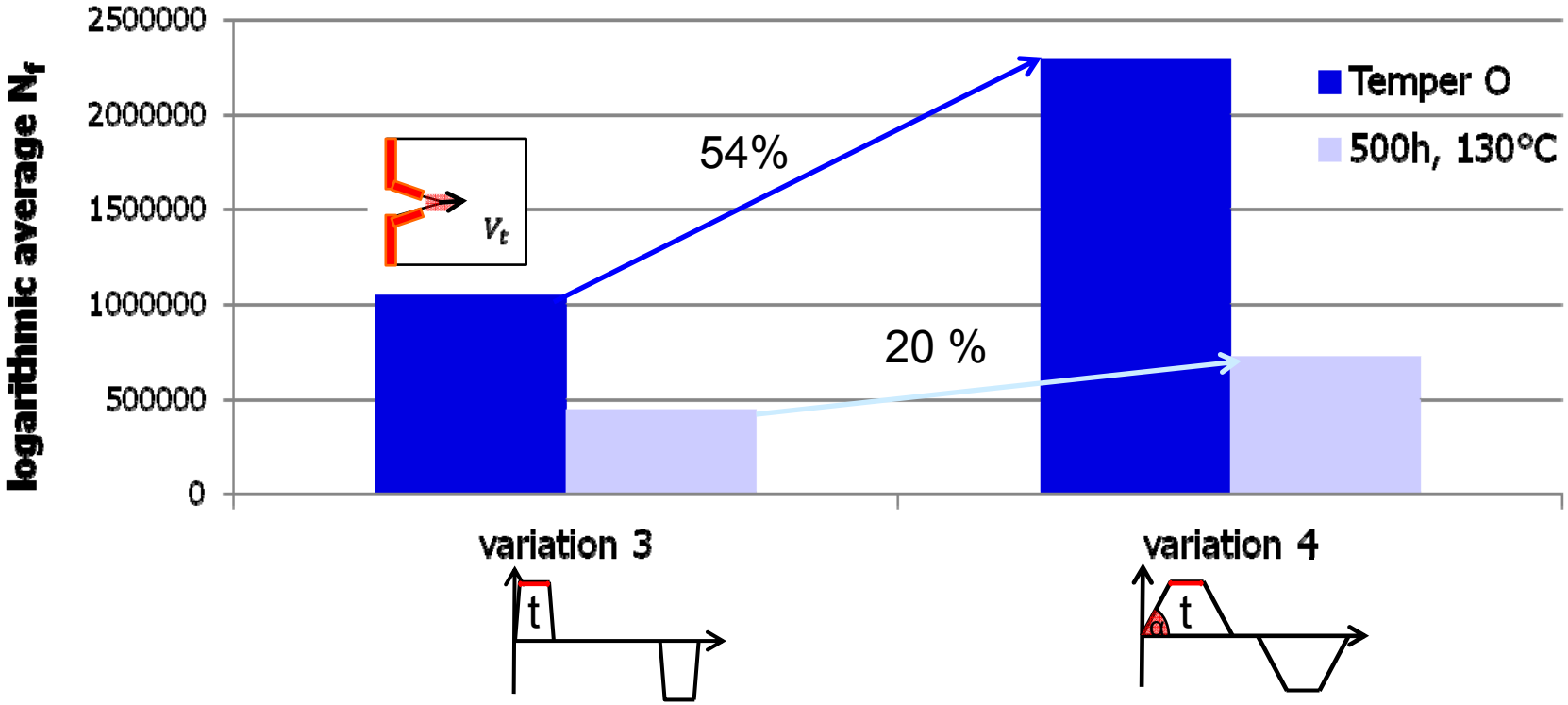
Summary of the Results
Influence of the Variation of Load Waveforms



strain rate [1/s]	0,41	0,41
dwell period [s]	ca. 0,1	0,025

- The influence of reduction of the dwell period on the highest sensitization level of 500h/130°C is more significant than on temper O (not sensitized).
- larger influence of the dwell period due to high sensitized condition

Summary of the Results
Influence of the Variation of Load Waveforms



strain rate [1/s]	0,41	0,041
dwell period [s]	0,025	0,025

- The influence of the strain rate is getting more pronounced for less corrosion sensitized material condition (temper O) in the test solution
- larger influence of strain rate due to better repassivation behavior

Influences of Strain Rate with Respect to repassivation behavior

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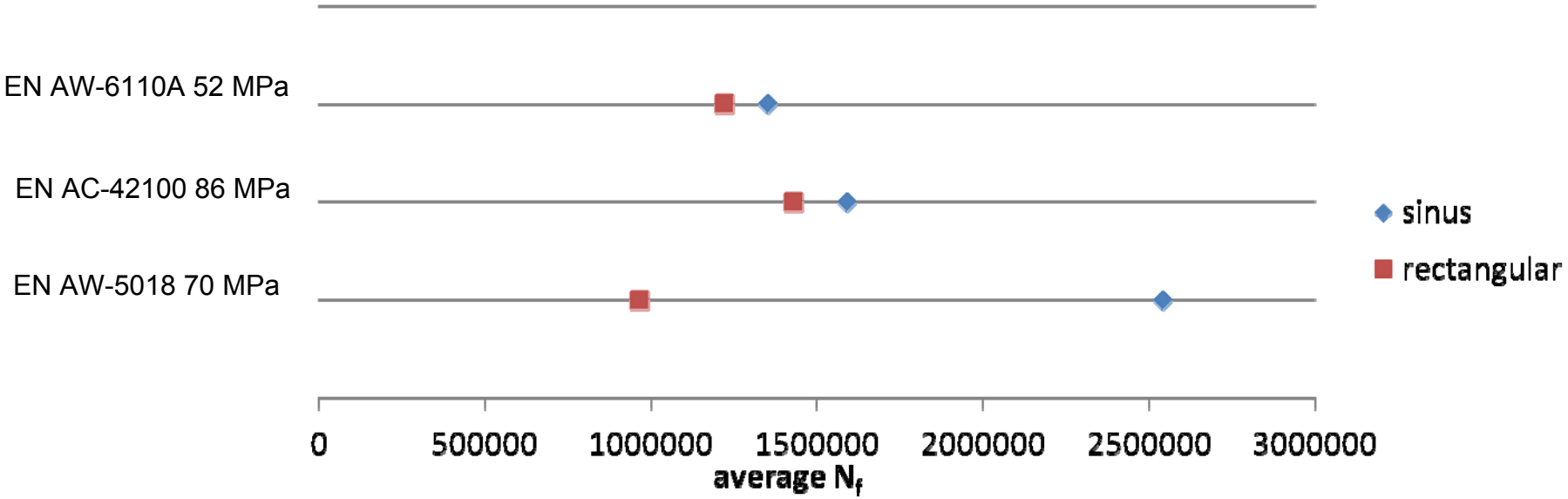
- According to the results of CF testing based on the alloy EN AW-5018 under the defined variations the influence of the waveform with respect to strain rate und dwell period can be clearly shown. In direction the smaller strain rate and shorter dwell period lead to longer fatigue life.

larger influence of strain rate due to better repassivation behavior?
larger influence of the dwell period due to high corrosive sensitized condition?

➔ CF Tests on aluminium alloys with evidently more corrosively sensitized material states under the sinus and rectangular load waveforms were also carried out.
- EN AW-6110A
- EN AC-42100

Comparison

Influence of Load Waveform on CF of Different Aluminium Alloys



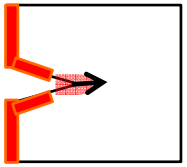
- The Influence of the waveforms, which was already improved on the base of the alloy EN AW-5018, can not be clearly shown on EN AW-6110A and EN AC-42100.
- Because of the lower ability of repassivition of EN AW-6110A and EN AC-42100 the rupture of the passivation layer cannot be rebuilt. The bare condition dominates the crack propagation. Influence of the strain rate will decrease.
- In this case there is no difference on duration of the crack opening (circa ½ T) between the both load waveforms .

➢ **larger influence of duration of crack opening due to the high sensitized corrosion condition**

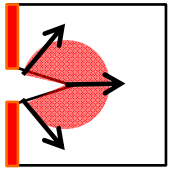
Summary

For the qualification of less corrosively sensitised material condition, such as EN AW-5018:
The Suitability of the conventional test approach (5% NaCl) is limited due to the gut repassivation properties of the material. Because of the partly repassivition at the crack tip the crack propagation rate is mainly controlled by strain rate. In order to achieve the reliable qualification the detrimental effect should be magnified.

- varying load waveforms with higher strain rate
- more aggressive solution
- longer test duration (low load level)
- variable amplitude



For the qualification of more corrosively sensitised material condition, such as EN AW-6110A or EN AC-42100:
Influence of the strain rate will decrease because of the bare condition at the crack tip. The crack propagation rate is mainly controlled by duration of crack opening. The conventional test approach (5% NaCl) is suitable.



Acknowledgement

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