# Strength and Mechanical Behavior of Half Cells within the Module

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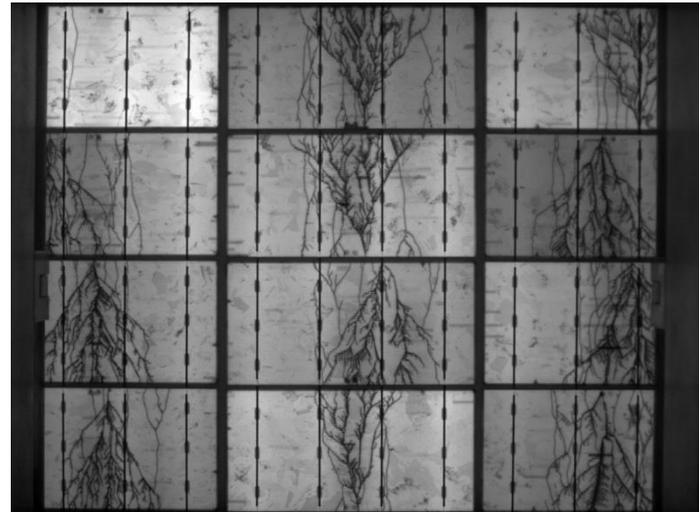
Motivation

- Cell strength of half cells

  - Laser cutting process:
    → additional defects to cell edge
    → reduction of characteristic fracture strength

  - Thermal laser separation (TLS) process:
    → no significant strength reduction compared to standard cells

- Questions:

  - What is the strength of half cells inside the module?

 - Are the cell breakage results transferable to module?

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Experimental Setup

- 4-point bending test on module laminates

- EL camera for characterisation of cell breakage and fracture origin
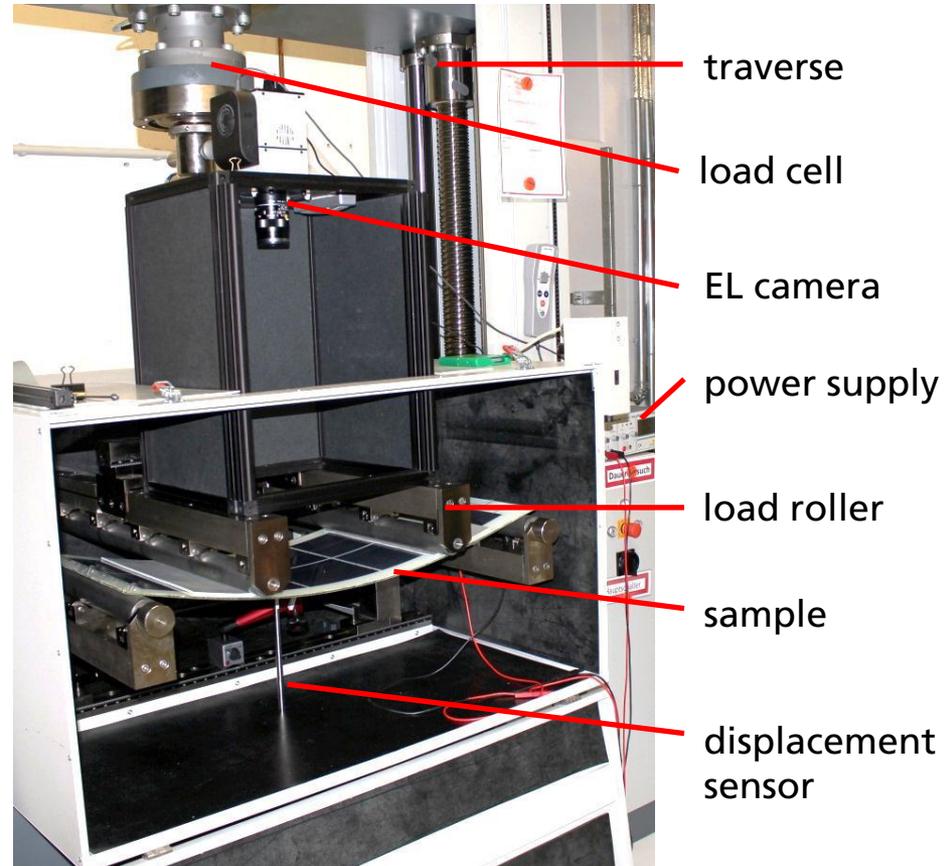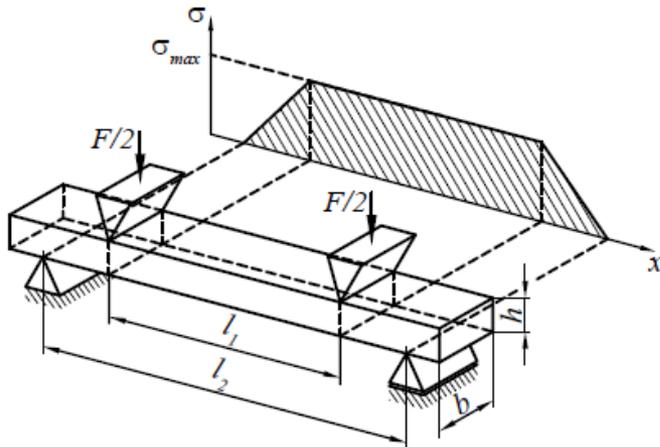
Experimental Setup

- Load setup:
  - cutting edges parallel to tensile stress in the laminate
- Samples:
  - 6 laminates with 6 standard cells
    → 36 standard cells
  - 3 laminates with 12 half cells
    → 36 half cells (Laser Cut)
  - 3 laminates with 12 half cells
   → 36 half cells (TLS)
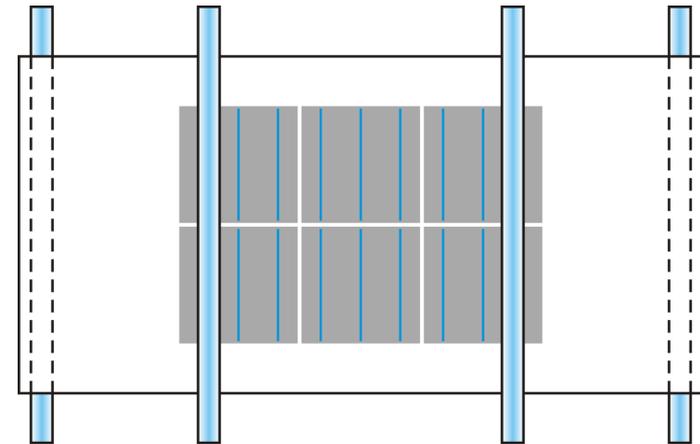
standard full cells
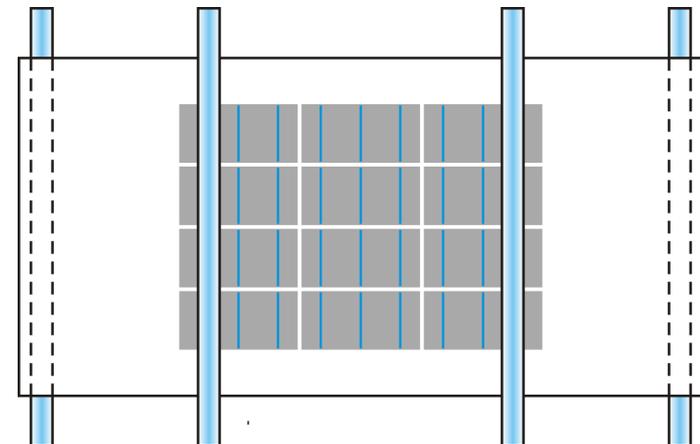
half cells (Laser cut or TLS)

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Experimental Approach
Mechanical loading

Test setup   **Test procedure**   **Evaluation**

Fracture force   Crack origin   Statistics (Weibull)
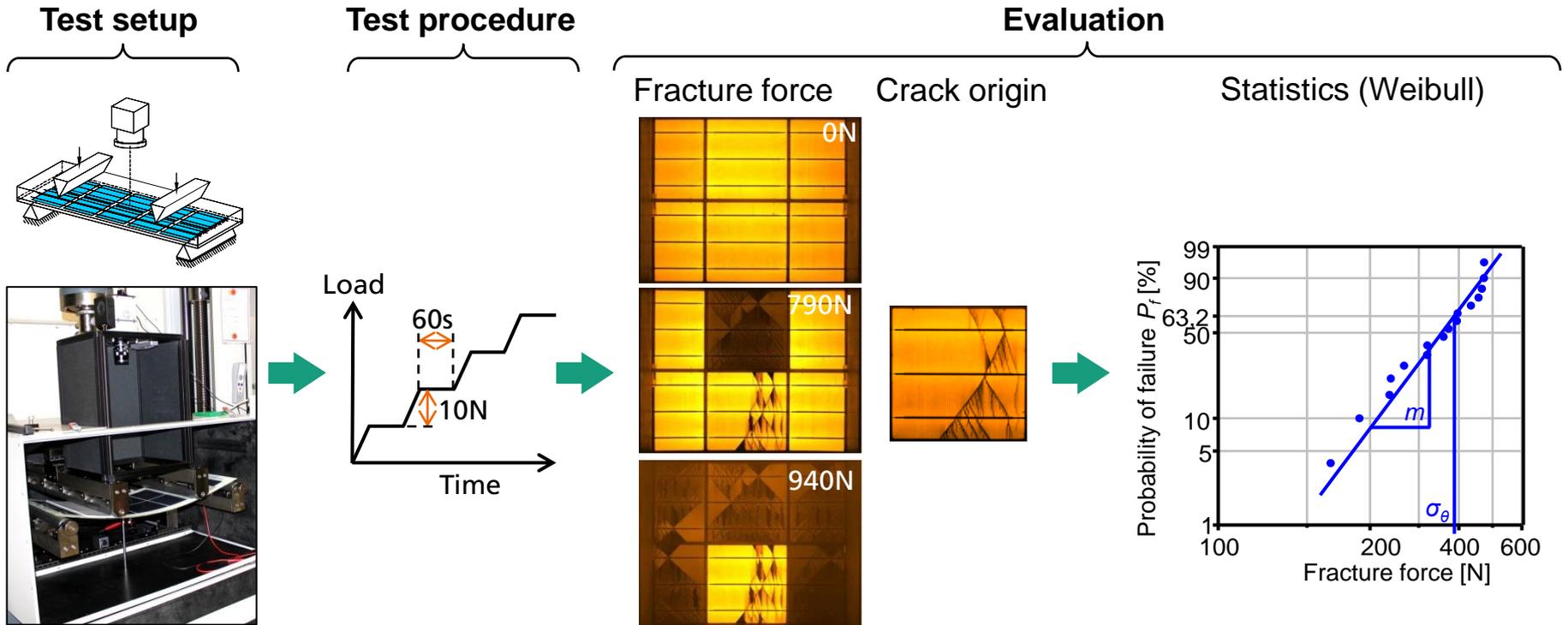
- Statistical evaluation of crack occurrences

- Implementation of Weibull distribution $P_f(\sigma) = 1 - e^{-\left(\frac{\sigma}{\sigma_\theta}\right)^m}$

- Determination of characteristic stress σ_θ and Weibull modulus m

M. Sander *et al.*; Solar Energy Materials & Solar Cells *111 (2013)*

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Examples for test evaluation – Standard Cell

□ Fracture on surface or near busbar

○ Fracture at pre-existing defect (crack)
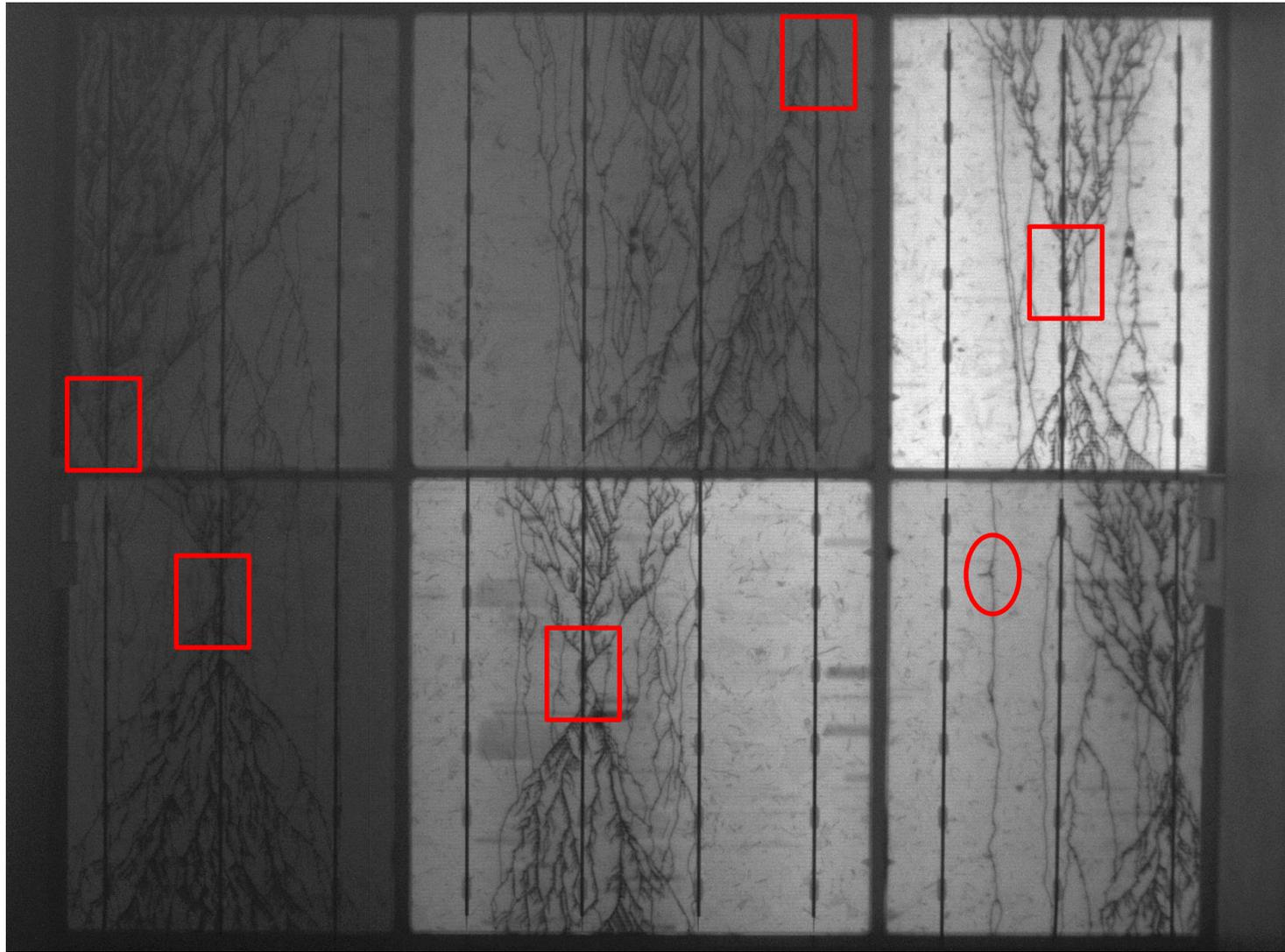
△ Fracture from edge

B1_P04
Standard Cell

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Examples for test evaluation – Laser Cut

☐ Fracture on surface or near busbar

◯ Fracture at pre-existing defect (crack)

△ Fracture from edge

B3_P03
Laser Cut

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Examples for test evaluation - TLS

☐ Fracture on surface or near busbar

◯ Fracture at pre-existing defect (crack)

△ Fracture from edge

B2_P01
TLS

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Examples for test evaluation - TLS

Fracture on surface or near busbar

Fracture at pre-existing defect (crack)

Fracture from edge

B2_P01
TLS

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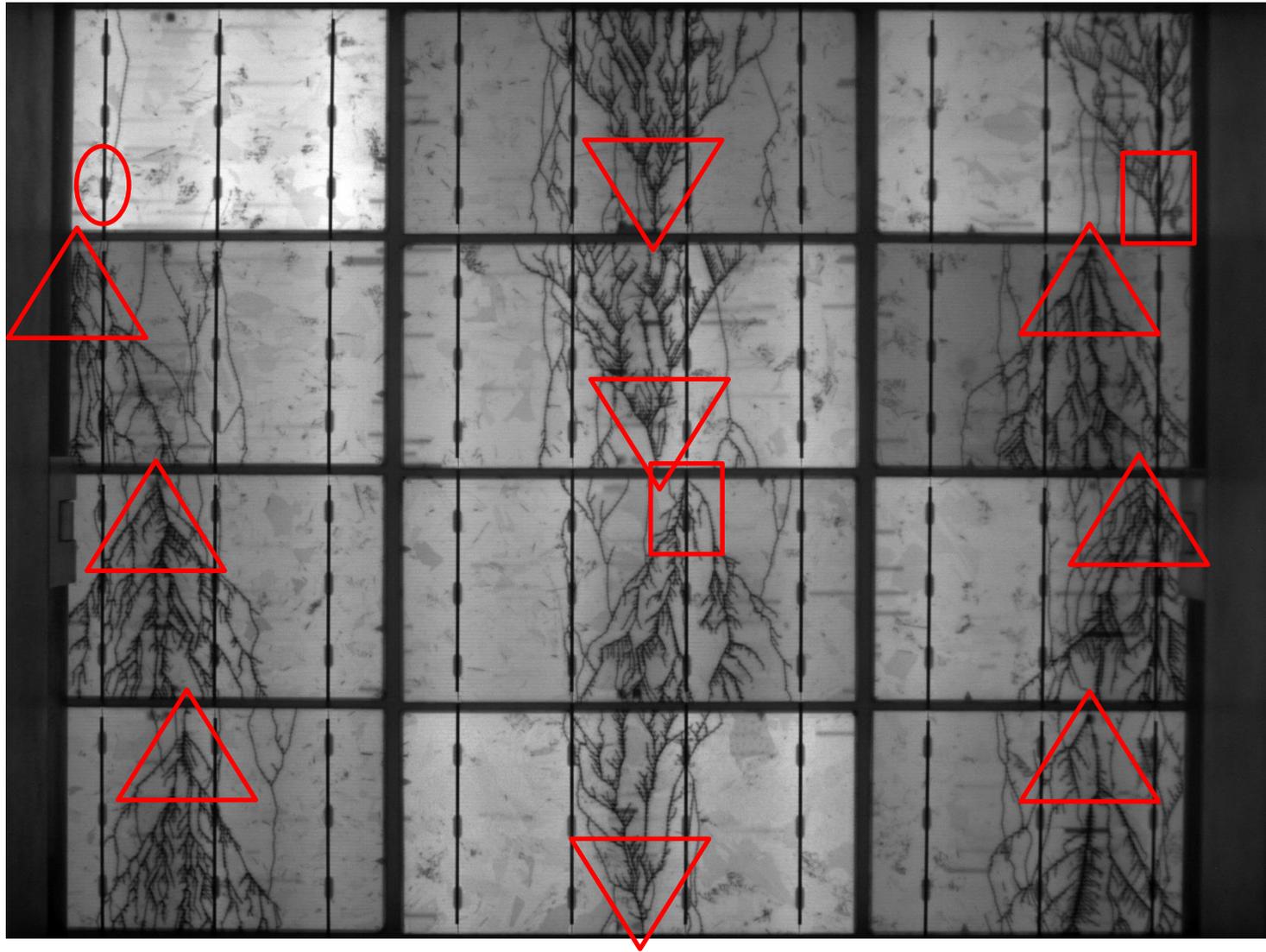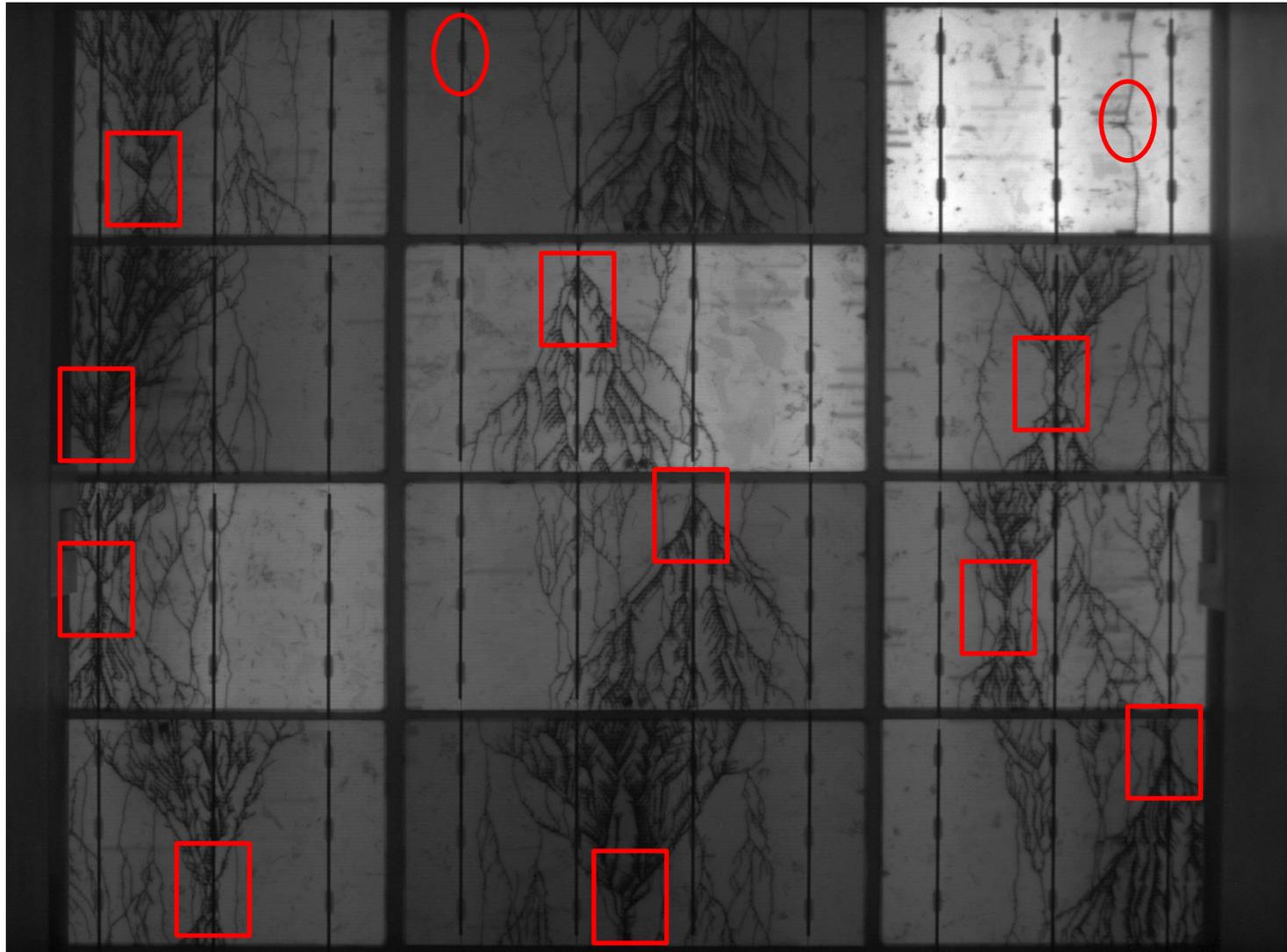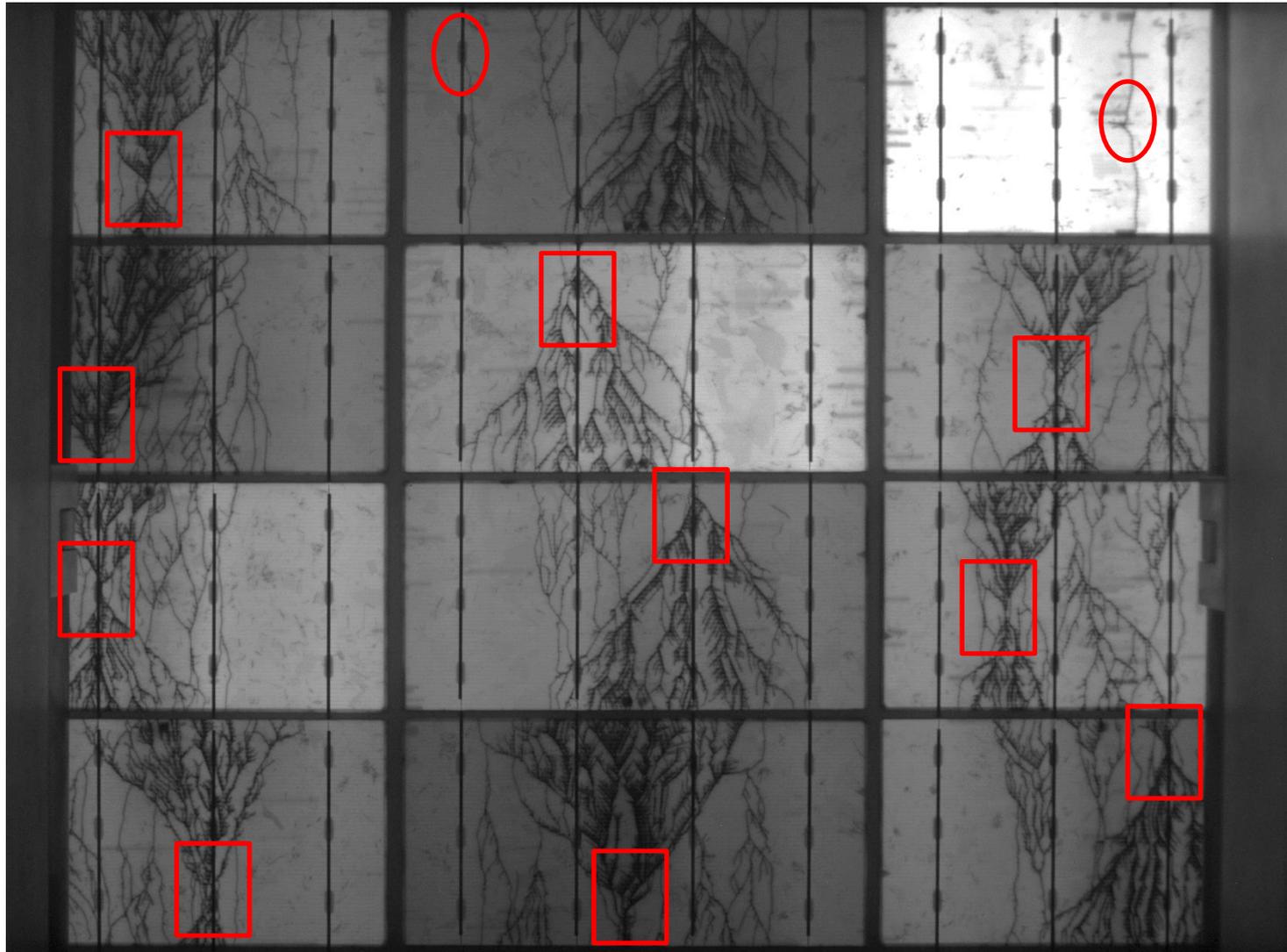
Preliminary Result

- Loading during production (wafer cutting, soldering and lamination) introduce specific defects
  → pre-cracks near the busbars or on cell surface
  → decrease cell strength for all batches

- Standard cells and TLS half cells: show fracture origin on the surface and/or near the busbars

- Laser cut half cells dominated by fracture origin on the laser edge

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Evaluation

- Soldering + lamination process lead to initial defects, which can NOT be traced back to the cell separation process → outliers

- For comparrison of cell separation process → outliers were filtered

- remaining data better suited for Weibull Fit

- Lowest strength for laser cut cells
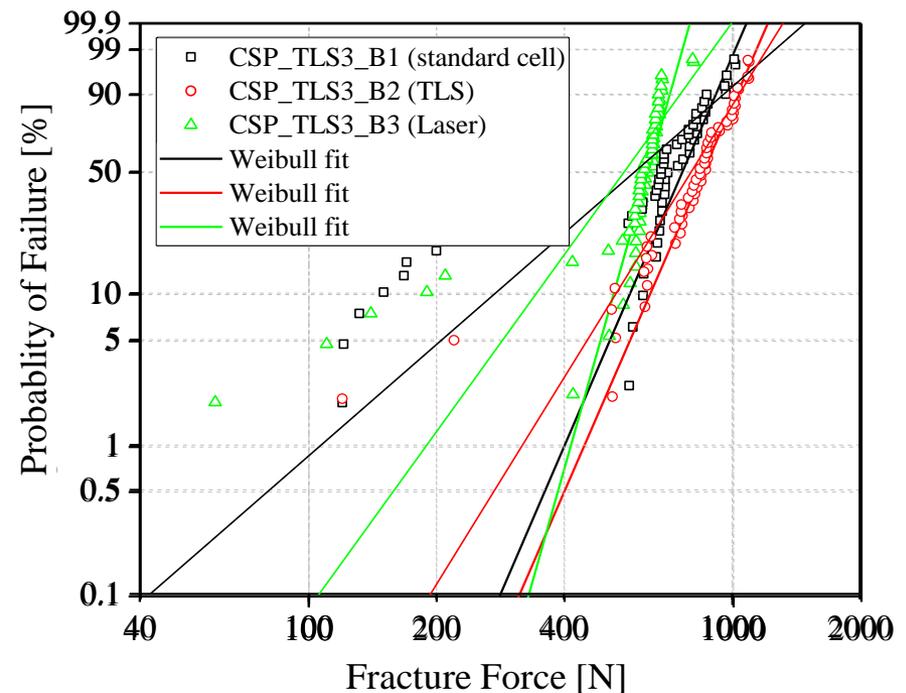
Result evaluation

- Finite element model of quarter of module laminate

- All material layers and properties included

- Evaluation of fracture stress at specific locations

1st principal stress [MPa]

	0
	14.98
	29.97
	44.95
	59.93
	74.92
	89.9
	104.88
	119.87
	134.85
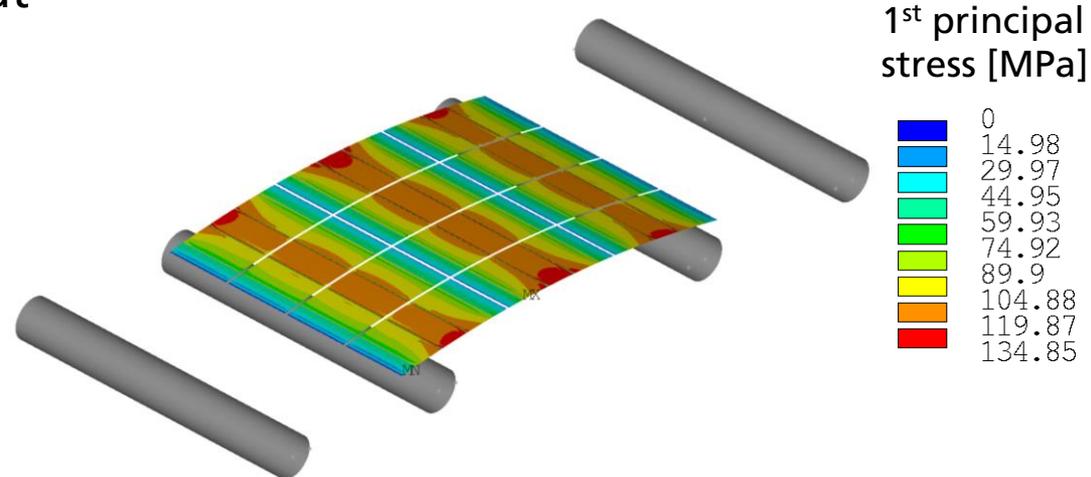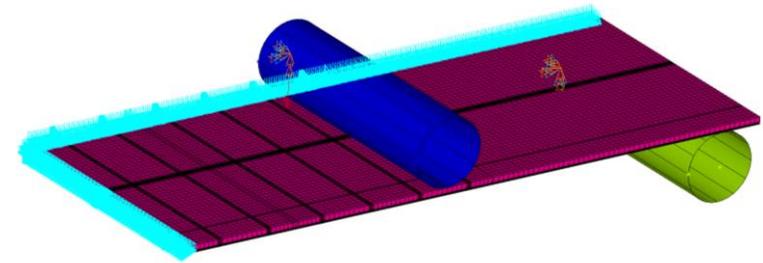
1st principal stress in cells at 1000 N

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Model validation

- Force-deflection curve is well represented by finite element model until failure of cells

- Breakage of cells decreases stiffness of laminate
  → increase in deformation
  (at the same load)

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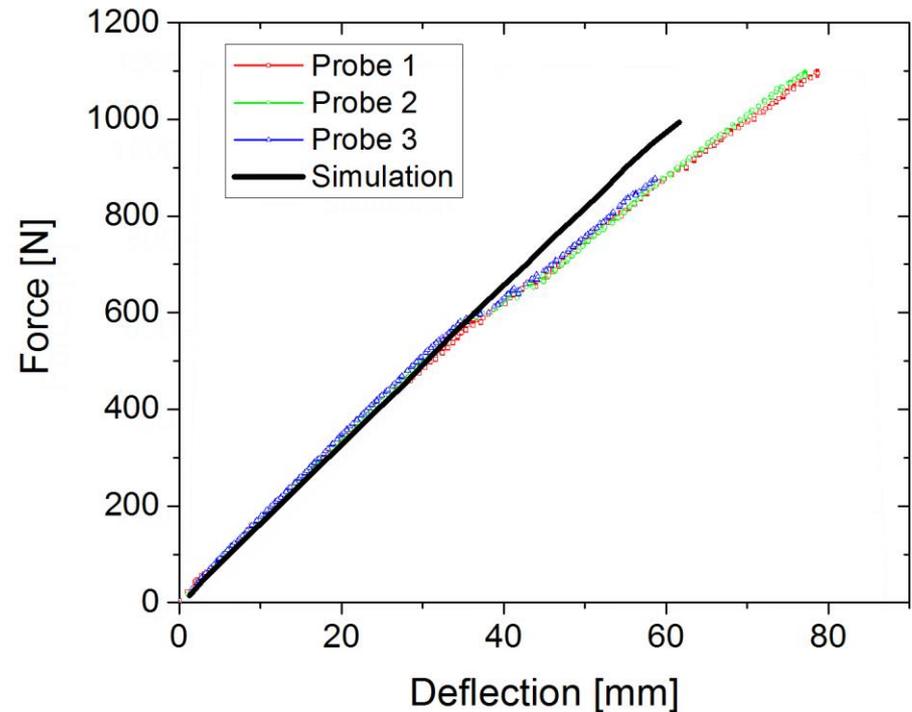
Evaluation – Comparison of strength parameters

- **Characteristic strength:**

 - higher strength for TLS cells
    → both fracture on surface
    → but size effect

  - reduction in strength for laser separated cells

- **Weibull modulus:**

  - TLS and standard cells identical
    → same defect distribution
    → **fracture on surface**

  - Increased modulus for laser separated cells
    → **fracture on laser cut edge**
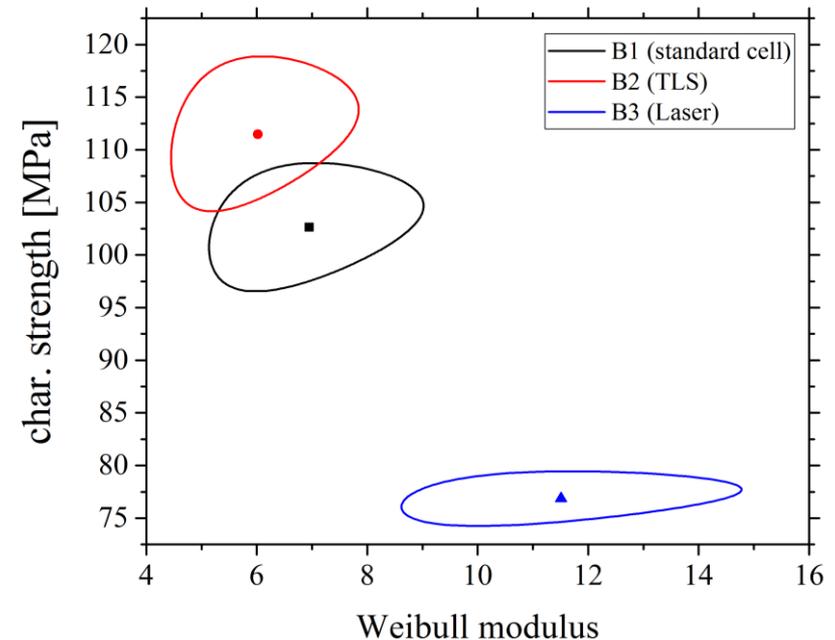
Strength parameters, confidence bounds

Summary

- 4-Point bending with EL: suitable test for measuring the influences of the production process on the cell strength within the laminate

- partially early cell breakage due to large soldering and lamination induced cell cracks → outliers have to be filtered

- Laser cutting: significant reduction in cell strength
  → generation of defects at laser cut edge
  → higher amount of cell breakage within the module

- TLS: slightly improved cell strength → size effect
  → smaller amount of cell breakage under same load

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