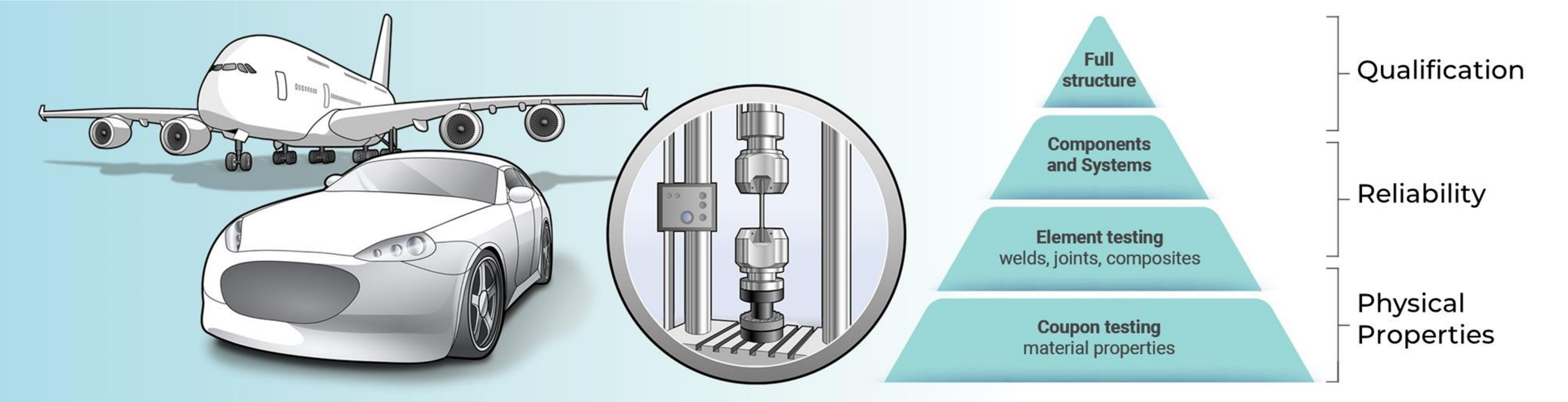
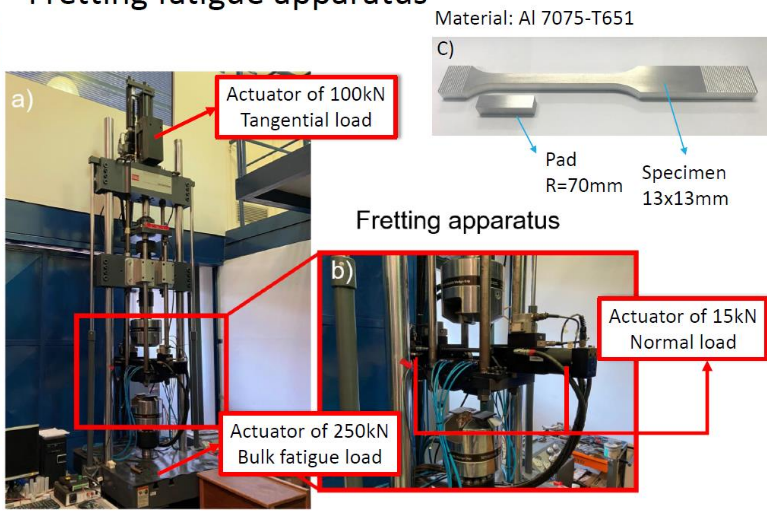


2023 HBK Technology Days

21 November 2023

Experimental work

- Fretting fatigue apparatus



- **Fretting fatigue under variable amplitude shear loading blocks considering partial slip regime: experimental/ numerical analysis**

Ph.D. André Luis Pinto,
University of Brasilia

Fretting fatigue under variable amplitude shear loading blocks considering partial slip regime: experimental/numerical analysis

Abstract

- Fretting fatigue can occur in many structures, such as riveted lap-joint connections in aircraft fuselage and blade-disc connections in aircraft engines. Fretting fatigue is complex and multiaxial but is commonly simplified to constant amplitude loading, however, this condition is not the reality for many industrial applications. Recent research proposes a new experimental and numerical methodology for the life assessment of components subjected to fretting fatigue under variable amplitude loading.

- Experimental tests were conducted by applying H-L (High-Low) and L-H (Low-High) alternating amplitude loading blocks to the tangential load while maintaining a constant static contact normal load, and a constant alternating amplitude bulk fatigue load. The new numerical methodology proposed for fretting fatigue life assessment includes the effects of crack nucleation, wear, and crack propagation.

- Crack nucleation life estimation results are compared using a traditional Miners' linear damage accumulation and a proposed new non-linear damage model from experimental observations of H-L and L-H loading sequences.

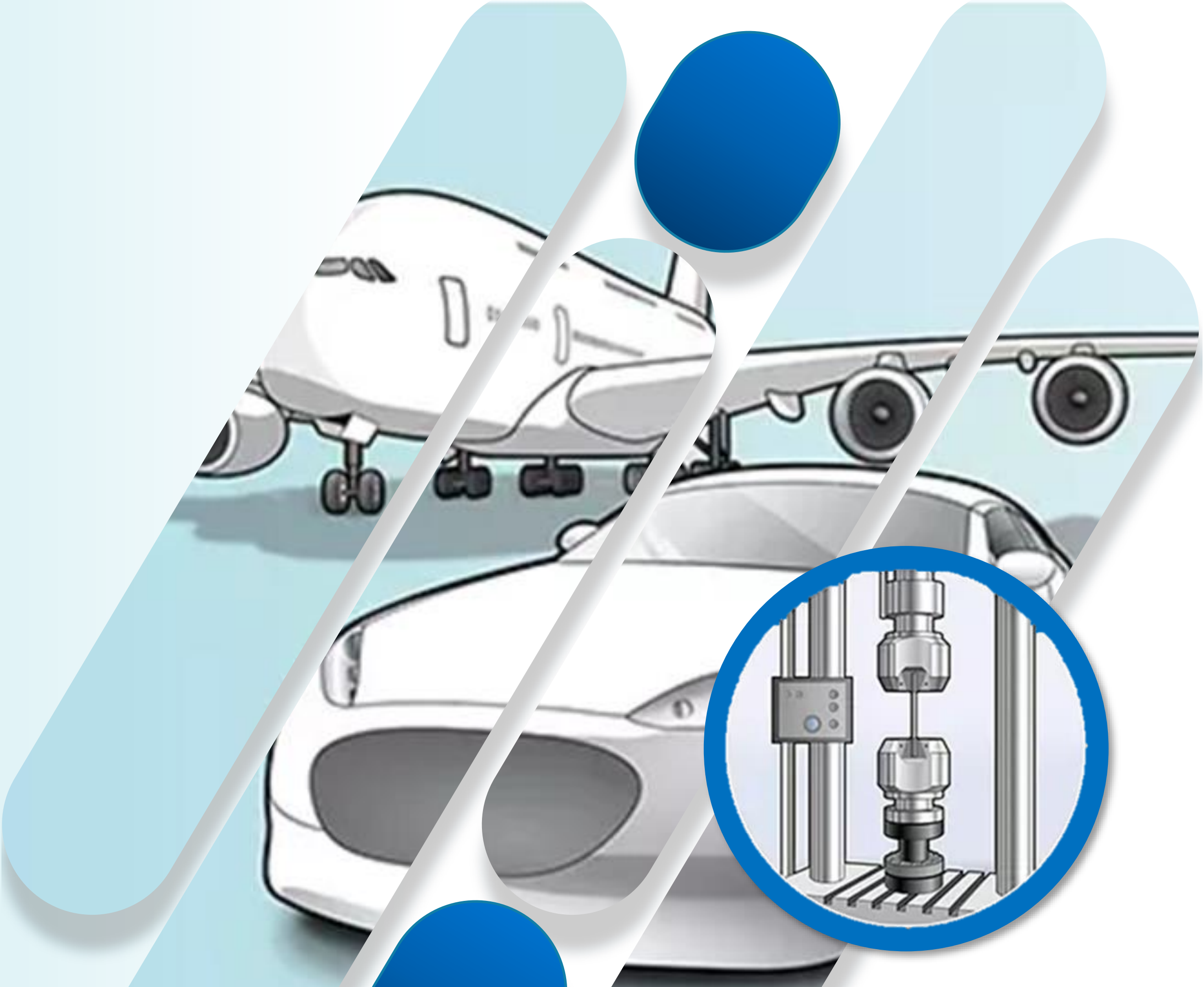
Fretting fatigue under variable amplitude shear loading blocks considering partial slip regime: experimental/numerical analysis

- About the presenter, Ph.D. André Luis Pinto, University of Brasilia
  - Professor at the Federal Institute of Brasília (IFB) and researcher at the University of Brasília (UnB). Ph.D. in Mechanical Sciences from the University of Brasília (UnB) and a Ph.D. in Engineering Technology from Katholieke Universiteit Leuven (KU Leuven).
  - In recent years, he has been working on research into Multiaxial Fatigue and Fretting Fatigue. He completed his master's degree in Mechanical Sciences at UnB (2018) and a degree in Mechanical Engineering at Universidade Evangélica de Goiás-UniEvangélica (2015). He has experience in Mining and Sugar and Alcohol Plants in the Engineering, Maintenance, and Project sectors. During his academic period, he developed research aimed at teaching Mechanical Engineering in Brazil, and Fracture Mechanics.

2023 HBK Technology Days

PH.D. ANDRÉ LUIS PINTO

Thesis: Fretting fatigue under variable amplitude loading



Session 5

Fatigue Testing, Simulation and Performance of Thin Sheet Joints

Brazil


Amazon rainforest
Northeast Coast
Archipelago Fernando de Noronha
Ouro Preto - MG
Waterfalls of Iguaçu
São Paulo - SP
Rio de janeiro - RJ

Brasília – DF, Brazil

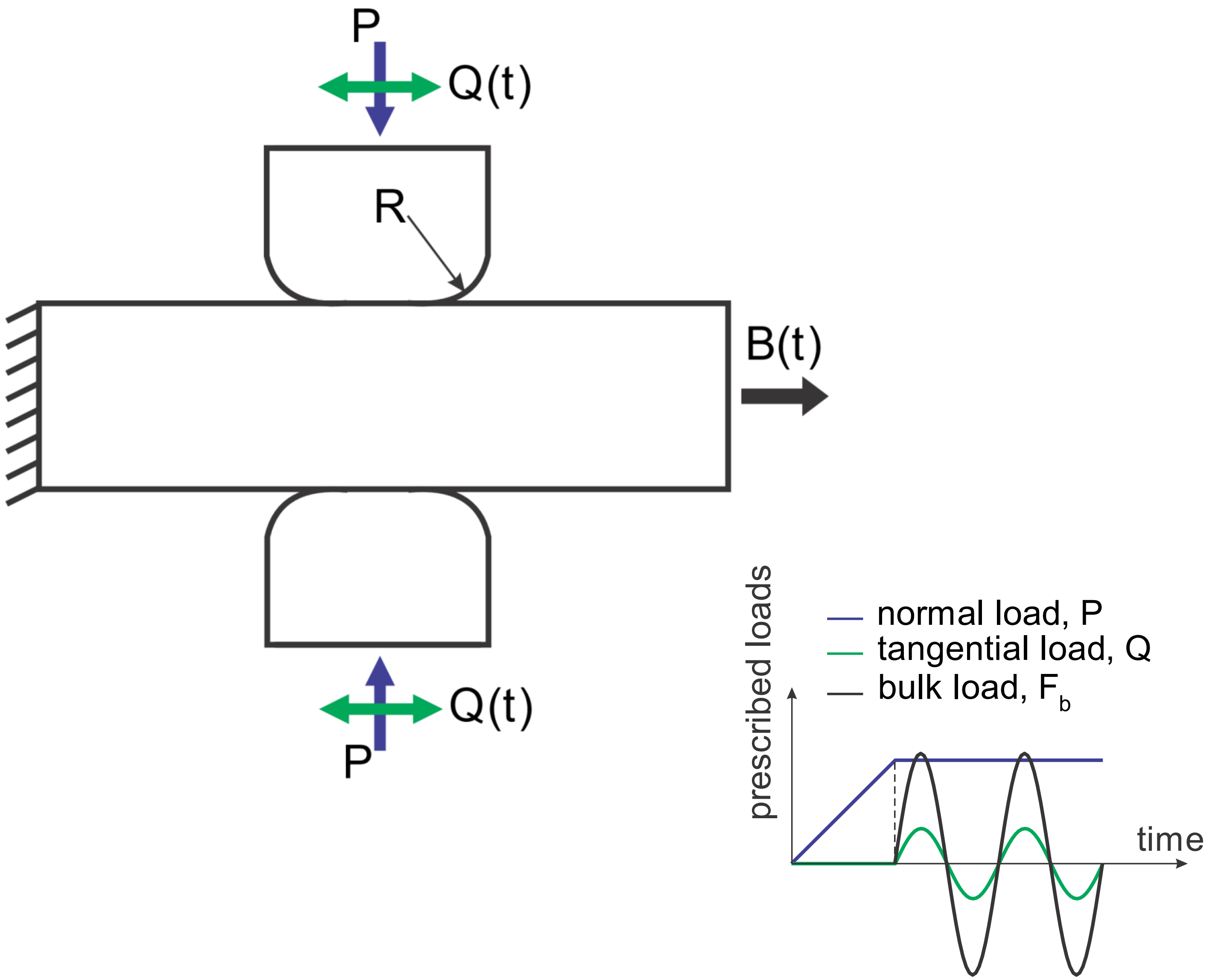
2.8 million population

Dual Ph.D.

- PhD in mechanical sciences - UnB:

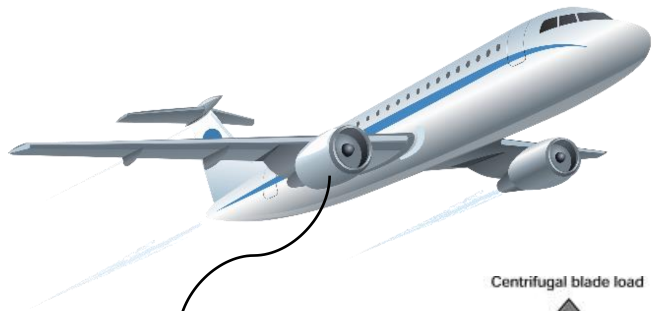
- Ph.D. in eng. technology - KULeuven:

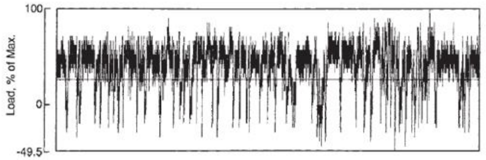
What is fretting fatigue?

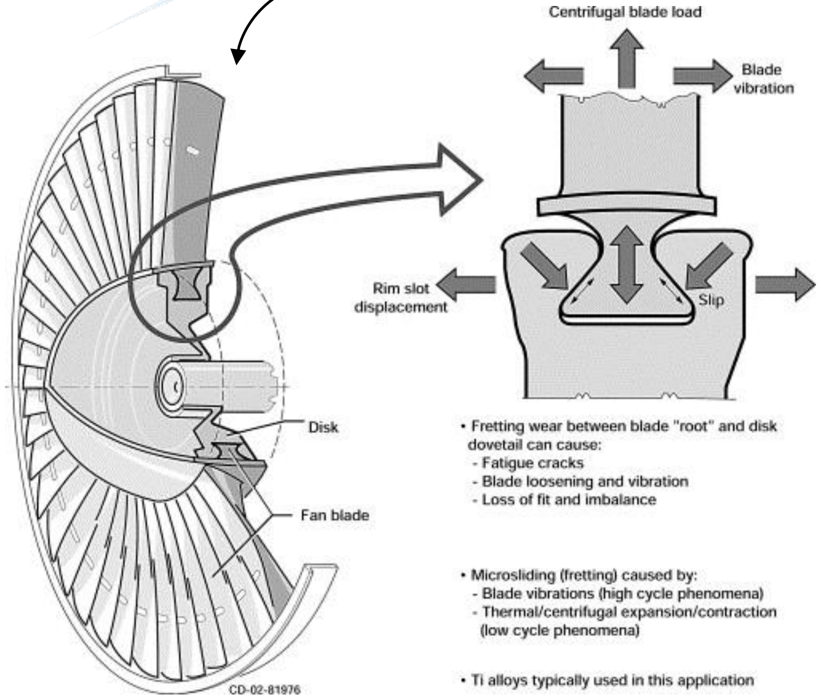


Motivation

- Aircraft engine (blade-disc connection)

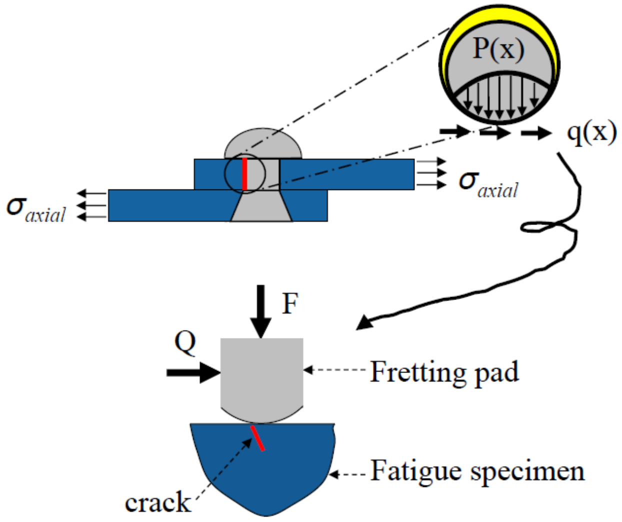






- Aircraft fuselage (lap-joint riveted connections)

(a) (b)



Goals

- The main objective is studying the loading sequence effect on fretting fatigue problem.

1

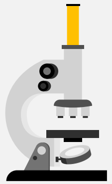
Numerical

To develop a FE model to estimate crack initiation and propagation life.

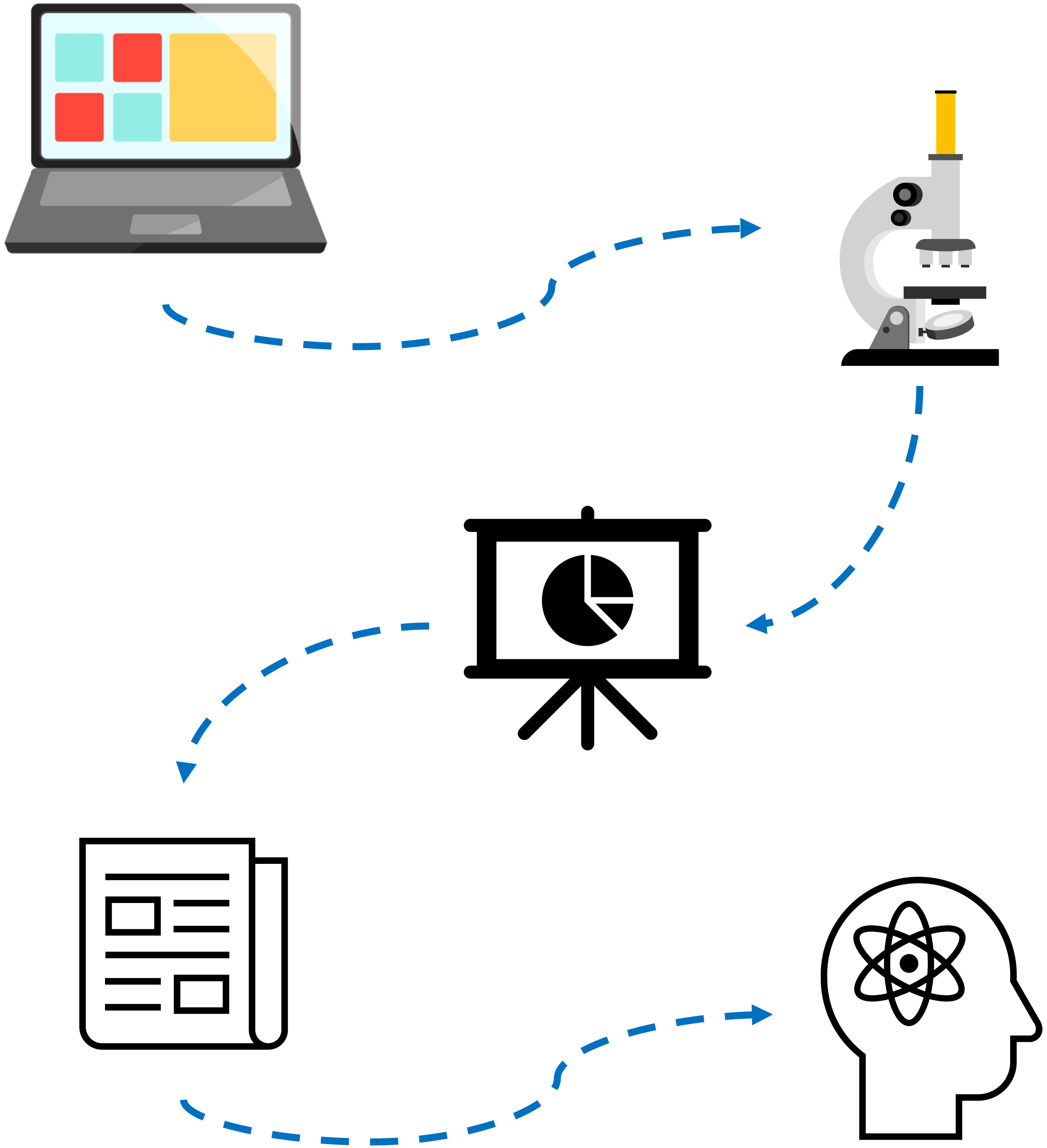
2

Experimental

To perform a set of new fretting fatigue tests under variable amplitude loading.



It was a journey!



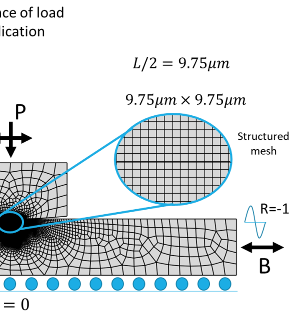
Numerical approach

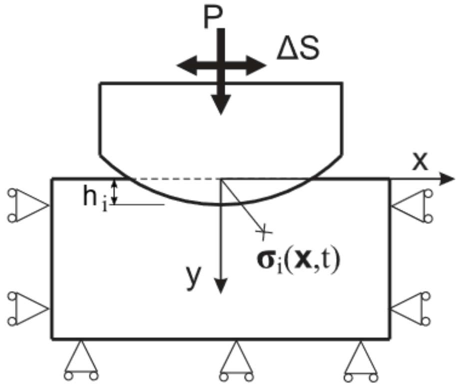
$$N_f = N_i + N_p$$

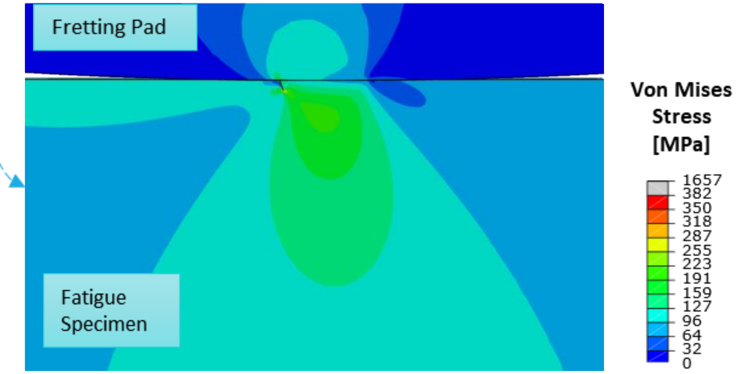
1. SWT calibration
2. Wear modelling
3. TCD

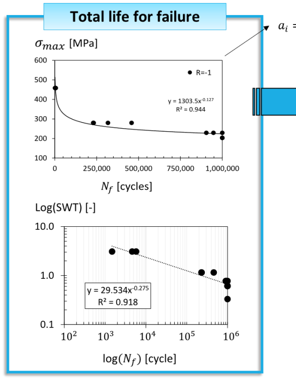
N_i + N_p

4. Crack initiation angle (CDM)
5. Crack propagation (SWT_L)

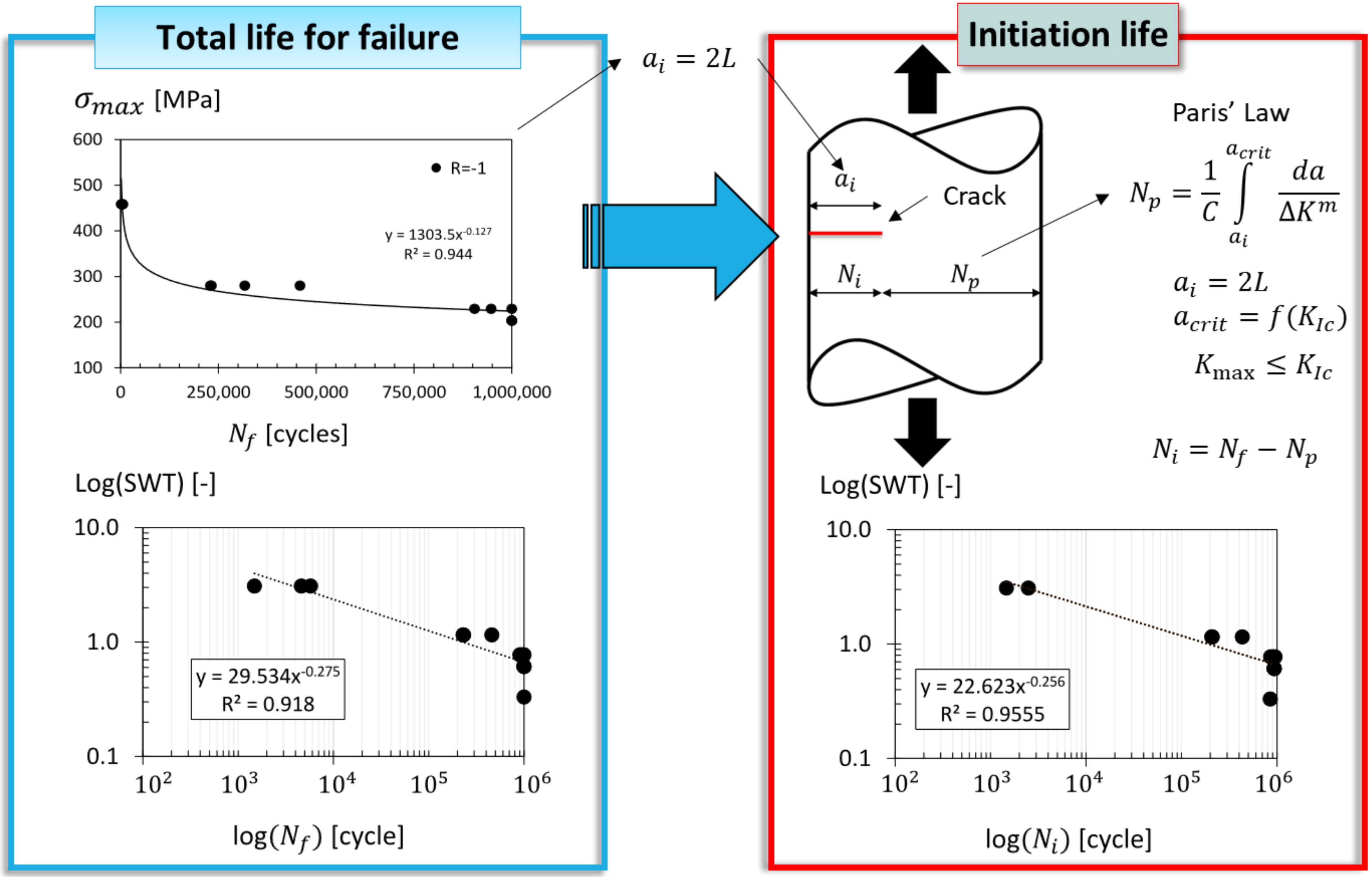






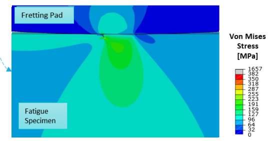


Numerical approach



N_p

4. Crack initiation angle (CDM)
5. Crack propagation (SWT_L)



- Archard's low to wear computation:

$$\Delta h_{i,j} = \sum_{k=1}^{n_{inc}} kp(x_j,t_k)\Delta s(x_j,t_k)\Delta N$$

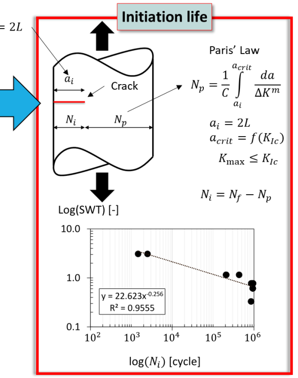
- SWT multiaxial fatigue criterion with Miner's rule:

$$SWT = \frac{\Delta\varepsilon_1}{2}\sigma_{n_{max}} \qquad D = \sum_{i=1}^{n_{inc}} \frac{\Delta N}{N_{fi}}$$

- The TCD by means of the point method:

$$L_M = AN_f^B$$

Numerical approach



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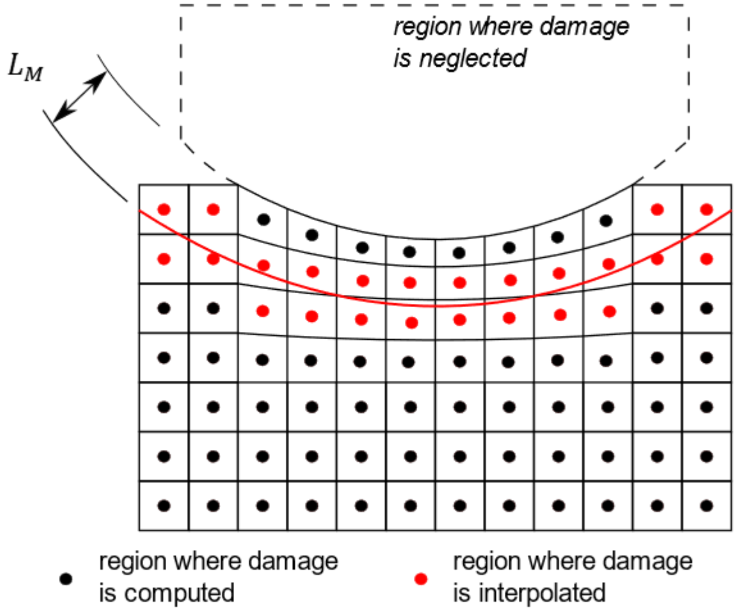


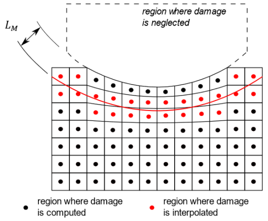
$$\bar{\sigma}_n(\theta,t) = \frac{1}{2L}\int_0^{2L} \sigma_n(r,\theta,t)dr$$

$$\bar{\sigma}_{n,max}(\theta) = \max_t \bar{\sigma}_n(\theta,t)$$

$$\bar{\varepsilon}_n(\theta,t) = \frac{1}{2L}\int_0^{2L} \varepsilon_n(r,\theta,t)dr$$

$$\bar{\varepsilon}_{n,a}(\theta) = \frac{1}{2}\left(\max_t \bar{\varepsilon}_n(\theta,t) - \min_t \bar{\varepsilon}_n(\theta,t)\right)$$

Numerical approach

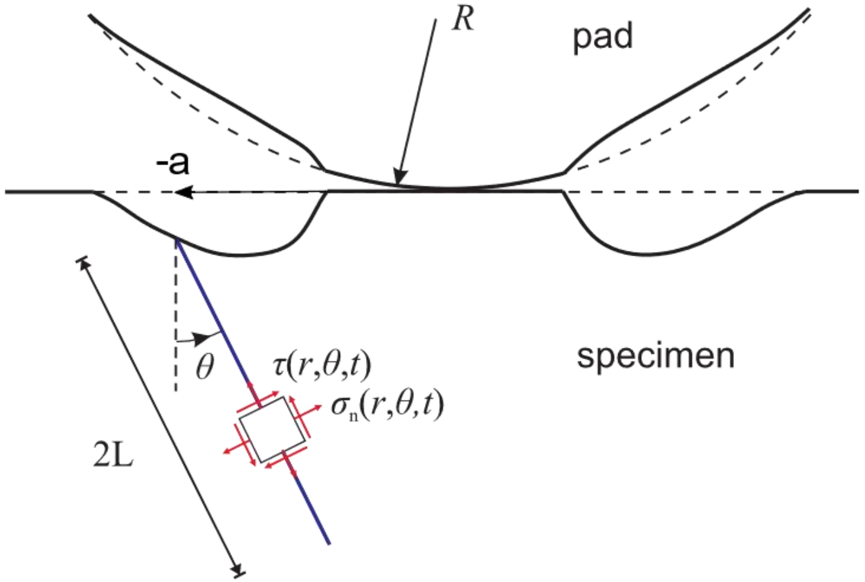


$$\bar{\sigma}_n(\theta, t) = \frac{1}{2L}\int_0^{2L} \sigma_n(r, \theta, t)dr$$

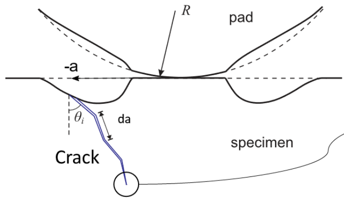
$$\bar{\sigma}_{n,max}(\theta) = \max_t \bar{\sigma}_n(\theta, t)$$

$$\bar{\varepsilon}_n(\theta, t) = \frac{1}{2L}\int_0^{2L} \varepsilon_n(r, \theta, t)dr$$

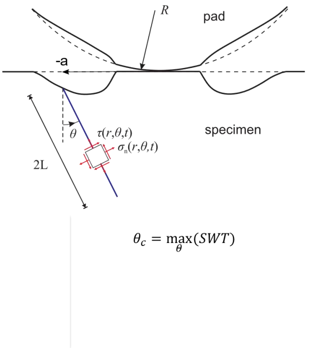
$$\bar{\varepsilon}_{n,a}(\theta) = \frac{1}{2}\left(\max_t \bar{\varepsilon}_n(\theta, t) - \min_t \bar{\varepsilon}_n(\theta, t)\right)$$

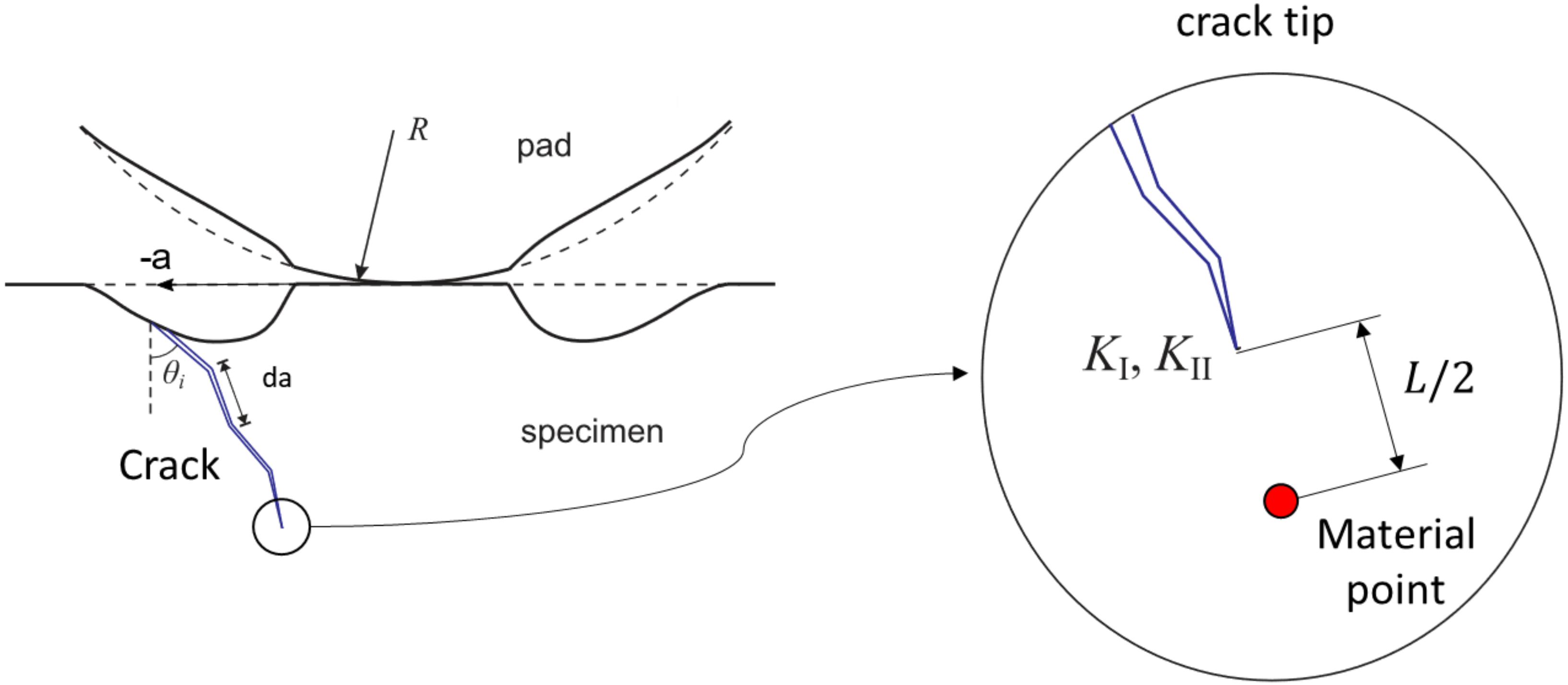


$$\theta_c = \max_\theta(SWT)$$

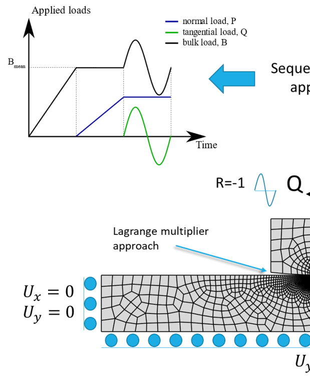


Numerical approach

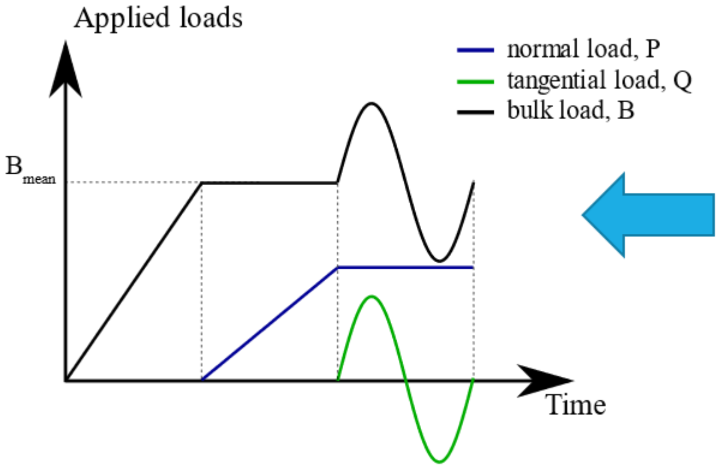




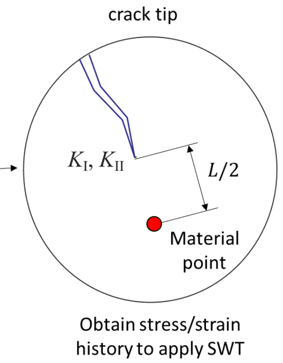
Obtain stress/strain history to apply SWT

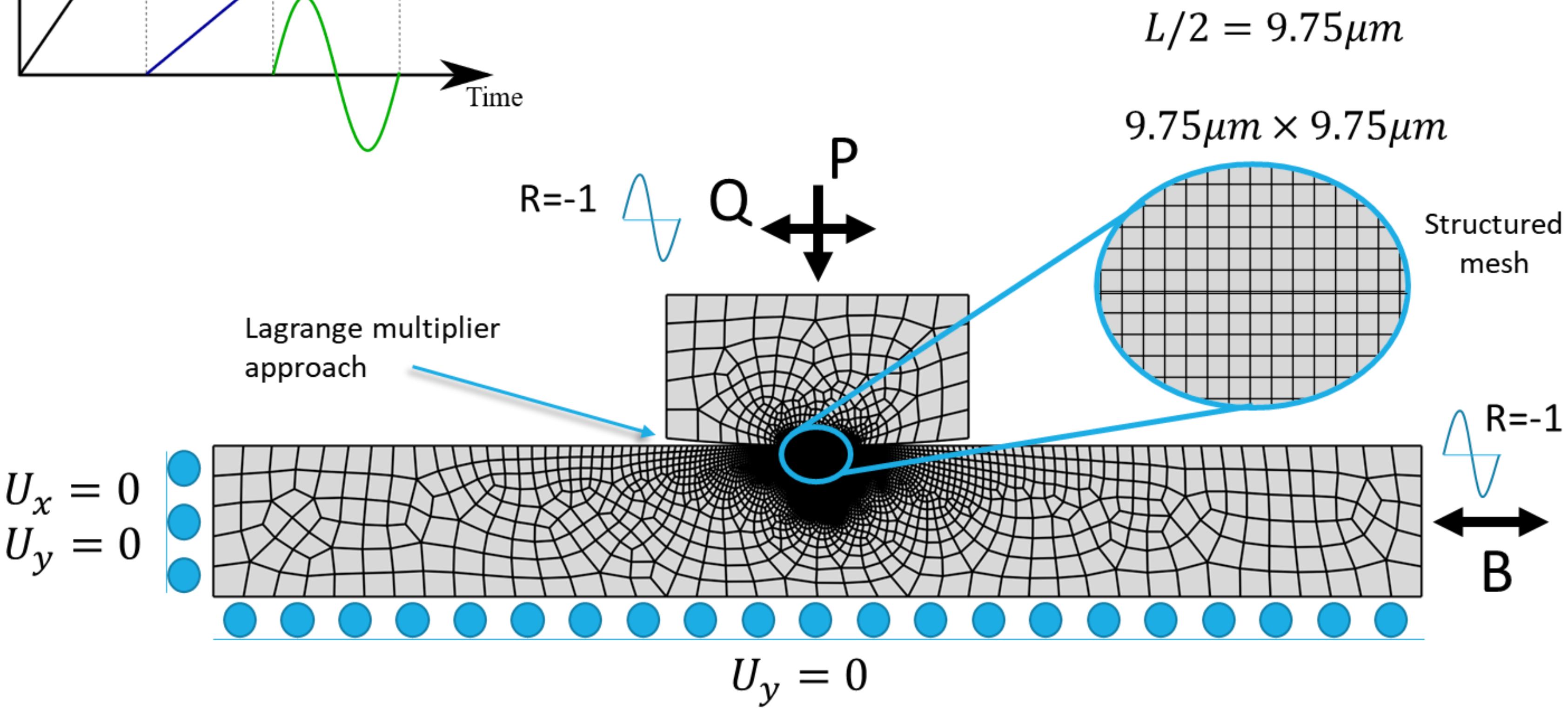


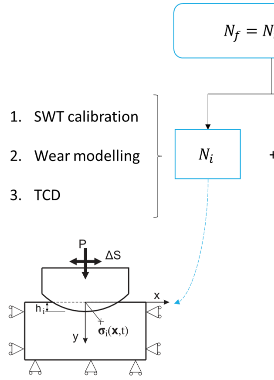
Numerical approach



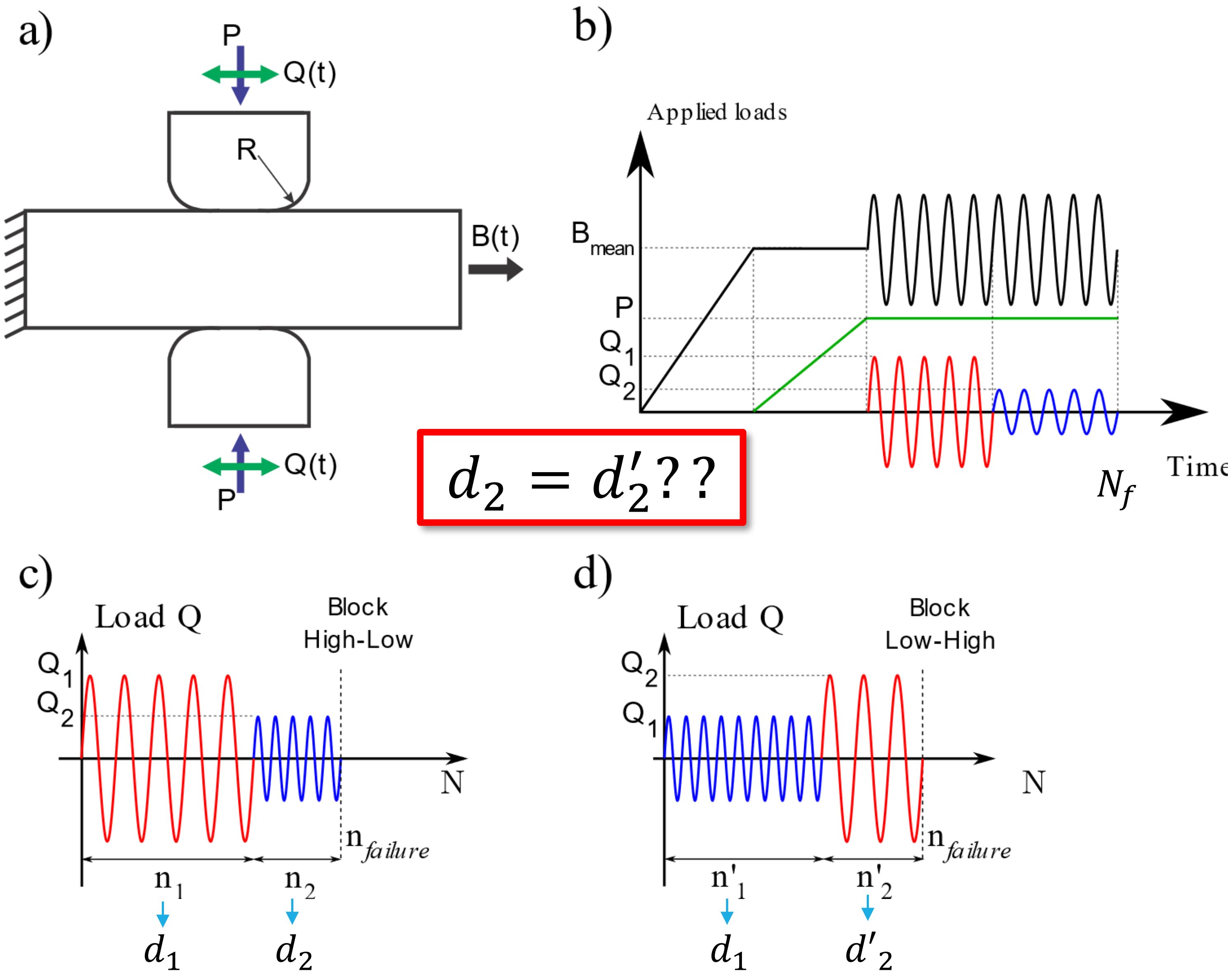
Sequence of load application







Experimental work

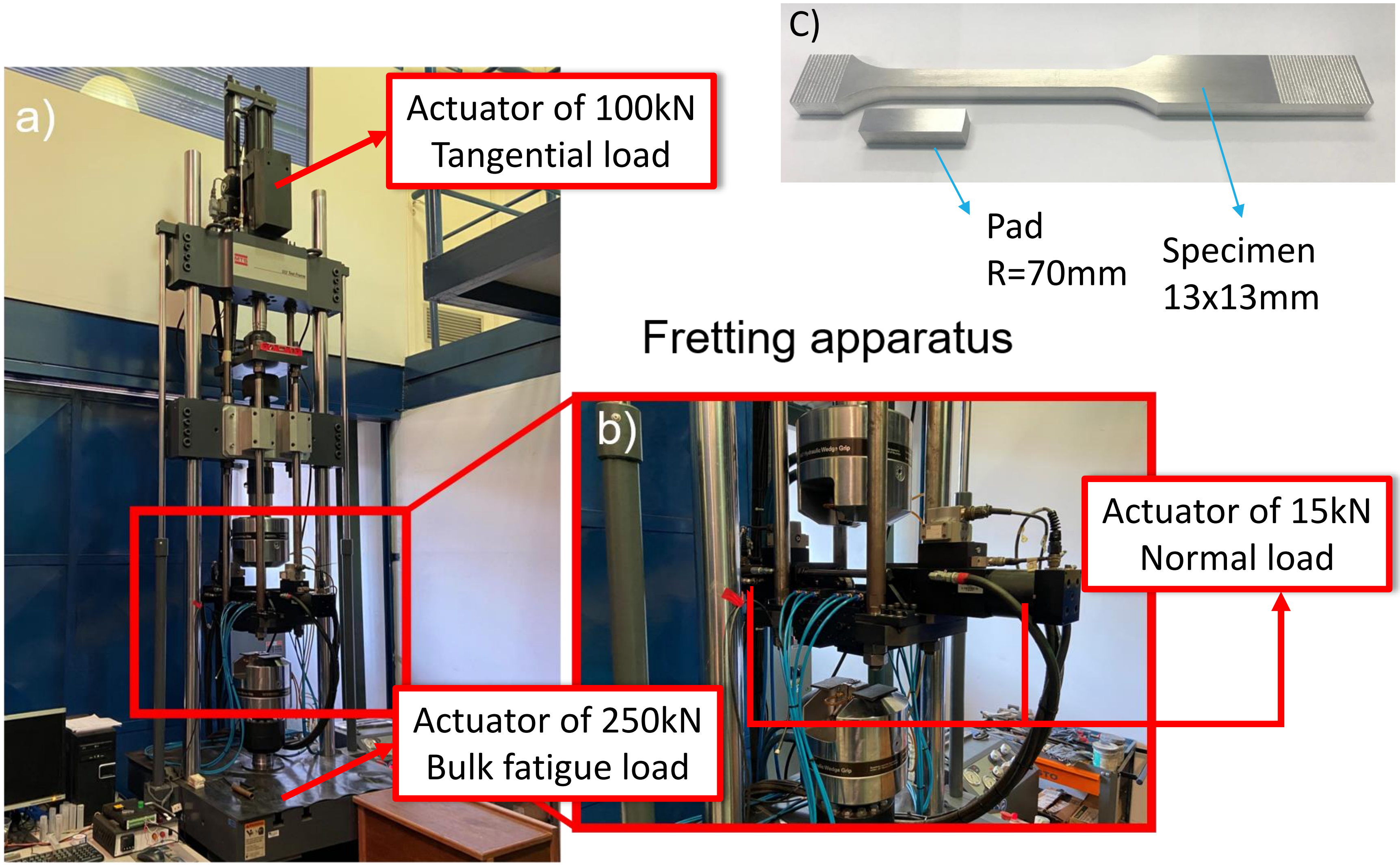


$$\boxed{d_2 = d_2'??}$$

Experimental work

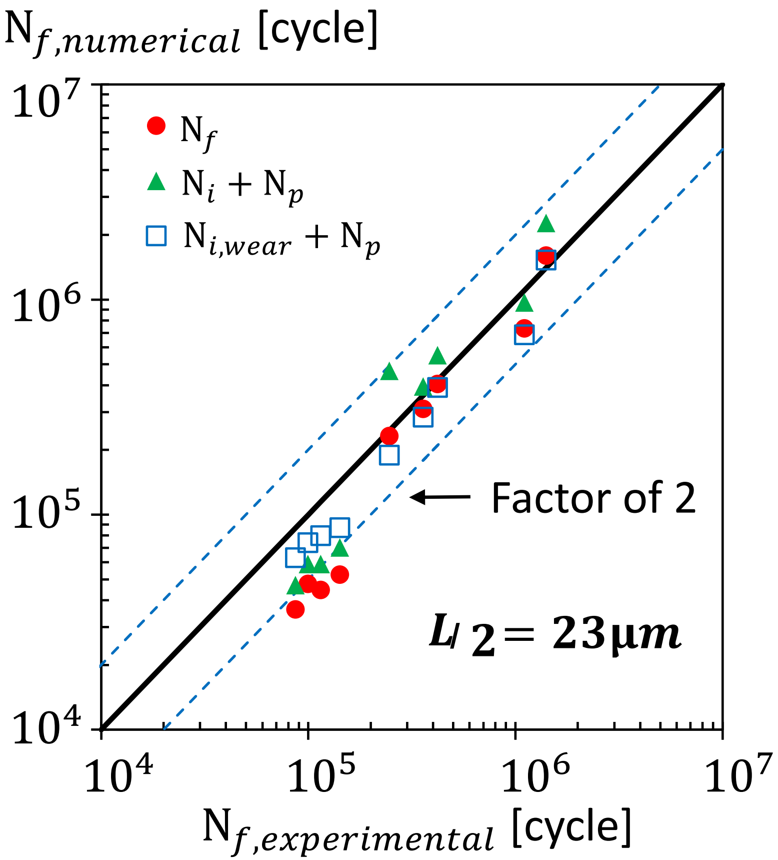
- Fretting fatigue apparatus

Material: Al 7075-T651



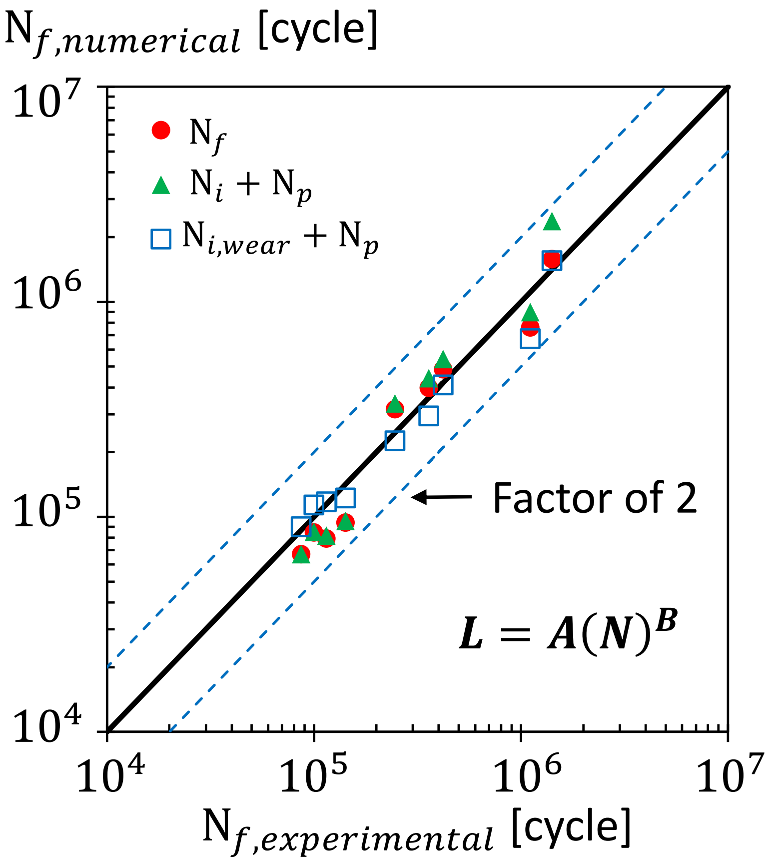
Results

a)



- **Pinto, A. L.,** Araújo, J. A., & Talemi, R. (**2021**). Effects of fretting wear process on fatigue crack propagation and life assessment. *Tribology International*, *156*, 106787.

b)



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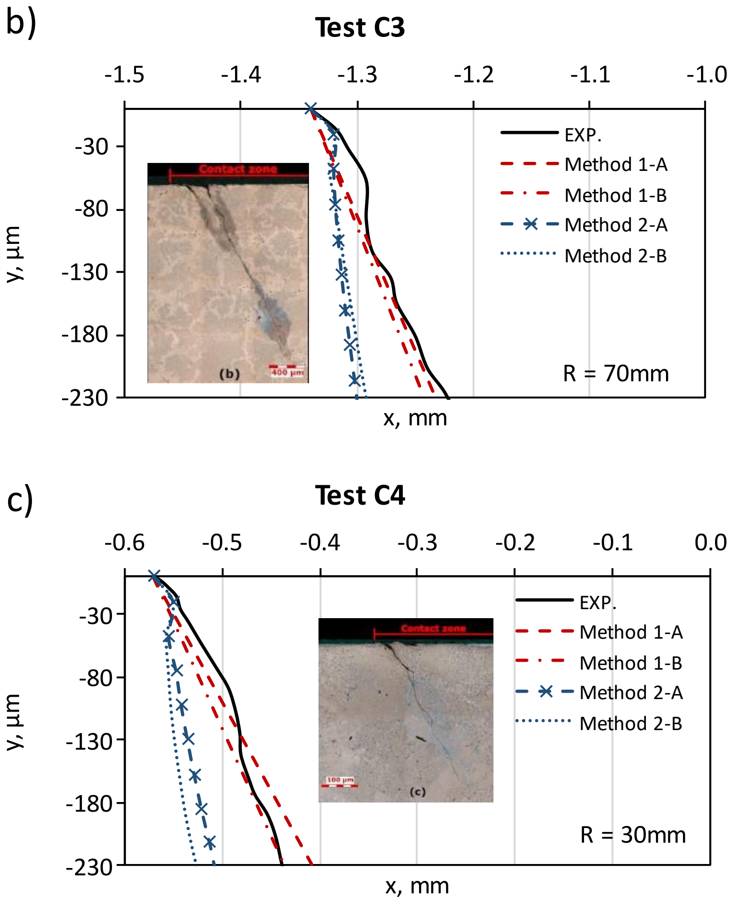
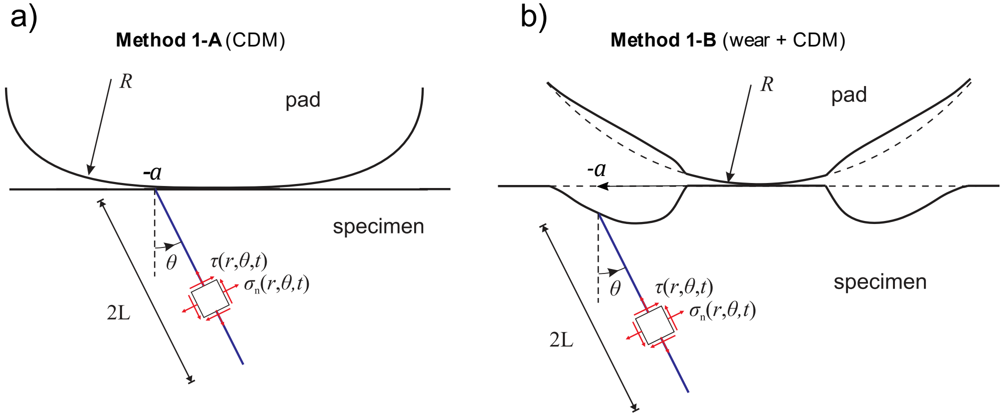
Results





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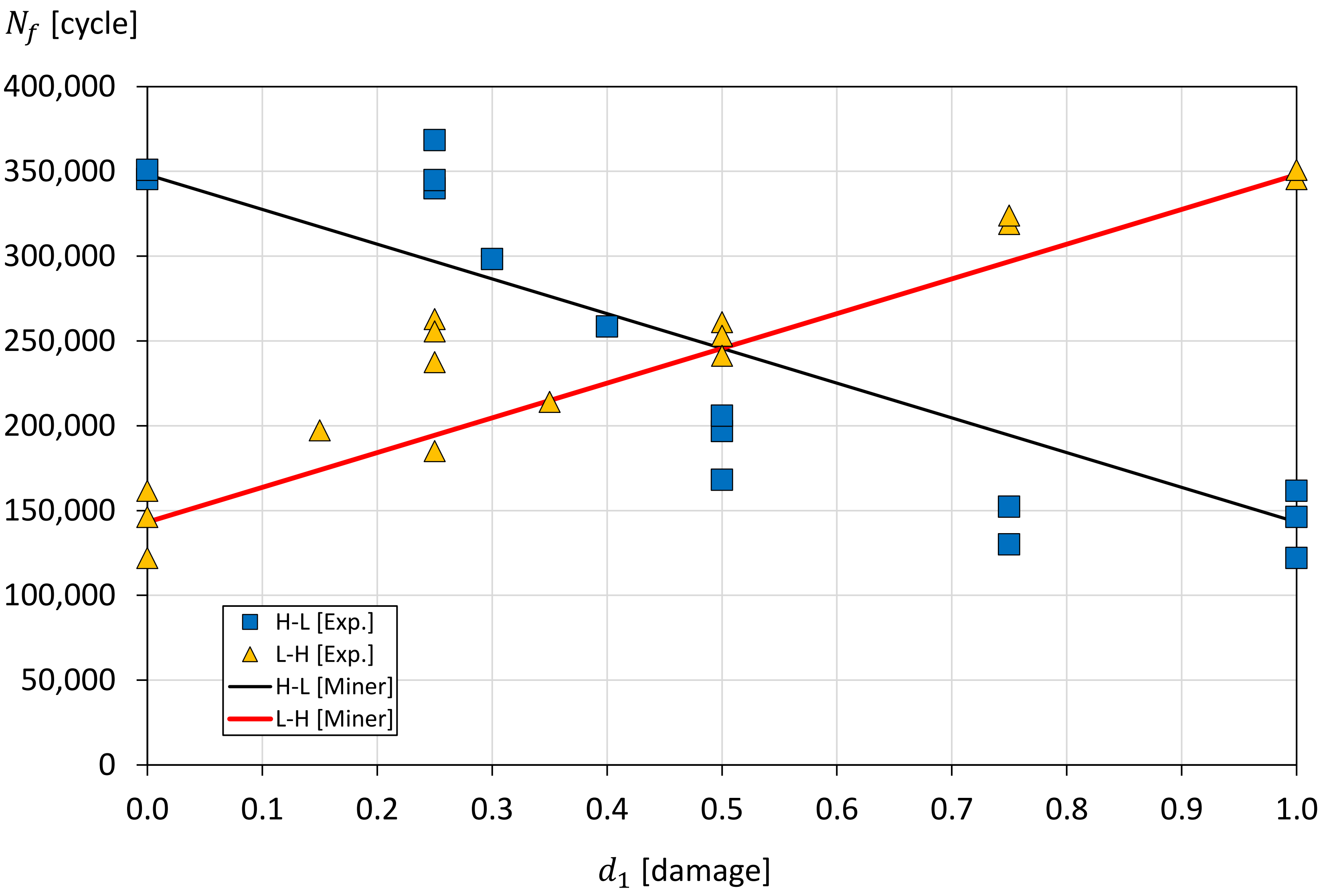
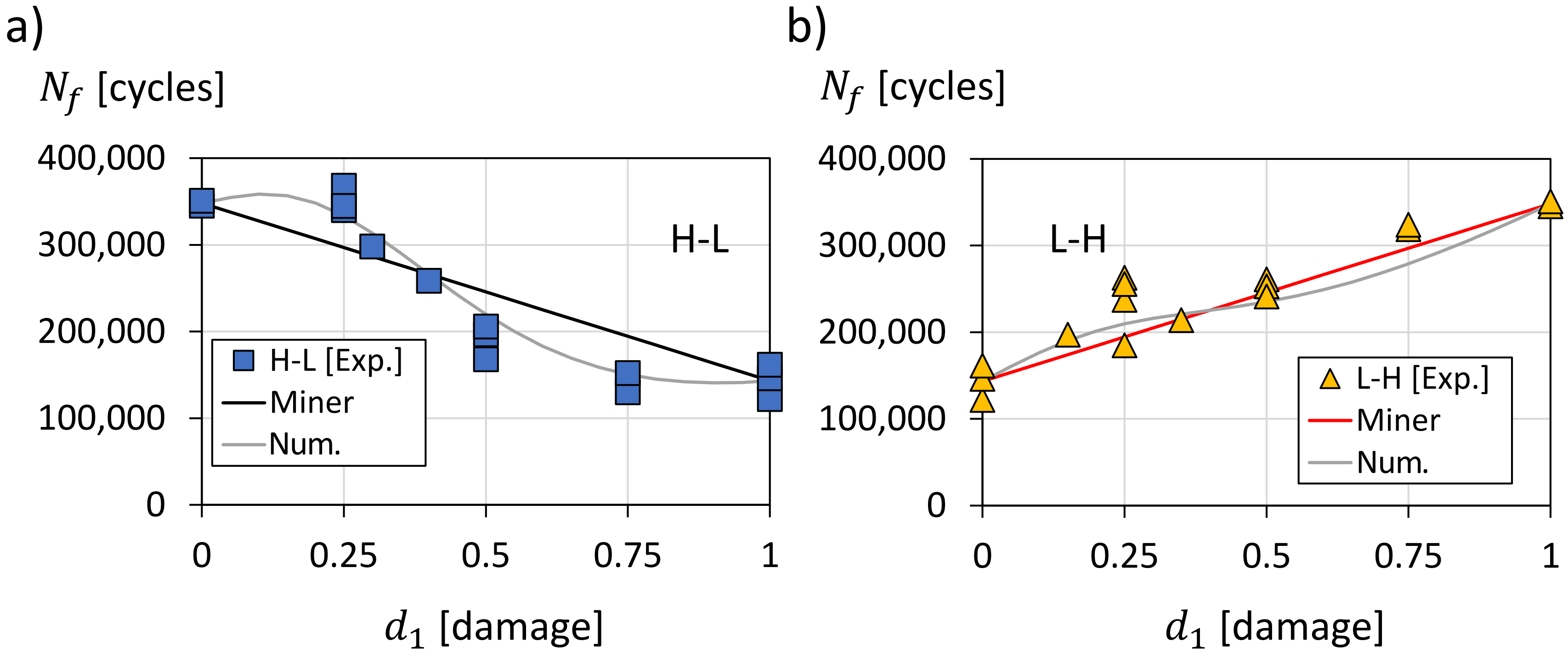
Results



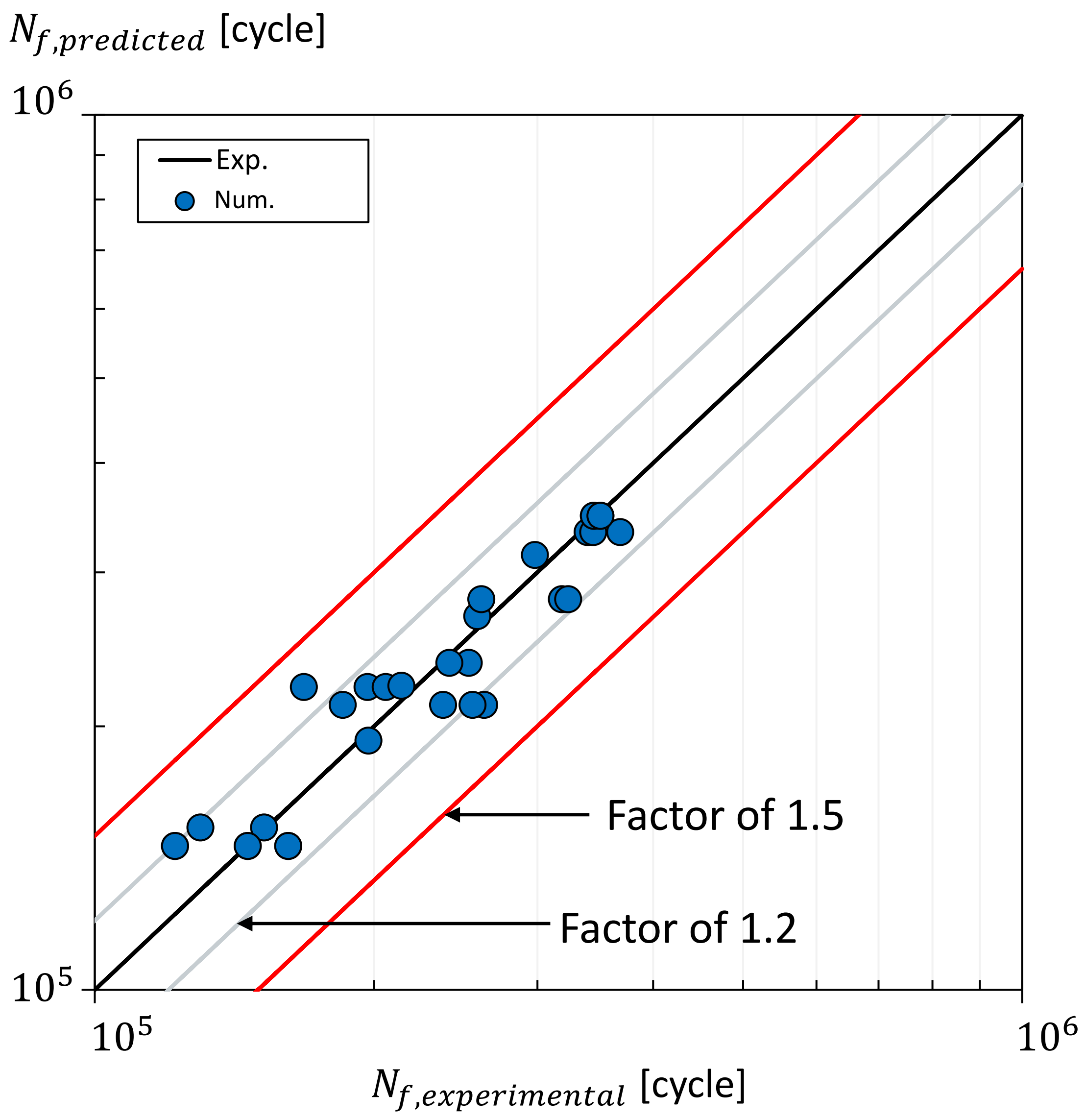
N_f [cycle]
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
d_1 [damage]
H-L [Exp.]
L-H [Exp.]
H-L [Miner]
L-H [Miner]

Results

- $D = \left(\frac{n_1}{N_1}\right)^{\beta} + \frac{n_2}{N_2}$ → (Numerical damage rule)
- $\beta = \left(\frac{N_h}{N_l}\right)^{\left(2.5\frac{n_1}{N_1}-1\right)}$



Results

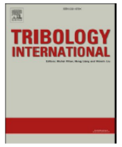


$N_{f,predicted}$ [cycle]
10^6
10^5
Exp.
Num.
Factor of 1.5
Factor of 1.2
10^5
10^6
$N_{f,experimental}$ [cycle]

Publications

2023

Pinto, A. L.,Talemi, R., & Araújo, J. A. (2023). **Fretting fatigue under variable amplitude loading considering partial slip regime: numerical/experimental analysis.** Tribology International, 182, 108367.



1 citation

2022

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11 citations

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7 citations

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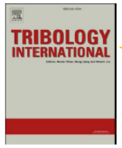
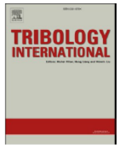


34 citations

2020

Pinto, A. L., Cardoso, R. A., Talemi, R., & Araújo, J. A. (2020). **Fretting fatigue under variable amplitude loading considering partial and gross slip regimes: Numerical analysis.** Tribology International, 146, 106199.



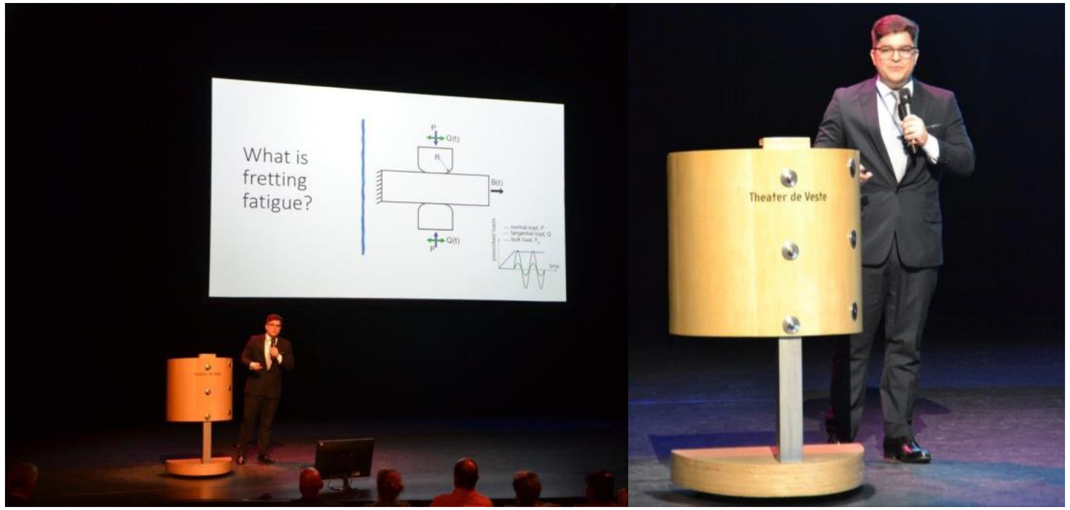
16 citations

Conclusions

- The proposed numerical approach including the **wear effect** in the crack nucleation phase, the **CDM** to estimate initiation angle, and SWT close to the crack tip to predict the **crack propagation path** provides results with high accuracy in terms of life assessment for fretting fatigue problems;
- The experimental tests showed that the **damage accumulation is non-linear** in the fretting fatigue problems under variable amplitude loading blocks;
- The **new damage rule** provided results within a scatter band of **1.2**.

Jaap Schijve Award 2023

From left to right: Prof. Dr. Reza Talemi (KU Leuven), Prof. Dr. André L. P. (IFB), Prof. Dr José A. A. (UnB).



The **Jaap Schijve award** recognizes works of excellence in the area of Aircraft Structural Fatigue and Damage Tolerance by young researchers with up to 10 years of doctorate.

This award is awarded by the **Royal Netherlands Aerospace Center NLR** and the Faculty of Aerospace Engineering at **Delft University of Technology** in the Netherlands.

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CNPq
Conselho Nacional de Desenvolvimento Científico e Tecnológico

Universidade de Brasília

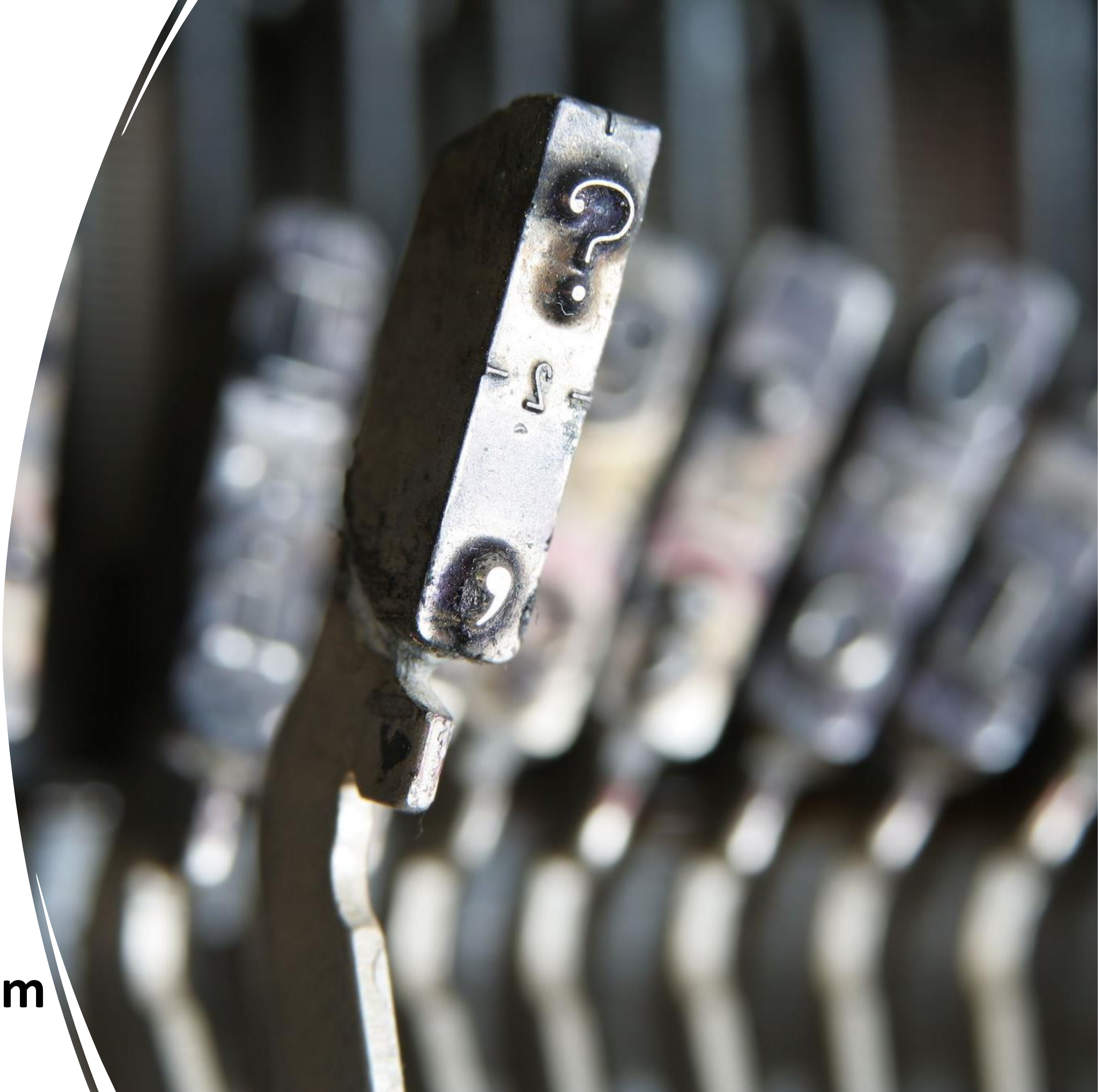
Acknowledgments

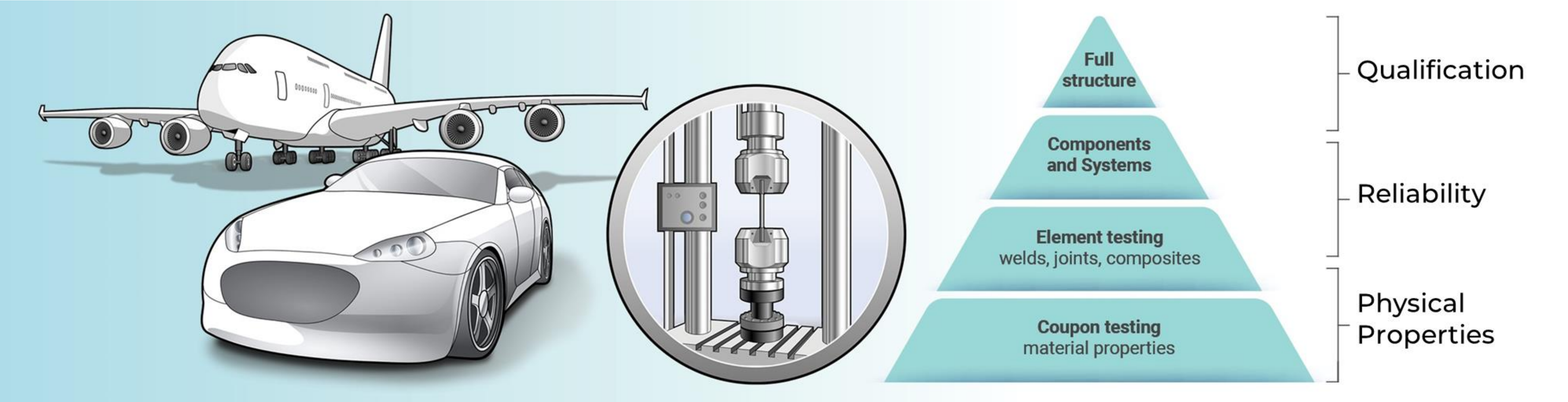
KU LEUVEN

Questions?

- **Contact information:**

André Luis Pinto
andreluiseng.mecanica@gmail.com



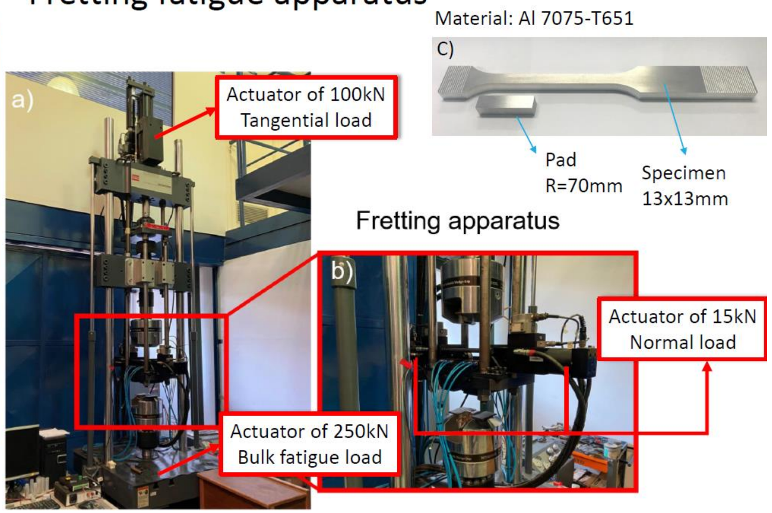


2023 HBK Technology Days

21 November 2023

Experimental work

- Fretting fatigue apparatus



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