TECHNISCHE UNIVERSITÄT DRESDEN

DRESDEN concept

Faculty of Mechanical Science and Engineering, "Friedrich List" Faculty of Transport and Traffic Sciences

Discussions on the influence of residual stresses to the fatigue of layered polymer composites

Institute of Lightweight Engineering and Polymer Technology (ILK)

ISMEM2017 – Lyngby, 9th November 2017

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Project details

Deutsche Forschungsgemeinschaft

"Evaluation and modelling of the fatigue damage behaviour of polymer composites at reversed cyclic loading"

Objectives

- Analysis of damage behaviour of CFRP under tension and compression on fibre-matrix-, ply- and laminate-level
- Experimental and numerical characterisation of tension-compression asymmetry
- Influence of tension-induced delaminations on compression behaviour
- Mathematical description of the effects of load reversal, block sequence and block length on the damage process
- Extension of existing FEM damage model

Institut für Leichtbau und Kunststofftechnik

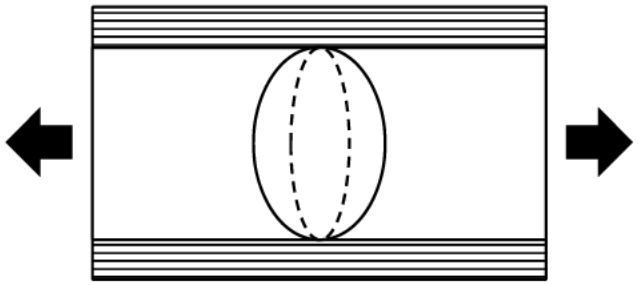
ISD INSTITUT FÜR STATIK UND DYNAMIK

TUHH POLYMER COMPOSITES

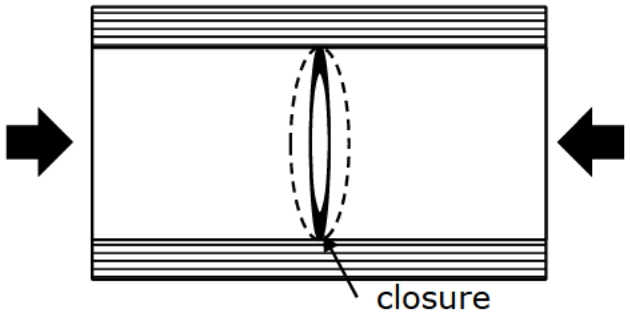
INSTITUT FÜR KUNSTSTOFFVERARBEITUNG IN INDUSTRIE UND HANDWERK AN DER RWTH AACHEN

Objectives of the presented work

- Understanding crack opening due to residual stresses
  - Controllable model environment (cross ply laminate)
  - Measuring residual stresses from COD
- Measurement of local strain field between adjacent cracks
  - Estimation of crack opening from strain measurements
  - Influence of load reversal on deformation behaviour



Crack opening by tension loads



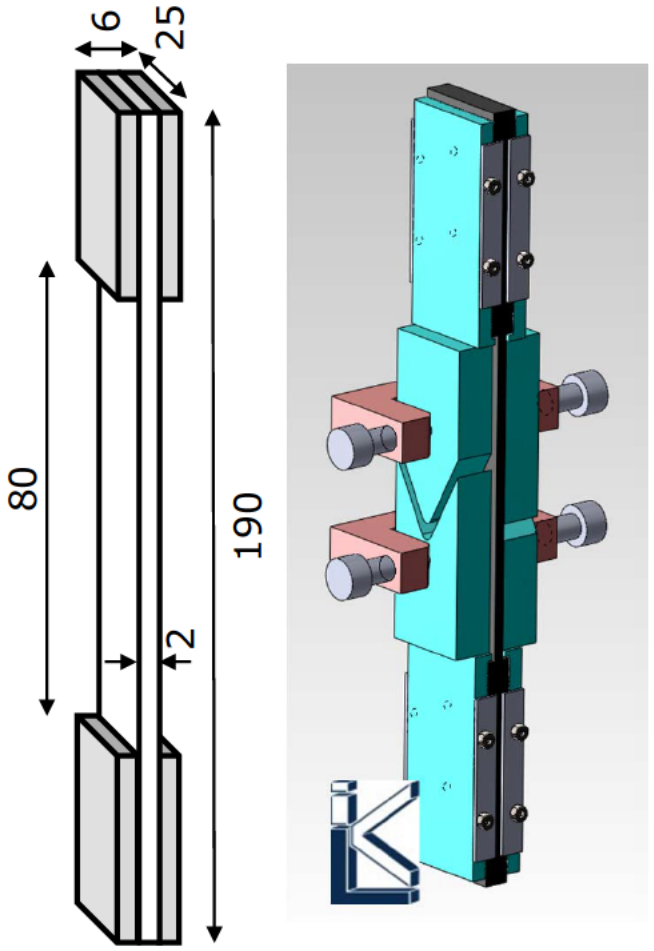
Partial crack closing by compression loads

Materials

- Fibre: T700SC carbon fibre (6k)
- Resin: Araldite LY556/HY917/DY070
- Lay-up: $[0_2/90_7/0_2]$
- Process: Filament winding + RTM
- Specimen geometry:
  - 190 x 25 x 2 mm (L x W x H)
  - 2 mm aluminium end tabs, extensometer
  - Ply thickness $t_{nom} = 0.181\ \text{mm}$

Elastic properties			
	Mean	Std. dev.	Units
E_{11}	129430	5445	MPa
E_{22}	8049	437	MPa
E_{33}	8049	437	MPa
v_{12}	0.317	0.00763	-
v_{13}	0.317	0.00763	-
v_{23}	0.41	-	-
G_{12}	3916	194.05	MPa
G_{13}	3916	194.05	MPa
G_{23}	2854	154.96	MPa

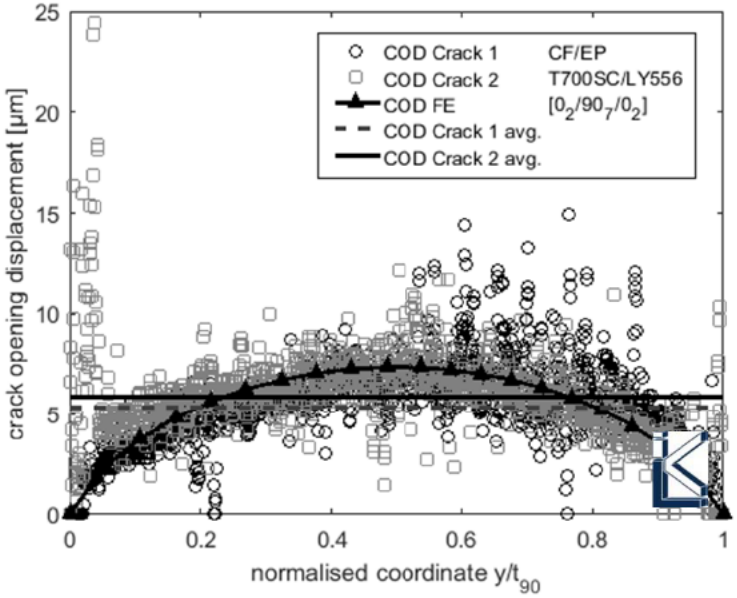
Strength Properties			
	Mean	Std. dev.	Units
$R_p^{(+)}$	2089	53	MPa
$R_p^{(-)}$	1032	221	MPa
$R_s^{(+)}$	36.2	5.3	MPa
$R_s^{(-)}$	164.4	7.9	MPa
R_{ps}	52.2	5.4	MPa



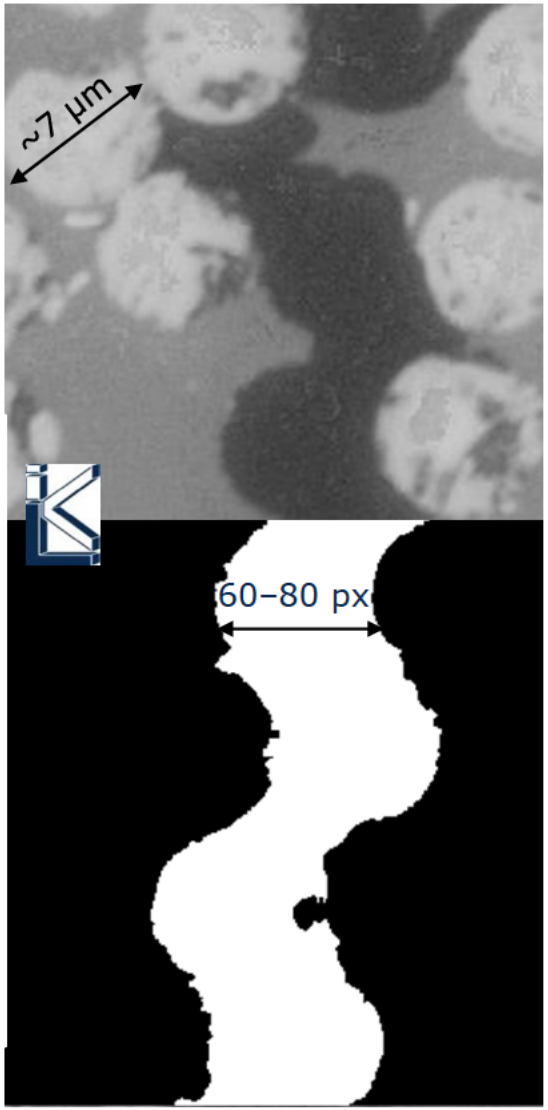
Specimen geometry and anti-buckling device

Residual crack opening

- Two non-interacting cracks after cyclic loading
  - $R = -1,\ \sigma_o^{lam} = 95\ \text{MPa},\ n = 5000\ \text{cycles}$
- High resolution microscopic images
  - 500-fold, z-stacking, BW-conversion, 60 – 80 pixels between crack faces
  - Row wise summation of white pixels, calibration
- Comparison to FE-results for calculating residual stresses

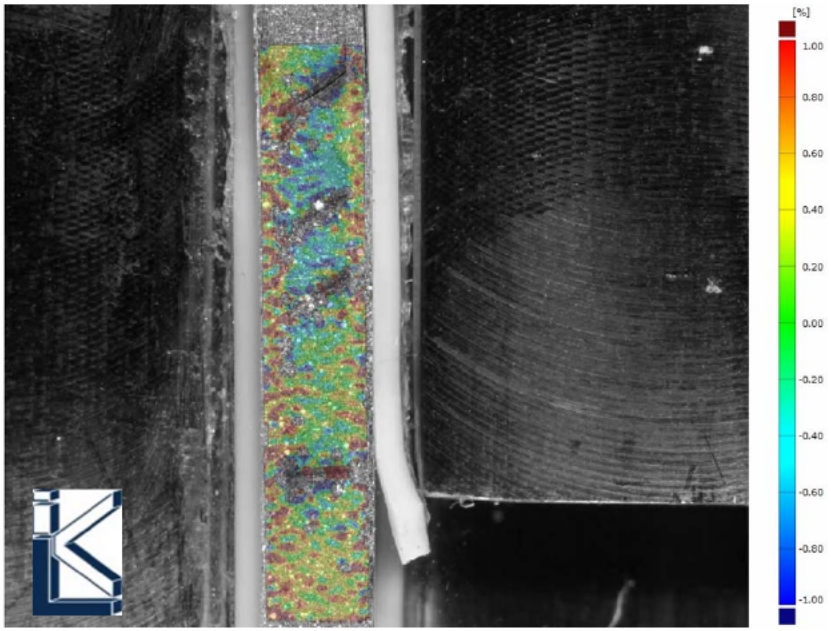


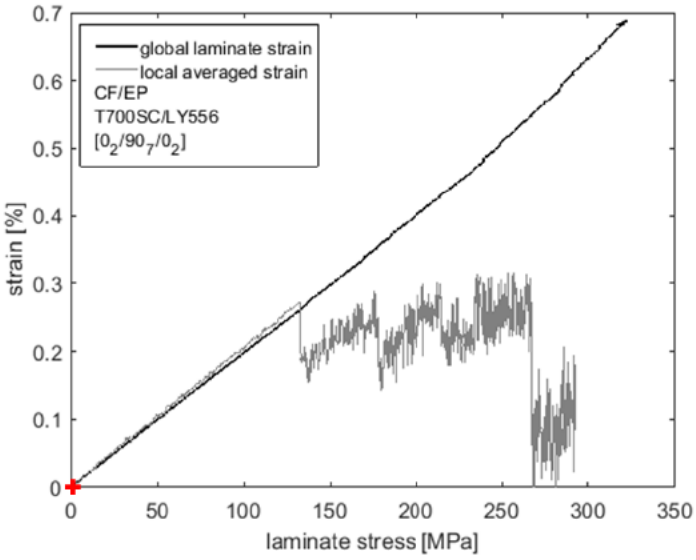
$\sigma_{res,2}^{90} = 25.7\ \text{MPa}\ @\ \Delta T = 110\ K$



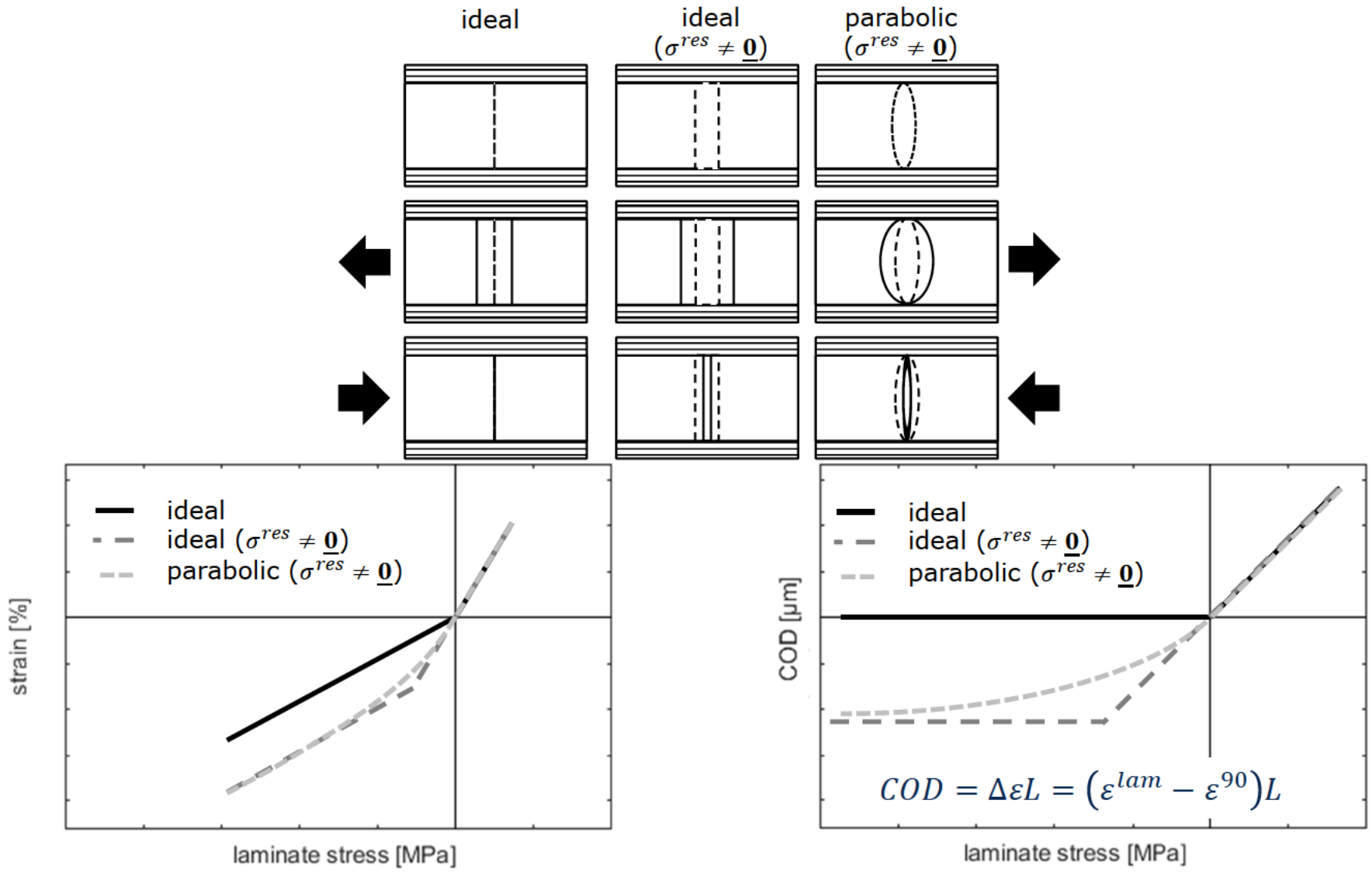
Analysis of local strain field

1. Yielding transverse cracks by static tension load
   - Relaxation of strains in 90°-ply
   - Cracks form where strains are recovered
2. Cracked specimen loaded in tension and compression
   - $R = \{0; -1; -2.66\}$
   - $\sigma_o = 95\ \mathrm{MPa}$



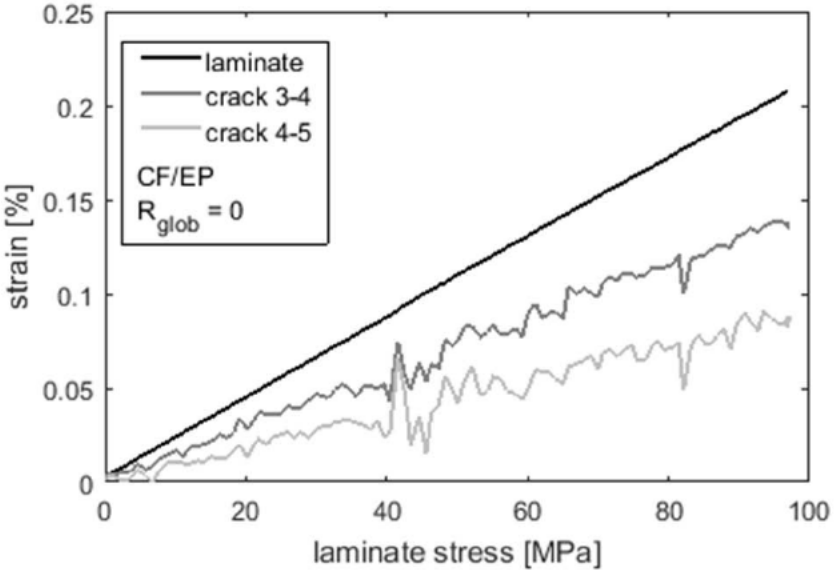


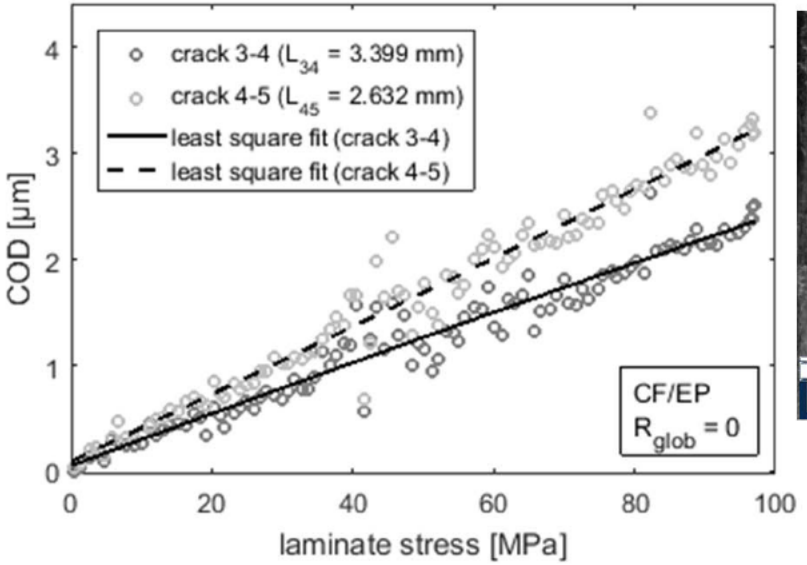
Estimations for load reversals

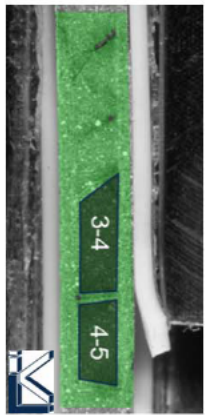


COD under load reversal

Tension-tension ($R = 0, \sigma_o = 95$ MPa)



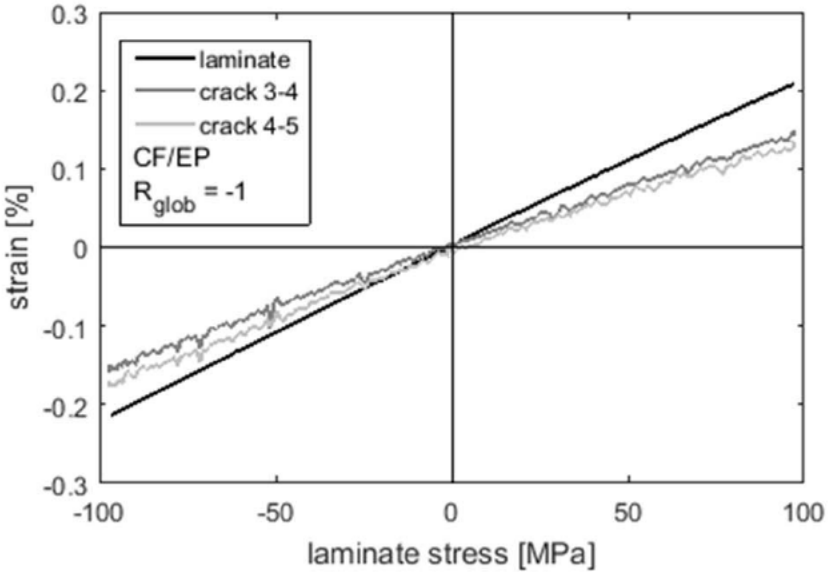


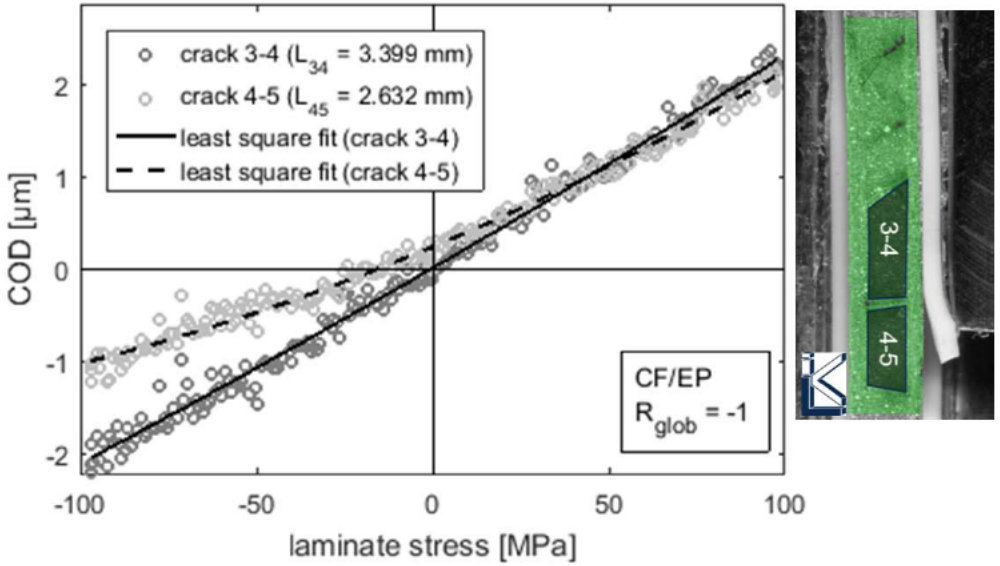


$$COD = \Delta\varepsilon L = \left(\varepsilon^{lam} - \varepsilon^{90}\right)L$$

COD under load reversal

Tension-compression $(R = -1, \sigma_o = 95\ \text{MPa})$

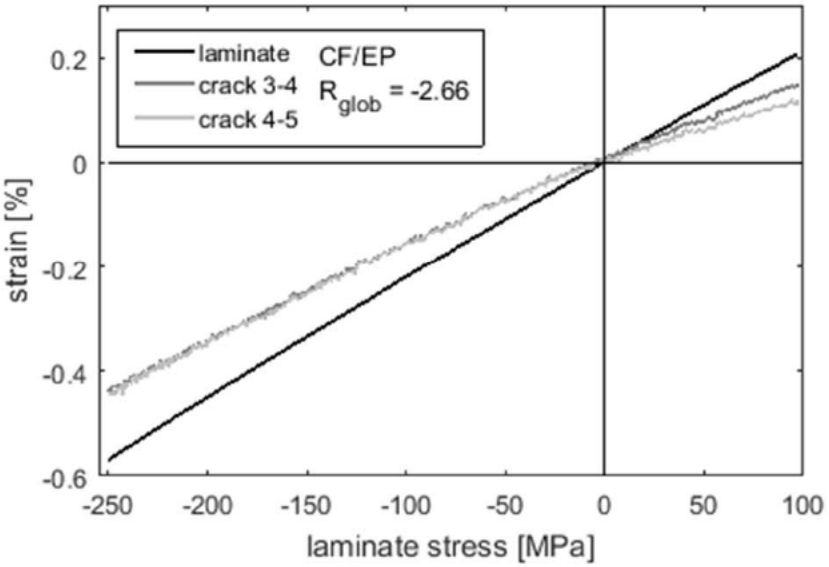


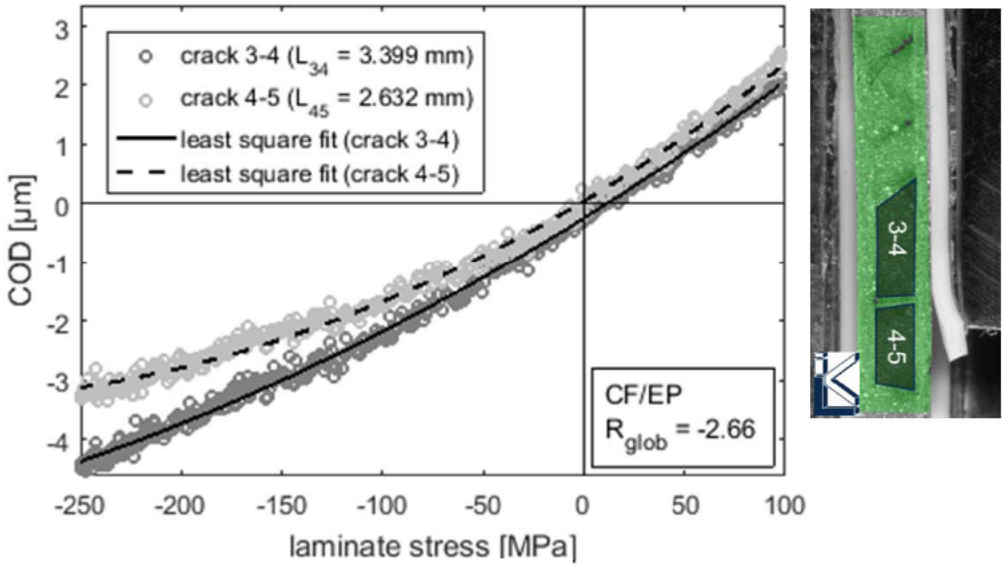


$$COD = \Delta\varepsilon L = \left(\varepsilon^{lam} - \varepsilon^{90}\right)L$$

COD under load reversal

Tension-compression $(R = -2{,}66, \sigma_o = 95\ \text{MPa})$





$$COD = \Delta\varepsilon L = \left(\varepsilon^{lam} - \varepsilon^{90}\right)L$$

Conclusion

- Transverse cracks remain open in case of residual tension stresses
- Layerwise residual stress evaluation possible
- Cracks open under tension and close gradually under compression
  → source for nonlinearities and local change of stress ratio
- Comprehensive fatigue modelling strategies should consider:
  - Residual stress state
  - Physical damage behaviour (cracking, delamination)
  - Damage dependent tension-compression asymmetry

Outlook

- Comprehensive understanding of stress-strain-hysteresis
- Quantification of stress ratio effects and incorporation to existing FE-based damage models