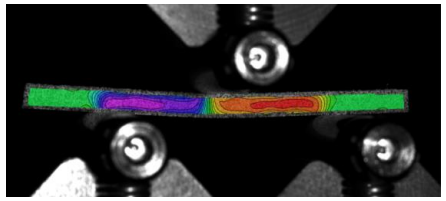
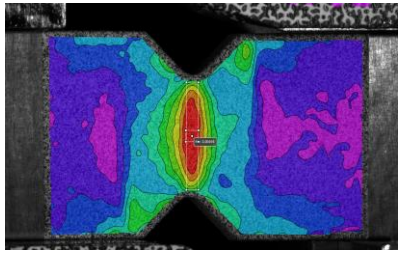
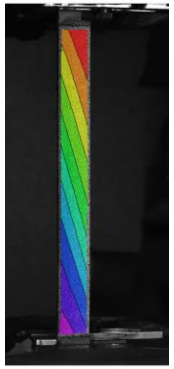
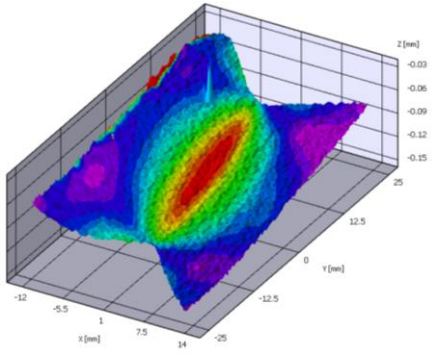
Investigation of the Interlaminar and Intralaminar Shear Properties of FRP using Digital Image Correlation

Dr.-Ing. Matthias Merzkirch, Guest Researcher,
Matthias.Merzkirch@nist.gov

Workshop/Lecture, July 9th-13th, 2018

Center for Automotive Lightweighting (NCAL)

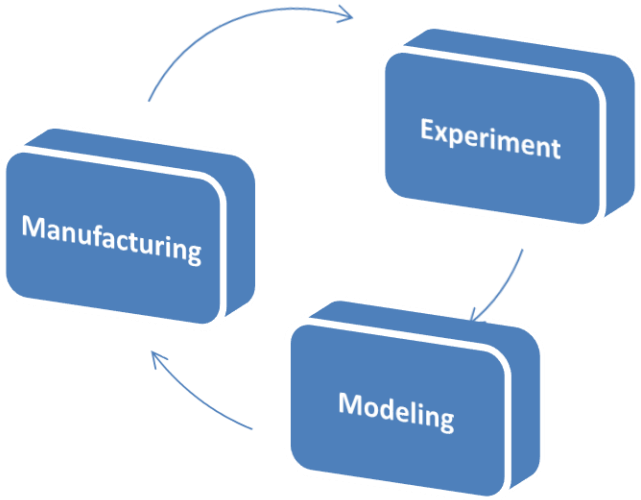






NIST Center for Automotive Lightweighting

Concept & Aims of Workshop/Lecture

- **Interdisciplinary Workshop/Lecture:**
  - 5 days: Monday through Friday
  - Theoretical and experimental parts
  - Handouts in English will be provided (‘fill in the gaps’)
  - Oral presentation in German (or English, if preferred)
- **Theoretical parts (lectures in the morning) (Σ~11 h):**
  - Modeling and manufacturing as motivation (‘Why testing?’)
  - Background/mechanics of experiments (DIC & shear)
  - Types of experiments for shear testing on prototypical UD composites (standardized and non-standardized)
  - Design of experiments (‘Everything is of interest but what/how much data is actually needed?’)
  - Experimental setup (MTS and DIC)
  - Data analysis and reduction
  - Sensitivity analysis (‘3 x same type of test vs. 1 test with 3 different views?’)
- **Experimental parts (lab in the afternoon) – knowledge transfer:**
  - Prototypical material: CFRP – UD and/or fiber reinforced material of interest
  - Design of experiments:
    - Selected types of experiments for shear testing
    - Experimental setup (MTS and DIC)
  - Data analysis and reduction
  - Sensitivity analysis
  - Discussion of results
- **Aims:**
  - Interdisciplinary view on experimental testing
  - Design of experiments (‘name, describe, choose’)
  - Mechanics background of shear testing
  - Challenges in mechanical shear testing
  - Data interpretation (sensitivity analysis)

Motivation & Outline of Workshop/Lecture

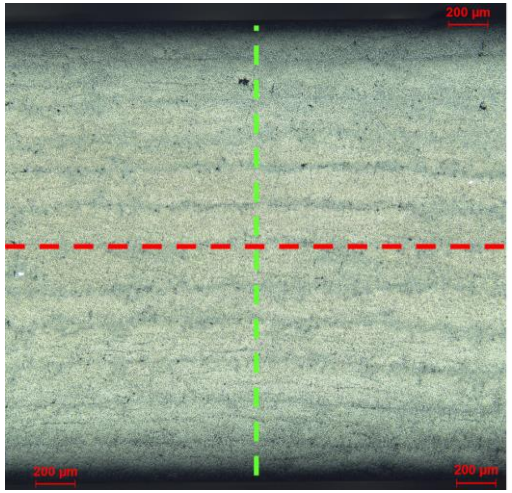


1. **Models** need 'data' for crash simulation!
   - How do models look like? What data is needed?
2. What is the appropriate **Experiment**?
   - What test method(s) provide the data needed?
3. Enhanced **Manufacturing** of complex composites
   - Restrictions/necessary improvements for the experiment?

UD: Interlaminar 31

- Short beam test (3pt bending): τ, (+ γ → G)
- Flexural testing (3pt): f(L/th) → G & E_{fl} vs. E_T
- Double beamshear test (5pt bending): τ, G

vs.

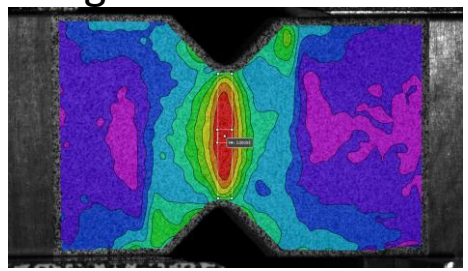


UD: Intralaminar 21

- V-Notched Beam (aka: Iosipescu): τ, γ → G
- V-Notched Rail: τ, γ → G
- 10° Off-axis: τ, γ → G (& E) = f(orientation)

Agenda 1/3

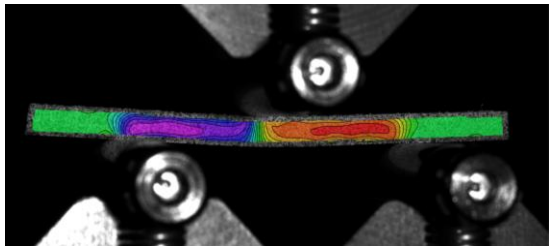
- **Monday, 09.07. (3 h + 3 h)**
  - Introduction:
    - Matthias Merzkirch & NIST
    - Audience
  - Motivation:
    - Automotive, aerospace, alternative power generation (wind turbines)
    - Lightweight aspect (Ashby)
    - Cohesive zone models
    - A quick view into standards
    - Use of DIC for automotive lightweighting
  - Digital Image Correlation: a short introduction:
    - Principle of stereo DIC, patterning, calibration
  - Overview: shear testing methods for FRP-UD
  - Recommended literature
  - Discussion, design and planning of experiments:
    - Interdisciplinary needs and expectations
- **Tuesday, 10.07. (2 h + 4 h)**
  - Tensile testing:
    - CFRP
    - Elastic shear properties of matrix material
    - Mechanics: shear stress/strain (Mohr circle)
  - Intralaminar testing:
    - V-Notched Rail
    - V-Notched Beam (aka: Iosipescu)
  - Sensitivity analysis:
    - Strains (location, DIC settings)
    - In-plane orientation
  - Restrictions and challenges
  - Workshop on V-Notched Beam using DIC
    - Setup (MTS and DIC)
    - Patterning (DIC)
    - Testing
    - Analysis and Discussion



Agenda 2/3

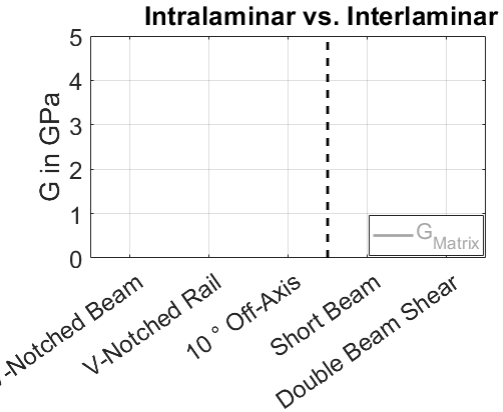
- **Wednesday, 11.07. (2 h + 4 h)**
  - Principles and mechanics of off-axis testing
  - Analytical solutions:
    - E = f(orientation)
    - σ = f(orientation)
  - 10° Off-axis:
    - Mechanics: shear stress/strain (Mohr circle)
    - Determination of E and G
    - Sensitivity analysis (strain, stress, setup, surface finishing)
    - Photomechanics (DIC) vs. analytical solutions
  - Restrictions and challenges
  - Workshop:
    - 10° Off-axis testing (preparation on previous day) or
    - V-Notched Beam (continuation)

- **Thursday, 12.07. (2 h + 4 h)**
  - Mechanics of flexural testing (3pt bending on matrix)
    - Shear stress
    - Shear correction factor
  - Short beam test (3pt bending on CFRP):
    - Shear strength
    - Analytical solutions f(L/th) → G
    - DIC for shear strain over thickness
  - Double beamshear test (5pt bending)
    - Strength and G (calculation)
  - Restrictions and Challenges
  - Workshop on short beam specimen:
    - Challenge: DIC pattern on face side
    - Patterning with airbrush
    - Setup (MTS and DIC)
    - Testing
    - Analysis and Discussion



Agenda 3/3 and Preparation

- **Friday, 13.07. (2 h + 1 h + 1 h)**
  - Discussion of results on shear properties:
    - Comparison of 5 different shear testing methods
    - Comparison: Interlaminar/Intralaminar
    - Comparison: Composite vs. Matrix

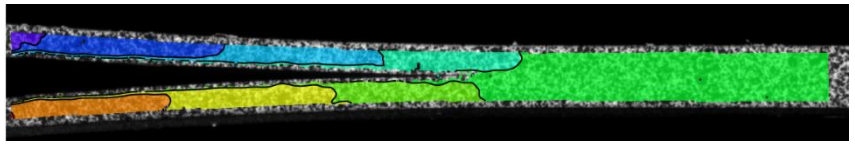


  - Multiple choice exam (1 h) on theoretical part (Σ~11 h):
    - ECTS: 2
  - Evaluation (15 min):
    - Theoretical part
    - Experimental part

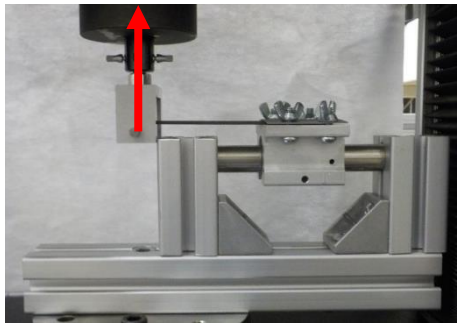
- **Friday, 06.07.**
  - Arrival
  - Preparation:
    - Lecture room
    - Print media (print slides without animation)
    - Testing material
    - Lab
    - Setups
      - V-Notched Beam
      - 10° off-axis tensile test
      - 3pt
    - DIC:
      - Stereo setup
      - Airbrush?

Outlook: Potential 2nd part in 2019

- **Mode I using DIC (double cantilever beam):**
  - 2D DIC Crack Tip Tracing
  - Fracture toughness G_I:
    - ASTM
    - DIN
    - ISO
    - Non-standardized method



- **Mode II using DIC:**
  - Fracture toughness G_{II}:
    - ASTM (3pt)
    - DIN (3pt)
    - Non-standardized method
    - ISO (end-loaded split test)
    - Comparison to shear test methods (Part I of workshop)



- **Through thickness properties using DIC:**
  - Tensile testing UTS & E
  - Analytical solution for UTS and E from Mode I testing data using DIC (crack opening displacement)

- **Comparison of Young's Moduli (CFRP):**
  - E_T From tensile test
  - Flexural testing
    - 3 pt
    - 4 pt
    - Double cantilever
    - End loaded split test

- **Woven vs. UD:**
  - Selected test methods

→ **Full description for cohesive zone modeling**