A FATIGUE DAMAGE MODEL FOR EPOXY RESIN AND ITS APPLICATION TO FIBER REINFORCED PLASTICS

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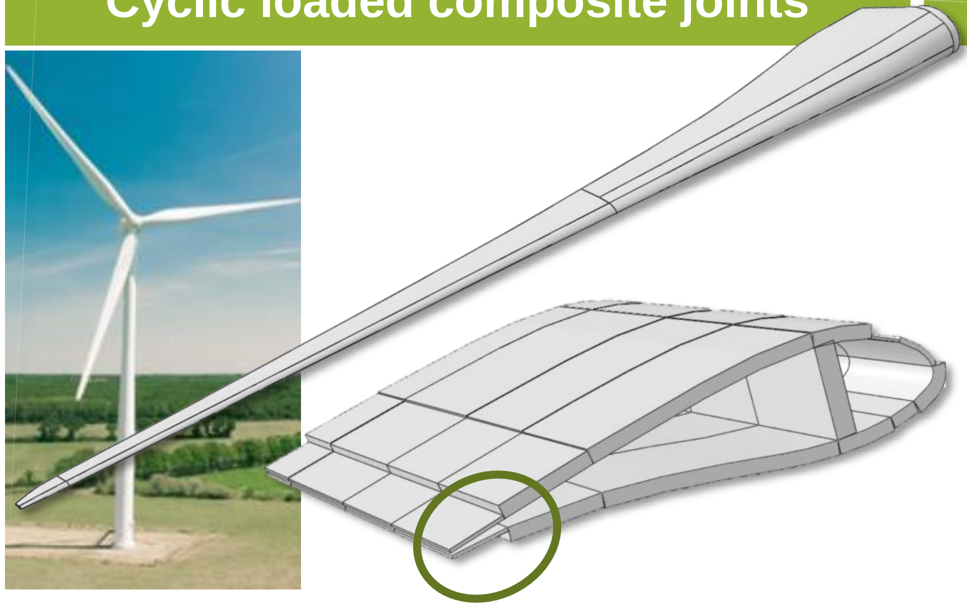
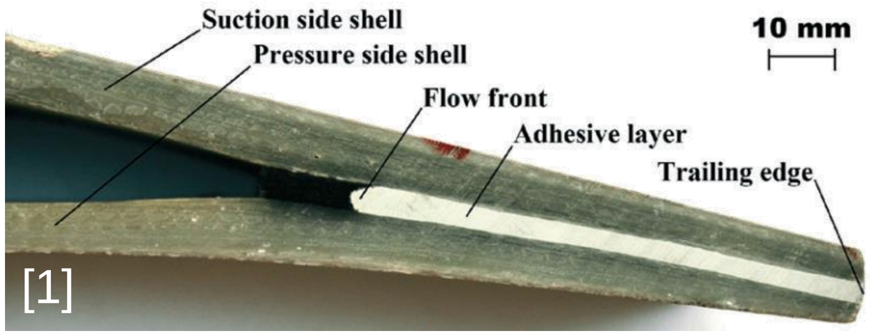
DLR

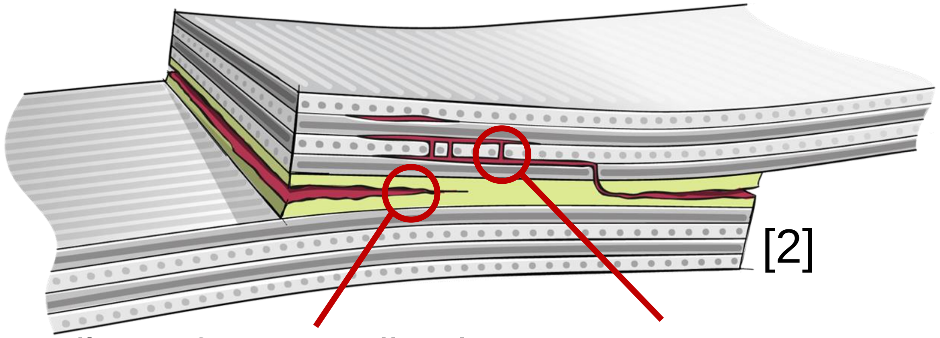
Role of epoxy resin in failure of adhesive composite joints

Cyclic loaded composite joints



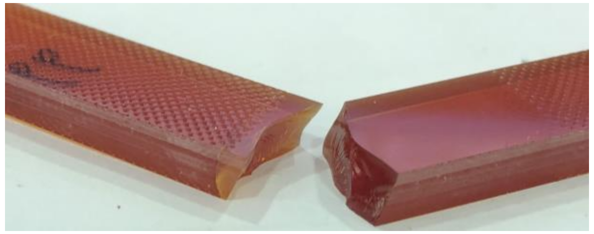


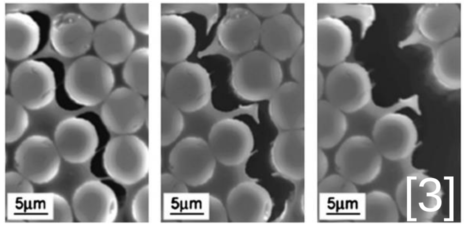
Damage phenomena in adhesive composite joints



Failure of epoxy adhesive

Failure of epoxy in composite





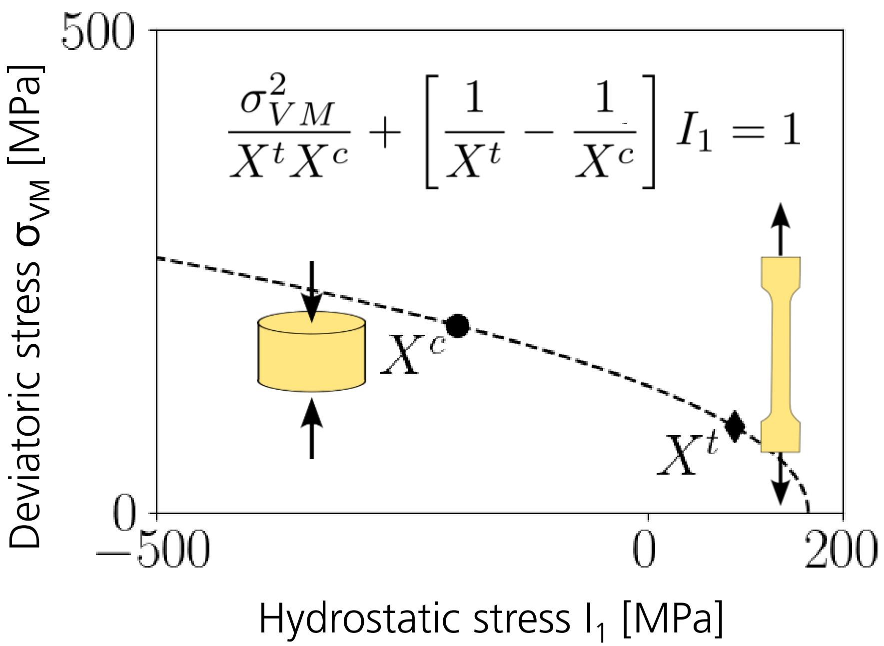
Fatigue behavior of epoxy resin contributes to fatigue failure of adhesive composite joints

[1] Eder et. al., 2014, DOI: 10.1002/we.1744
[2] Völkerink, 2022, DOI: 10.57676/hya4-2a09
[3] Hobbiebrunken et. al., 2006. DOI: 10.1016/j.compositesa.2005.12.021

Material behavior of epoxy
Experimental characterization

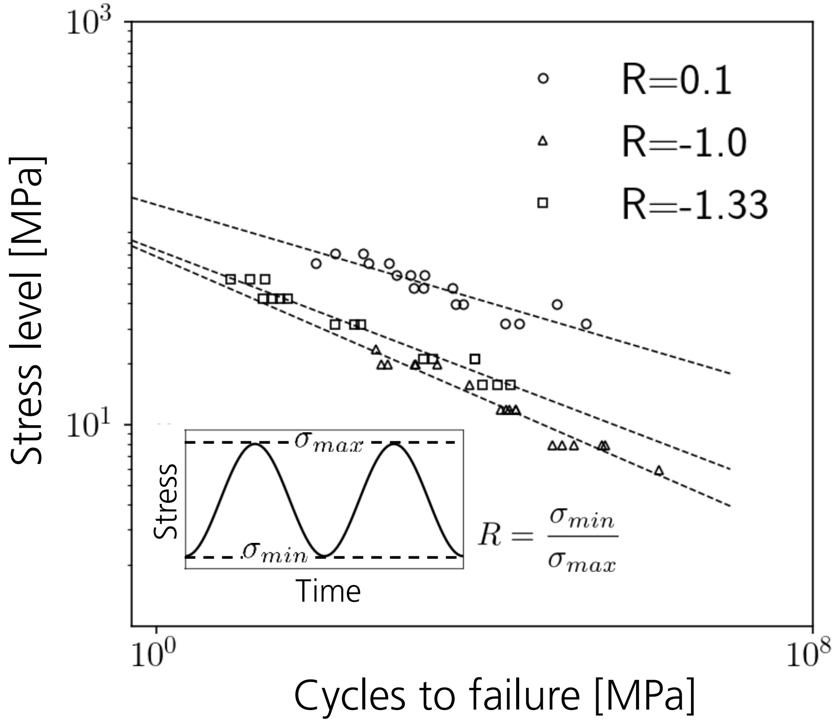
Quasi-static testing

Pressure dependent failure



Cyclic testing

Mean stress sensitivitv

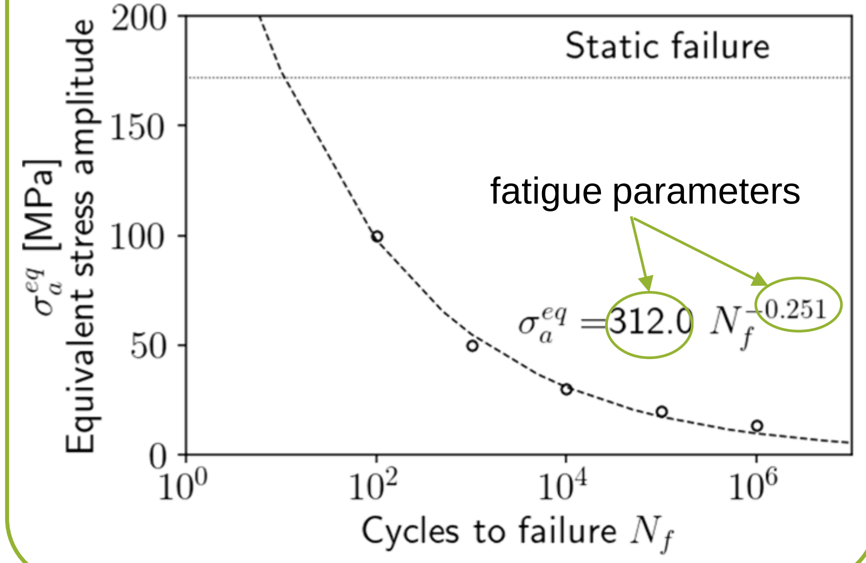


[4] Stassi-D'Alia,1967. DOI: 10.1007/BF02128173

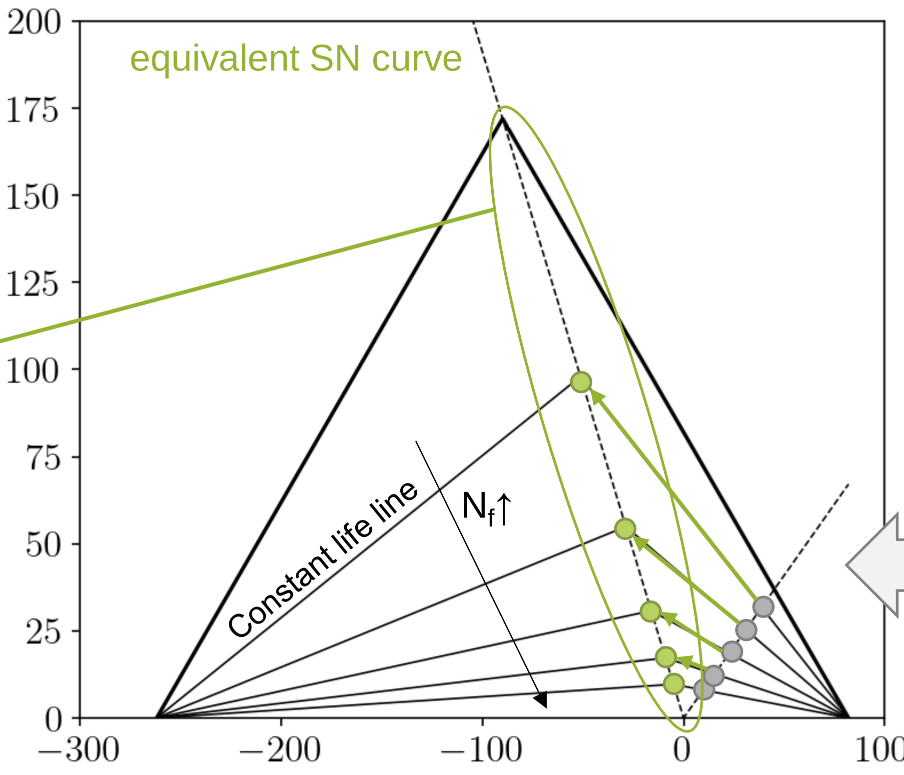
Material behavior of epoxy

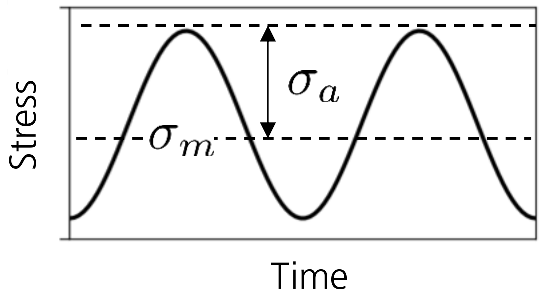
Modelling mean stress effect

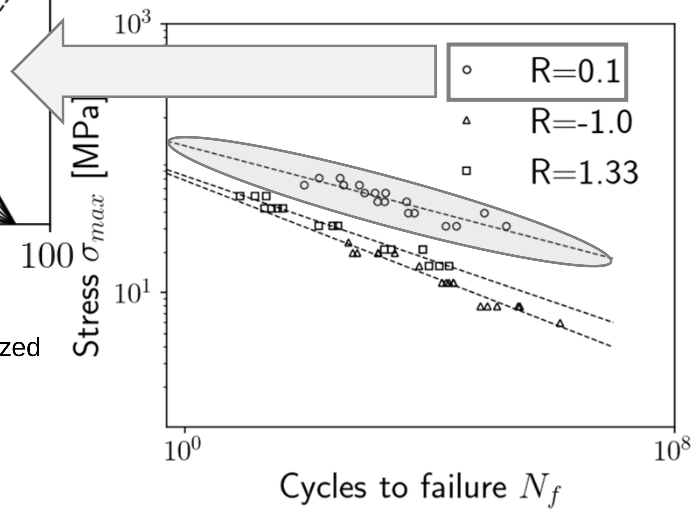
Equivalent SN curve



$$\sigma_a^{eq} = 312.0\ N_f^{-0.251}$$







[5] Kawai et. Al., 2007, 10.1016/j.compositesa.2007.01.016; linearized

Material behavior of epoxy
Multiaxial stress states

Testing & calibration based on uniaxial stress state

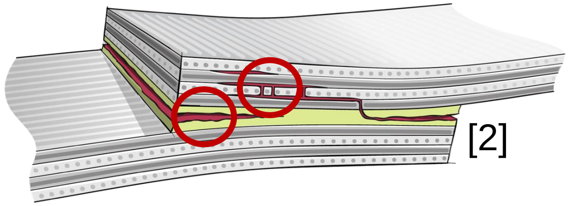
$$\underline{\underline{\sigma}} = \begin{bmatrix} \sigma_{11} & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

$$\sigma_a^{eq} = 312 \cdot N_f^{-0.251}$$

σ^{eq}

Multiaxial stress state in adhesive and composite

$$\underline{\underline{\sigma}} = \begin{bmatrix} \sigma_{11} & \sigma_{12} & \sigma_{13} \\ \sigma_{21} & \sigma_{22} & \sigma_{23} \\ \sigma_{31} & \sigma_{32} & \sigma_{33} \end{bmatrix}$$



[2]

σ_{VM}, I_1

Transfer multiaxial stress state→ equivalent uniaxial stress

$$\sigma^{eq} = \sigma_1^{eq} \longleftarrow I_1 \geq 0$$ tensile stress

$$\sigma^{eq} = -|\sigma_2^{eq}| \cdot \kappa \longleftarrow I_1 < 0$$ compression stress

$$\frac{\sigma_{VM}^2}{\kappa(\sigma^{eq})^2} + \left[\frac{1}{\sigma^{eq}} - \frac{1}{\kappa\sigma^{eq}}\right] I_1 = 1$$

$$X^t \Rightarrow \sigma^{eq}$$

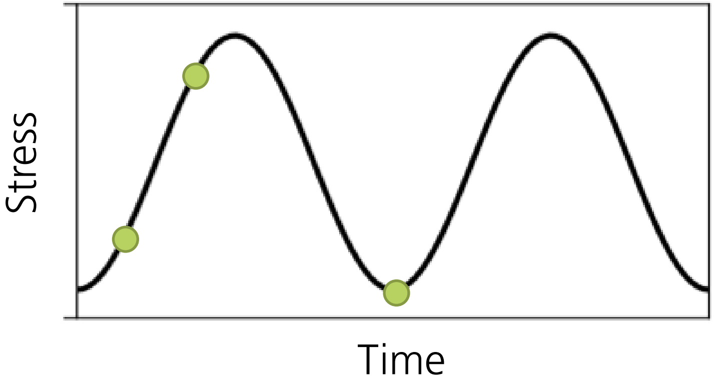
$$\frac{\sigma_{VM}^2}{\kappa(X^t)^2} + \left[\frac{1}{X^t} - \frac{1}{\kappa X^t}\right] I_1 = f$$

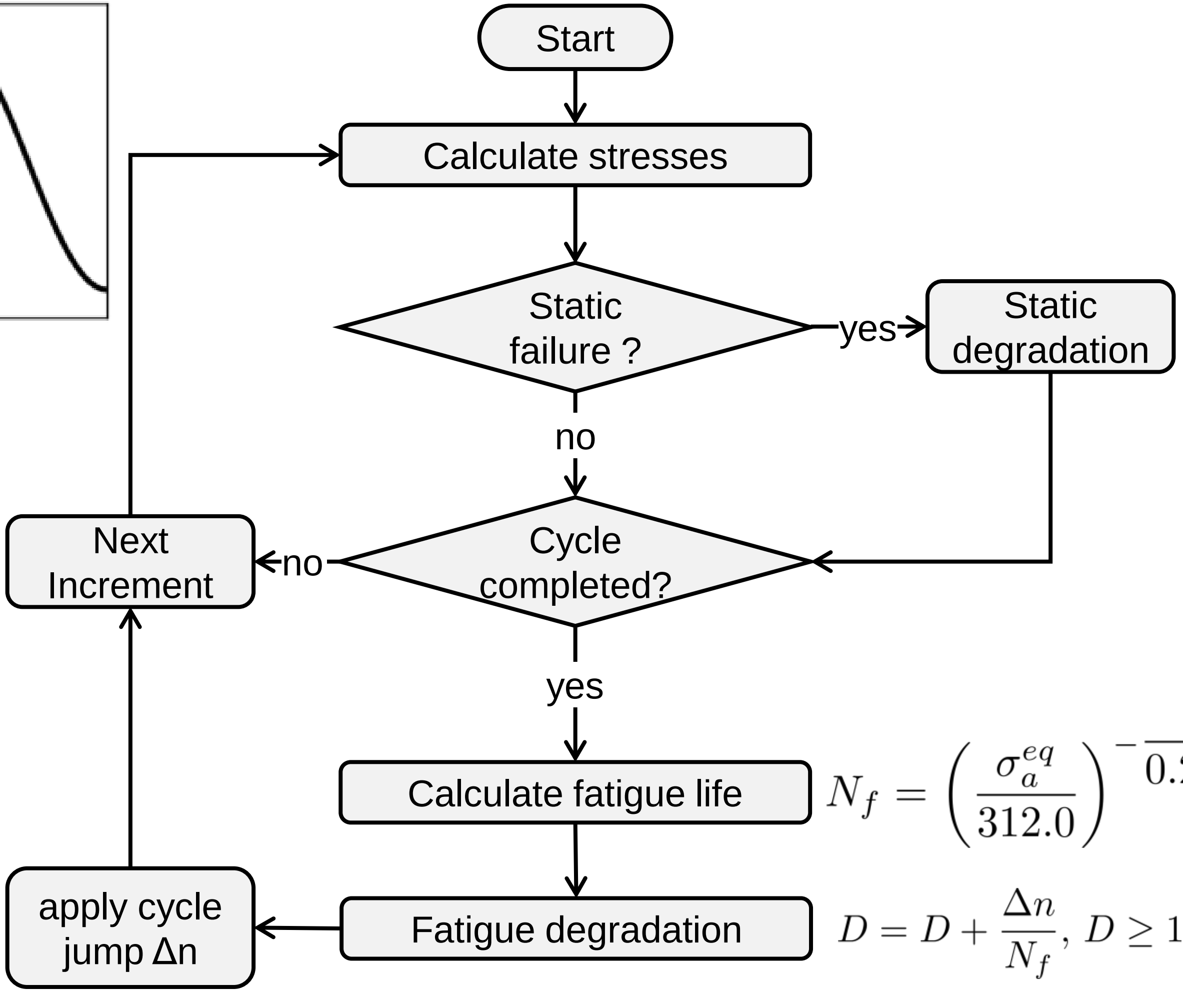
$$X^c = \kappa X^t$$

$$\frac{\sigma_{VM}^2}{X^t X^c} + \left[\frac{1}{X^t} - \frac{1}{X^c}\right] I_1 = f$$

[2] Völkerink, 2022, DOI: 10.57676/hya4-2a09
[6] Tao et. al., 2009, DOI: 10.1016/j.ijfatigue.2008.03.025

Modelling framework





$$f = \frac{\sigma_{VM}^2}{X^t X^c} + \left[\frac{1}{X^t} - \frac{1}{X^c}\right] I_1$$

$$f \geq 1 \longrightarrow E \approx 0$$

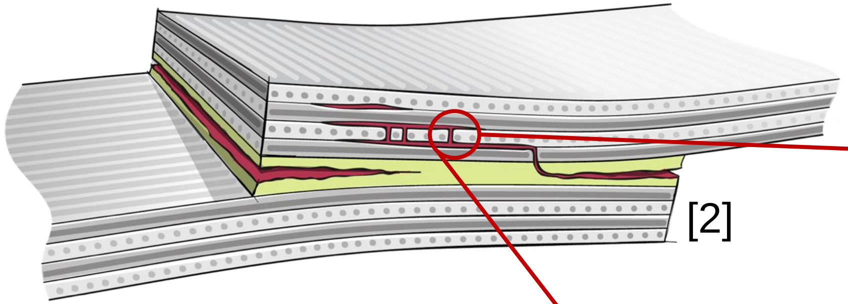
$$N_f = \left(\frac{\sigma_a^{eq}}{312.0}\right)^{-\frac{1}{0.251}}$$

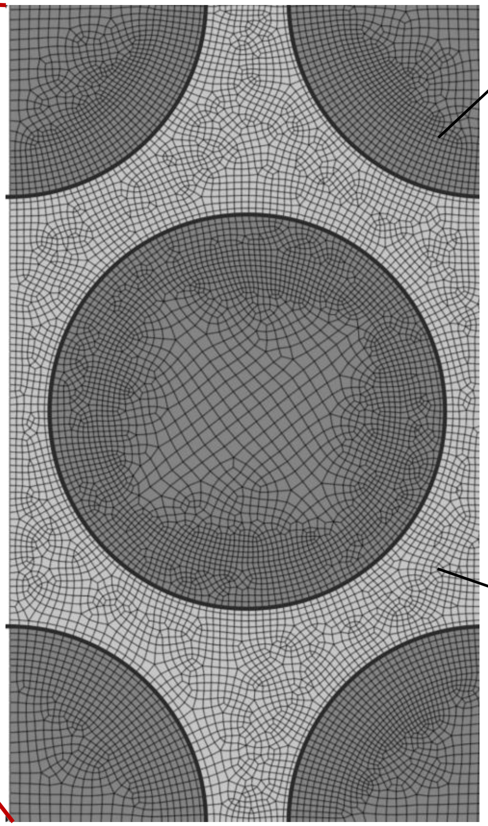
$$D = D + \frac{\Delta n}{N_f},\ D \geq 1 \longrightarrow E \approx 0$$

Implemented in open source code MCODAC

[7] Palmgren 1924; Miner 1945.

Predicting FRP* fatigue behavior
Representative Volume Element (RVE)

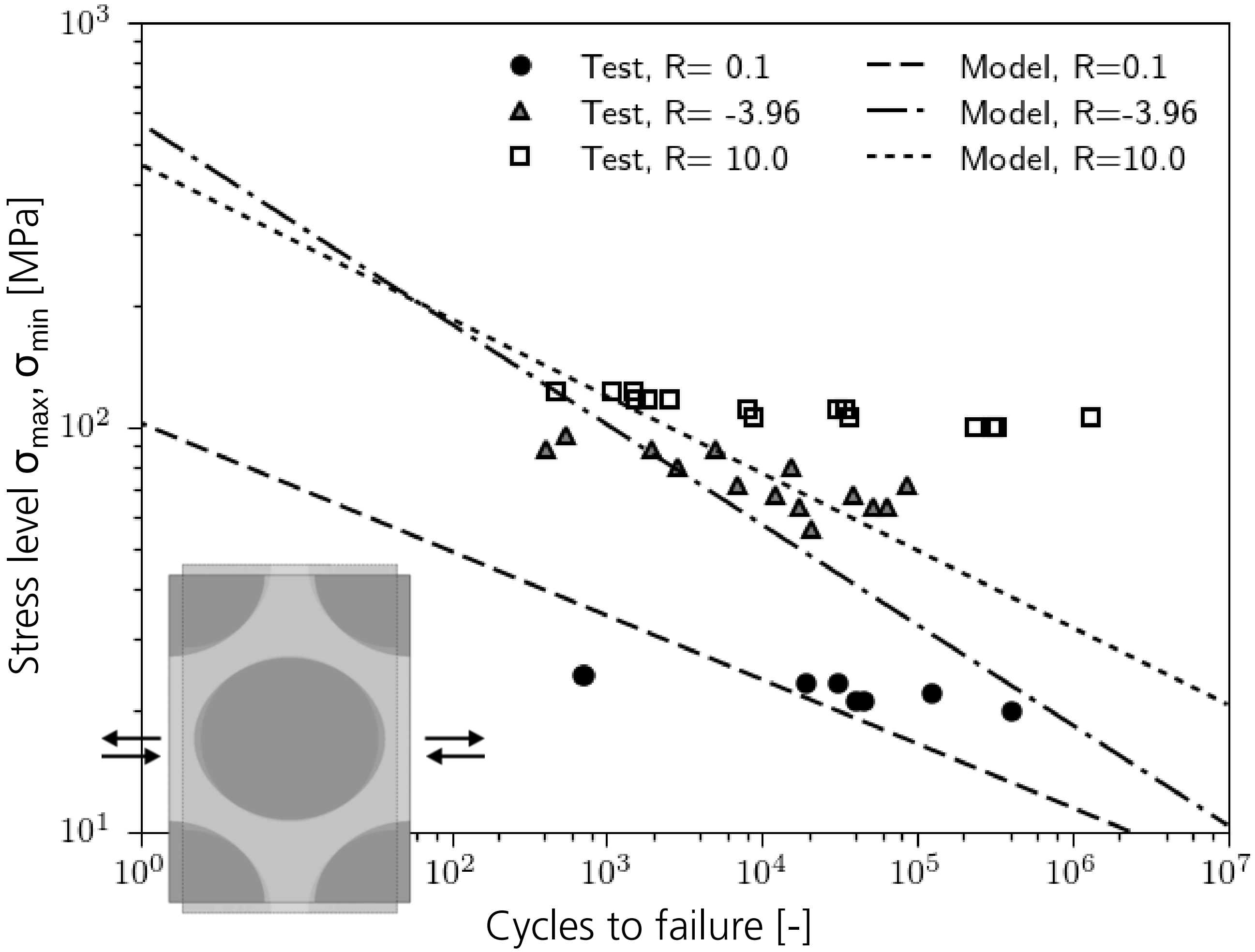


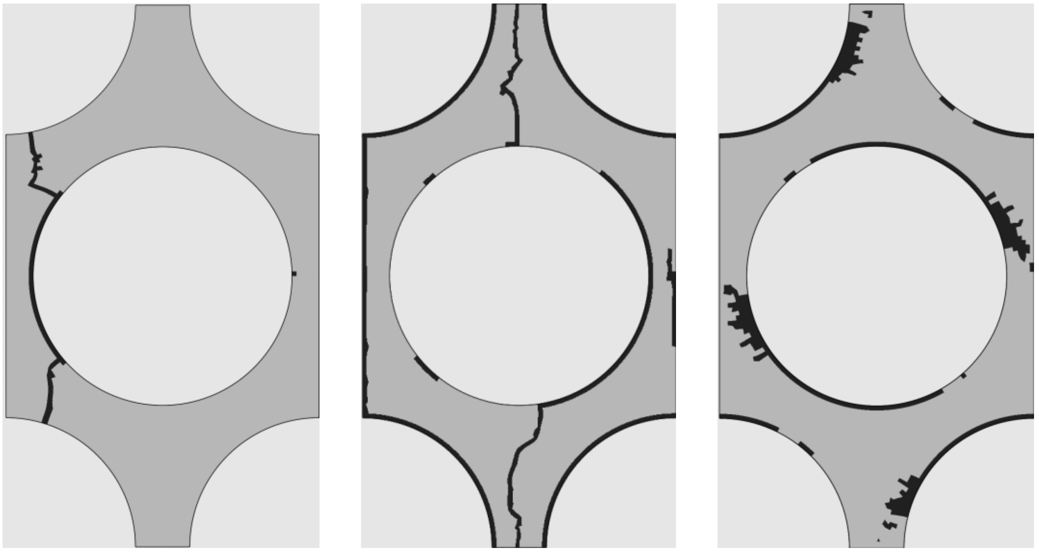


[2] Völkerink, 2022
DOI: 10.57676/hya4-2a09

FRP – Fiber reinforced plastic

Predicting FRP* fatigue behavior
Transverse loading





R=0.1 R=-3.96 R=10

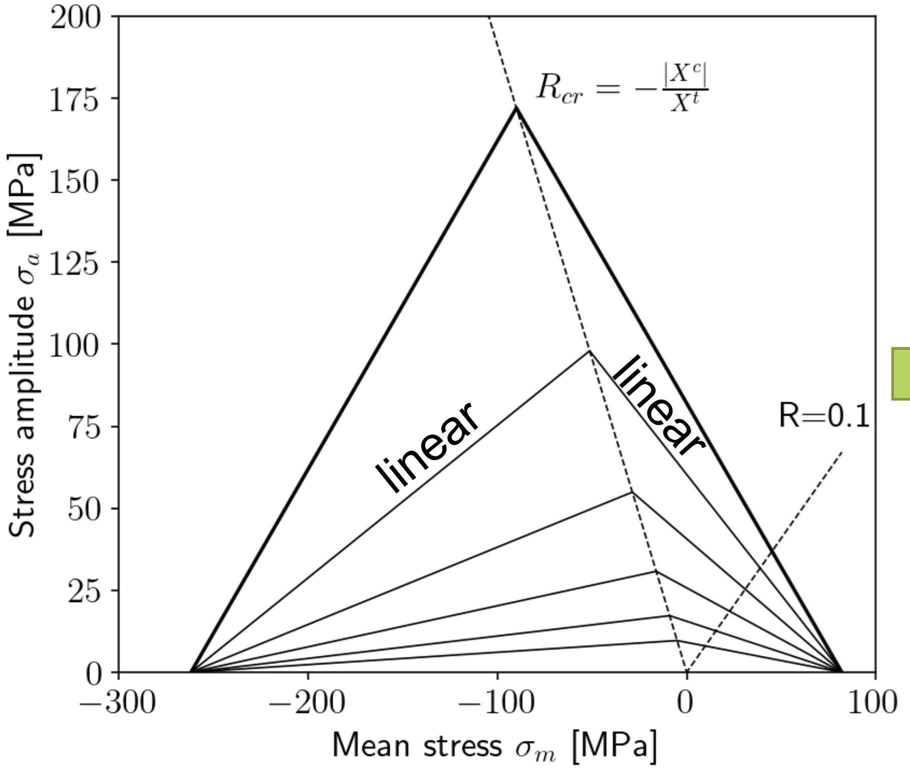
Mean stress sensitivity qualitatively captured.

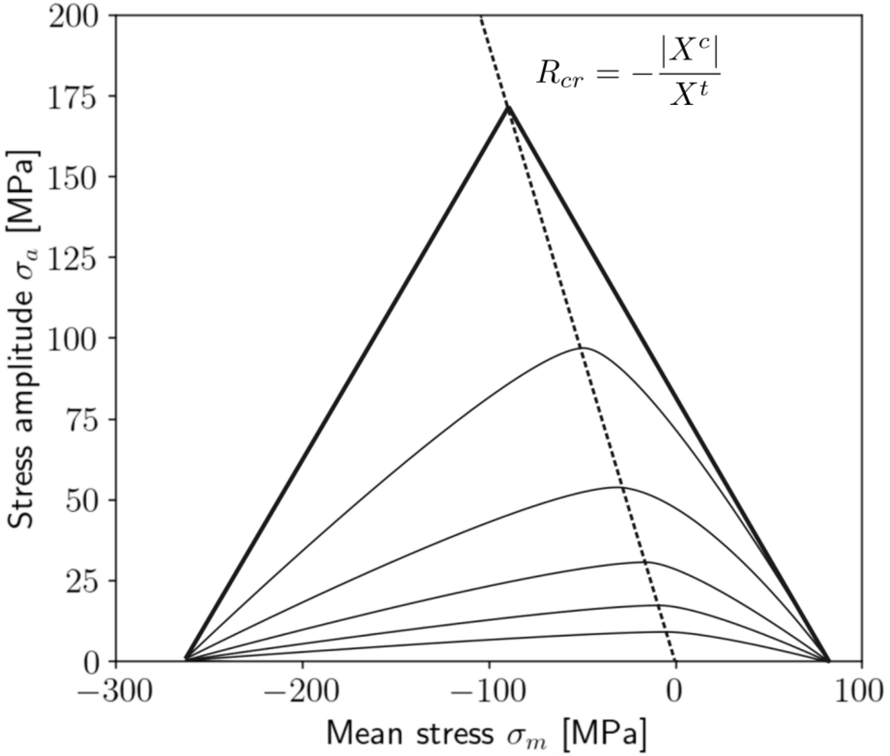
Fatigue strength underestimated in regime of higher cycles.

FRP – Fiber reinforced plastic

Challenges of stress-based fatigue modelling

Mean stress sensitivity





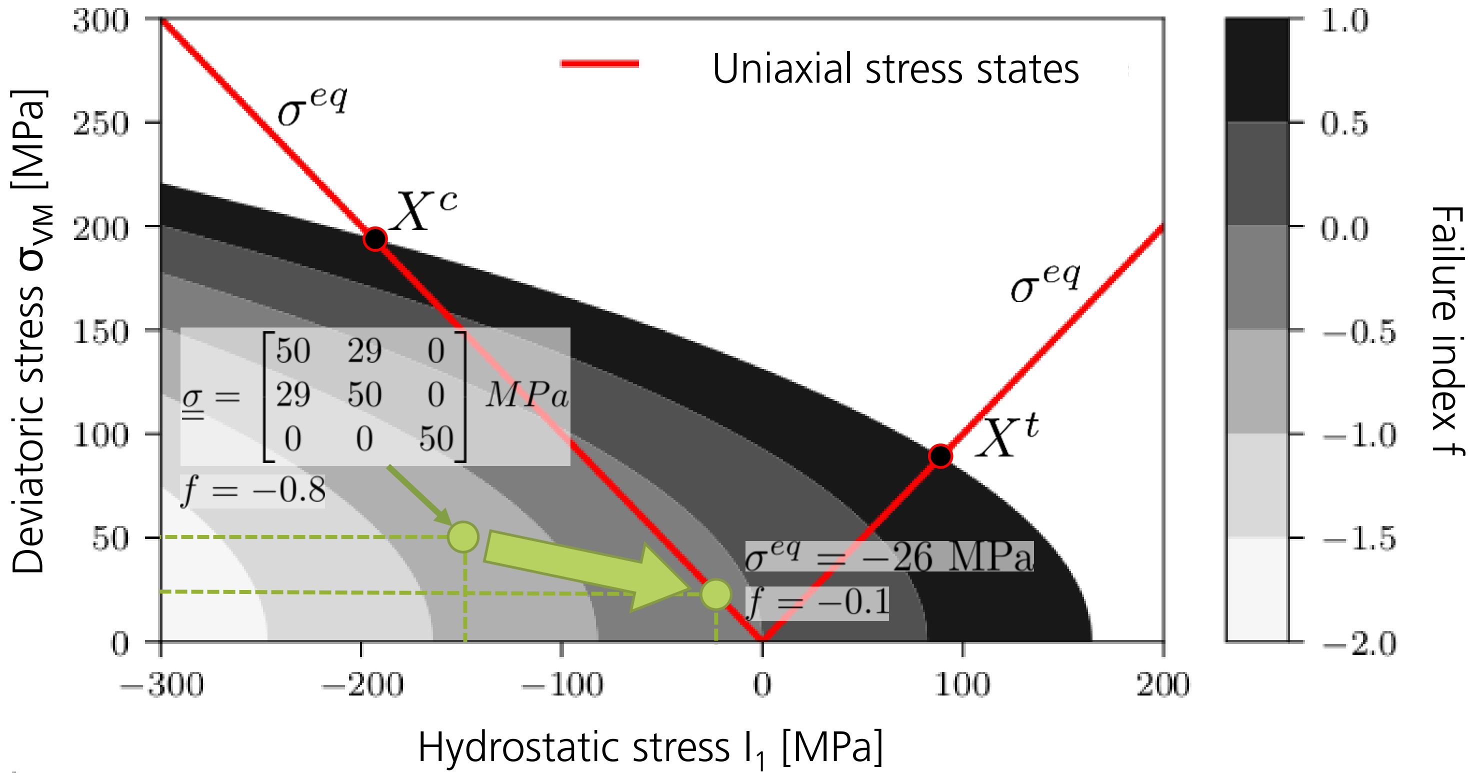
Fatigue strength underestimated at higher number of cycles [5]

→ SN curve for R_{cr} needed

[5] Kawai et. al., 2007, 10.1016/j.compositesa.2007.01.016

Challenges of stress-based fatigue modelling

Equivalent uniaxial stresses



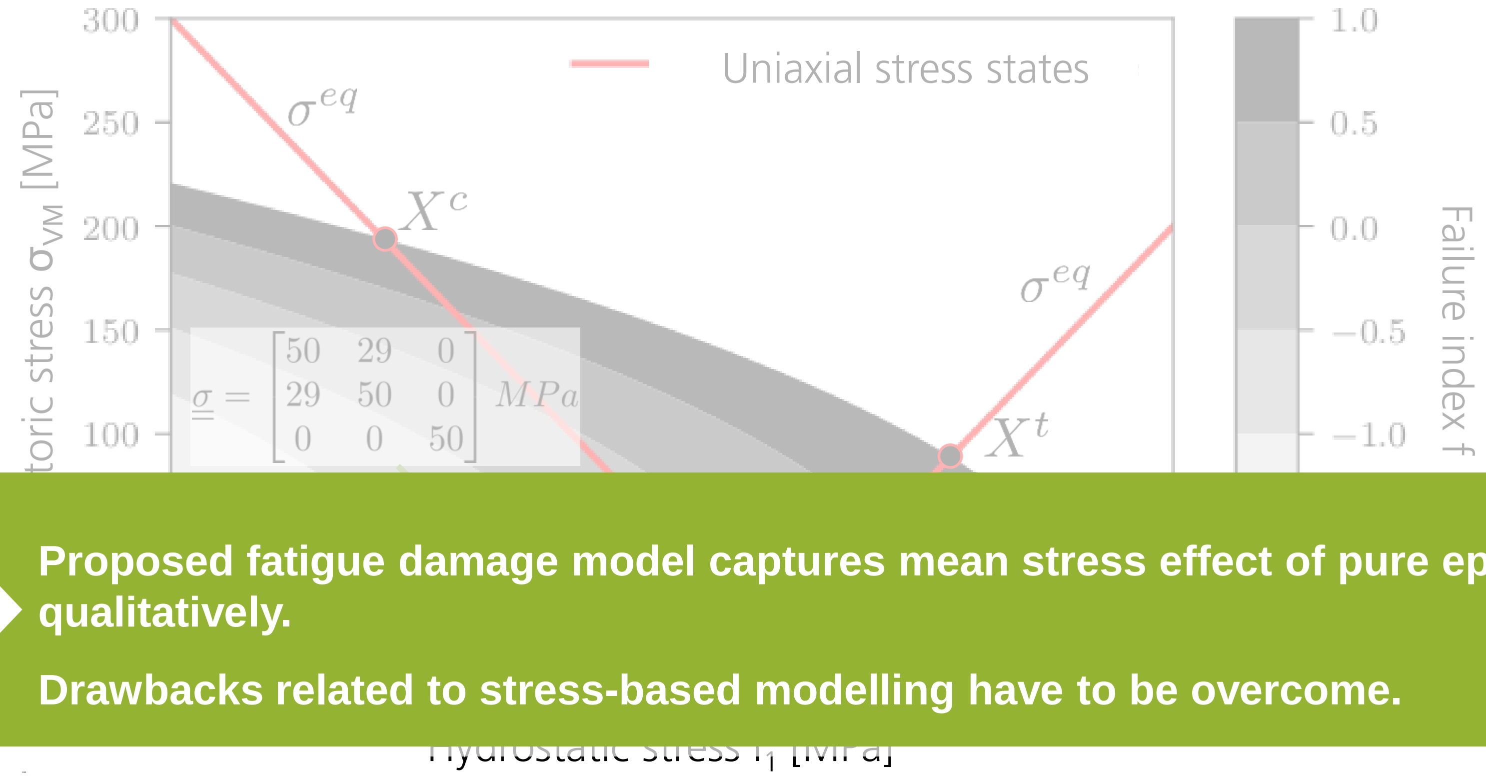
[4]

$$f = \frac{\sigma_{VM}^2}{X^t X^c} + \left[\frac{1}{X^t} - \frac{1}{X^c}\right] I_1$$

[4] Stassi-D'Alia,1967. DOI: 10.1007/BF02128173

Conclusion

Equivalent uniaxial stresses



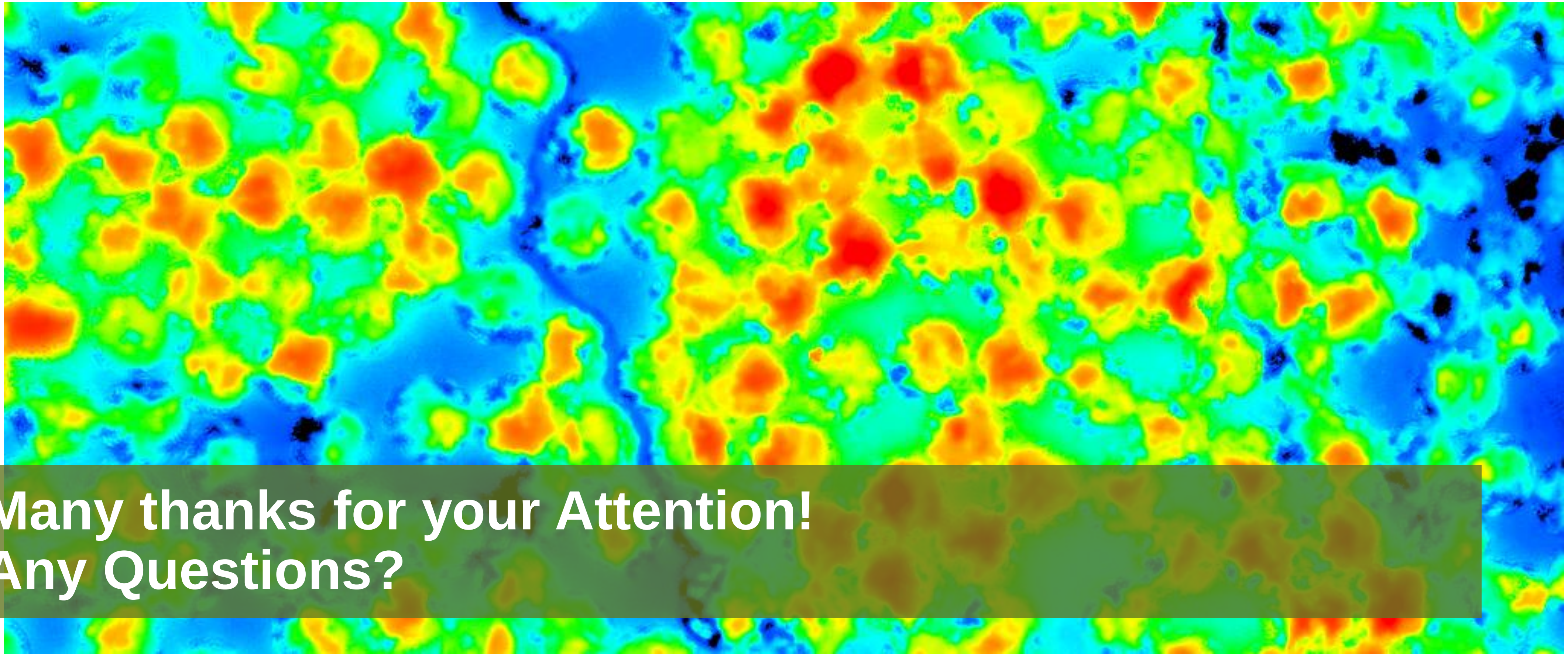
[4]

$$f = \frac{\sigma_{VM}^2}{X^t X^c} + \left[\frac{1}{X^t} - \frac{1}{X^c}\right] I_1$$

Proposed fatigue damage model captures mean stress effect of pure epoxy and epoxy composites qualitatively.

Drawbacks related to stress-based modelling have to be overcome.

[4] Stassi-D'Alia,1967. DOI: 10.1007/BF02128173



Many thanks for your Attention!
Any Questions?

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publications

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