4a TECHNOLOGIETAGE TT2018
SCHLADMING, 28.02 – 01.03.2018

LIFETIME ASSESSMENT OF SHORT-FIBER REINFORCED THERMOPLASTIC WELD LINES UNDER FATIGUE LOADING

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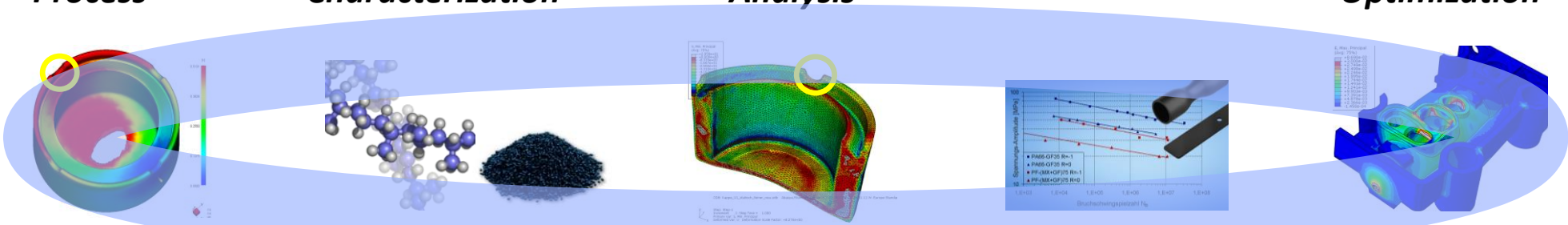
BOSCH

Lifetime assessment of weld lines under fatigue loading
Outline

1. Introduction
   - Integrative simulation chain for lifetime assessment
2. Weld lines
   - State of the art
   - Estimation of weld line quality
3. Fatigue strength assessment
   - Influence of weld line quality on fatigue strength
   - Correlation between weld line quality and fatigue strength
4. Summary and outlook

Lifetime assessment of weld lines under fatigue loading
Integrative simulation chain for virtual product development

Virtual Production Process | ***Virtual Material Characterization*** | ***Stress & Strain Analysis*** | ***Lifetime Assessment*** | ***Material& Design Optimization***



Optimization loop

AUTODESK SIMULATION MOLDFLOW | MoldSim | Converse | ANSYS | FEMFAT software FINITE ELEMENT METHOD FATIGUE | SIMULIA TOSCA

SIGMASOFT Virtual Molding | MICROMEC | FIBERMAP | ABAQUS | HBM | nCode | DYNA MORE | dynardo dynamic software & engineering

Moldex3D MOLDING INNOVATION | eXstream ENGINEERING | eXdigimat | LS-DYNA | LS-OPT | optiSLang®

Microstructural Properties → Material Properties → Stress, Strain, Deformations → Strength and Endurance Life → Component Reliability

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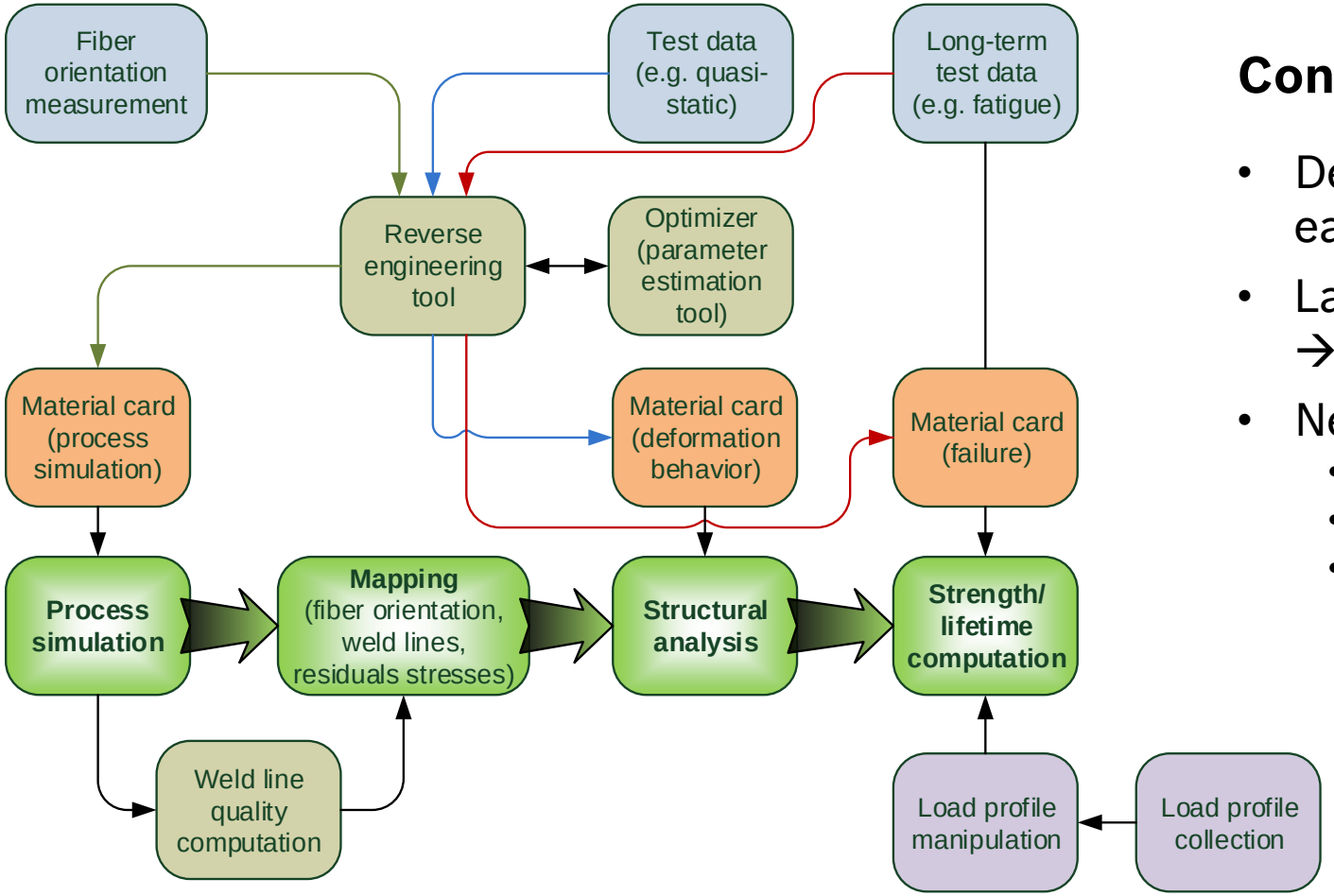
Lifetime assessment of weld lines under fatigue loading

Example of integrative simulation chain for fatigue



Considerations

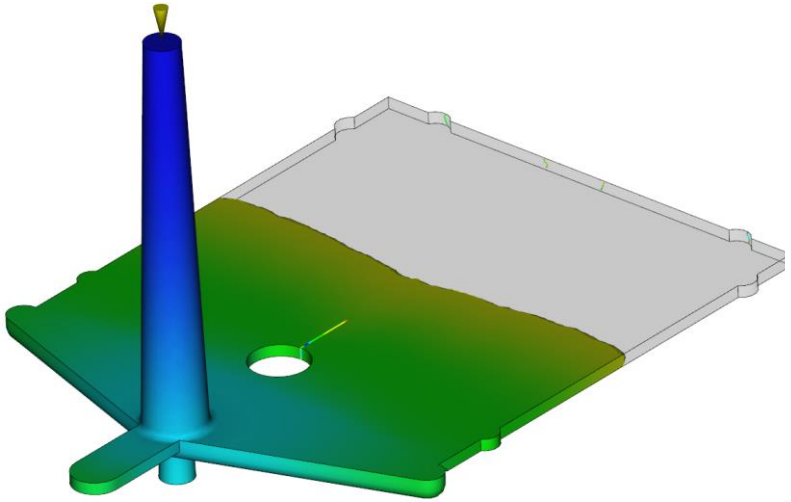
- Dedicated software packages for each step available
- Large number of interfaces involved → high effort and risk of errors
- Needs*:
  - Simplification of simulation chain
  - Standardization of interfaces
  - Standardization of material characterization

* Addressed in publicly funded project VMAP (vmap.eu.com)

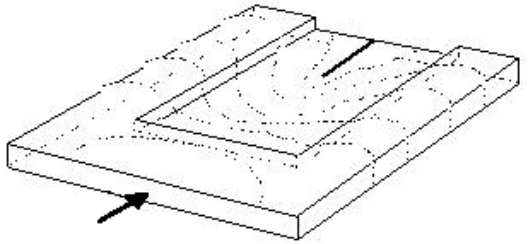
Lifetime assessment of weld lines under fatigue loading

Weld lines: how do they arise?

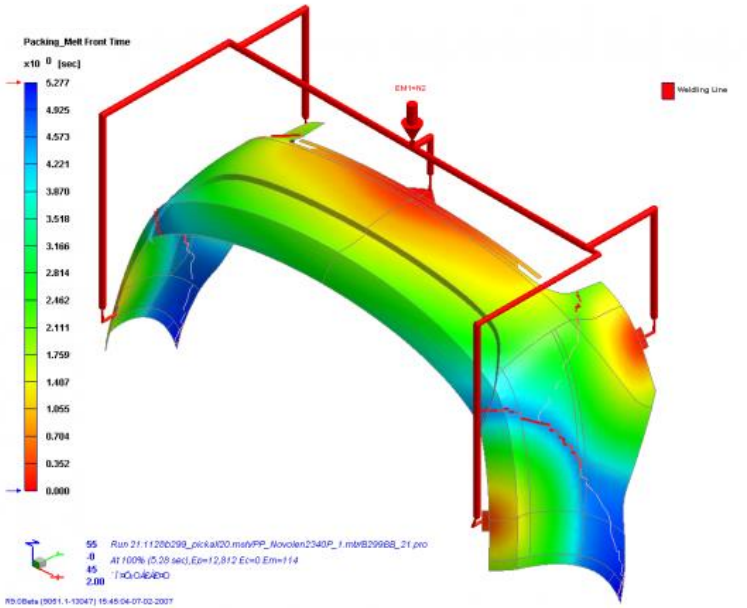
OBSTRUCTION



DIFFERENT WALL THICKNESSES

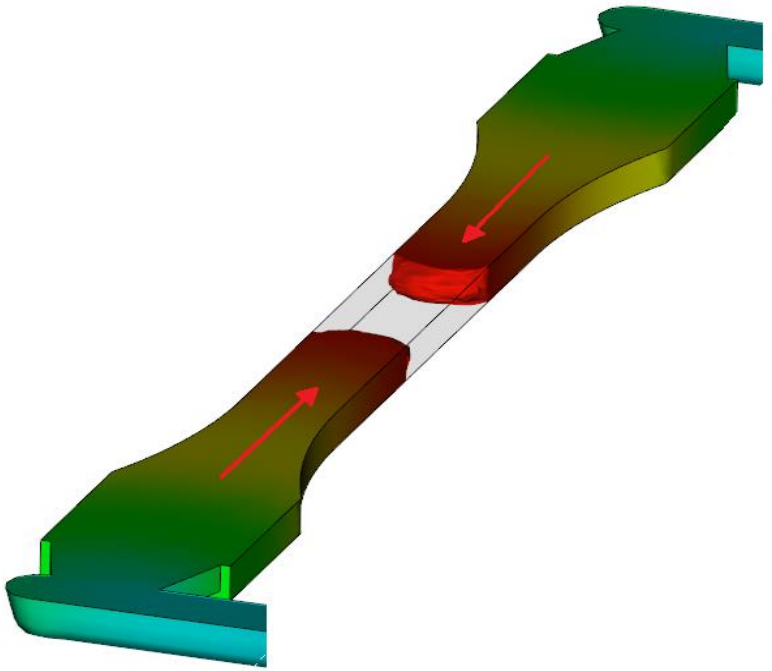


MULTIPLE GATING

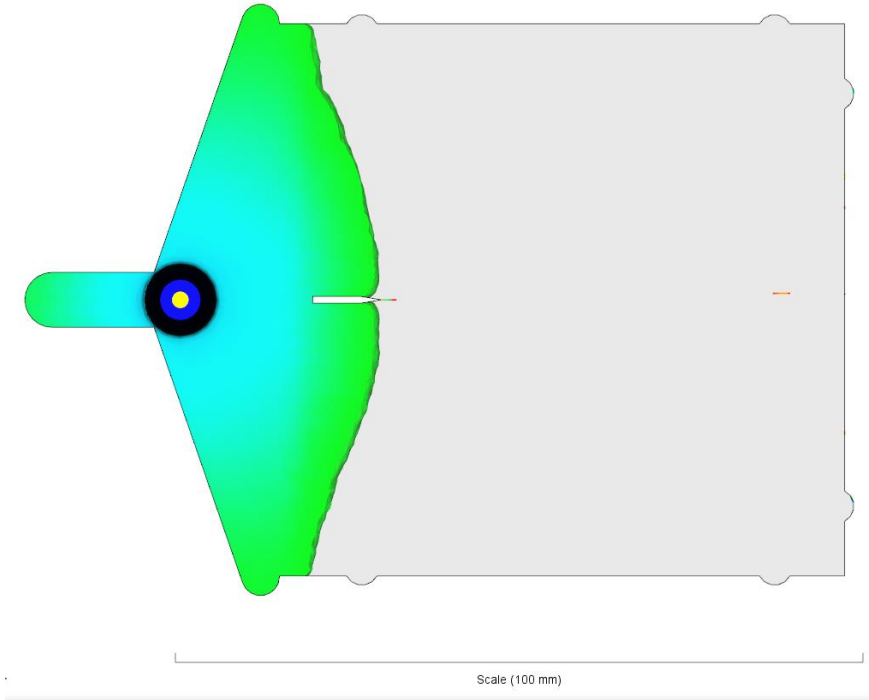


Lifetime assessment of weld lines under fatigue loading
Frontal vs. flowing weld lines

FRONTAL WELD LINE

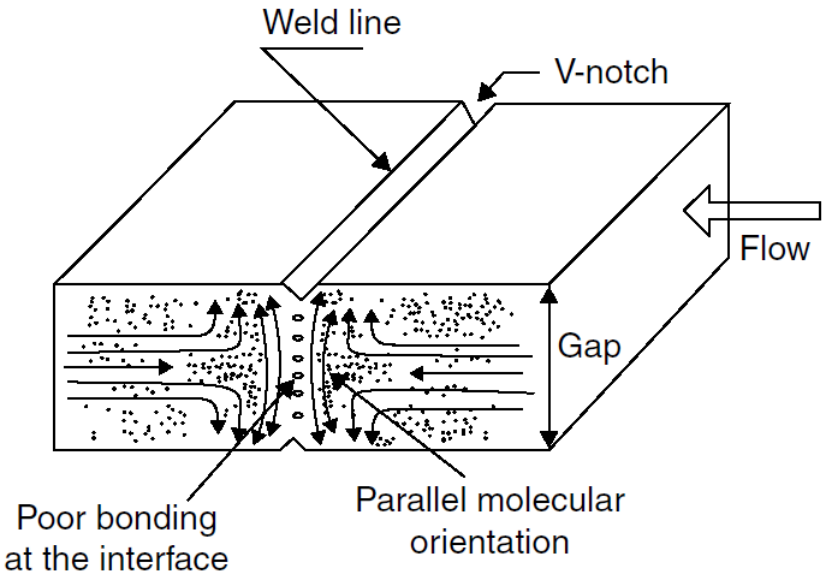


FLOWING WELD LINE



Lifetime assessment of weld lines under fatigue loading

Factors affecting weld line strength



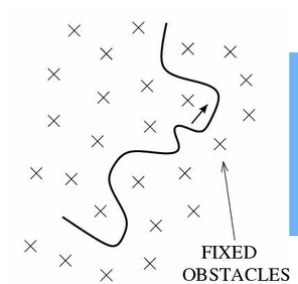
i. Incomplete bonding at the interface

ii. Molecular/fibre orientation

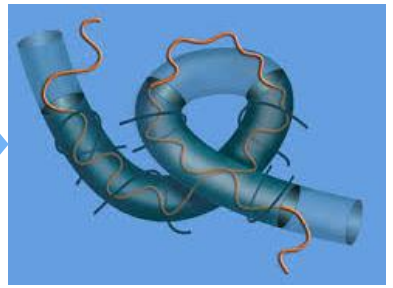
iii. V-notch at the surface

Lifetime assessment of weld lines under fatigue loading
Degree of bonding at the interface (weld line quality)

- Assumption: no fibres are crossing the weld line surface
- The degree of bonding at the interface depends solely on matrix healing
- Matrix healing: determined by the inter-diffusion of the polymer chains at the weld line surface
- Can be described by the reptation theory*

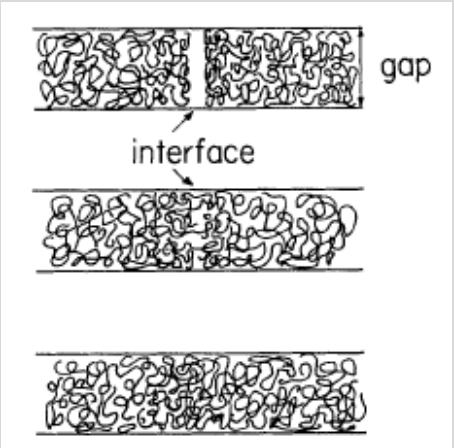


An entangled polymer is confined into a “tube”



- Polymer chain can only move along the curvilinear length of the tube.
- Initial configuration of the tube is lost after **one reptation time** (t_R) → i.e. It has diffused out of the “tube”.
- $t_R \propto \eta \propto M_w^3$

Healing Process

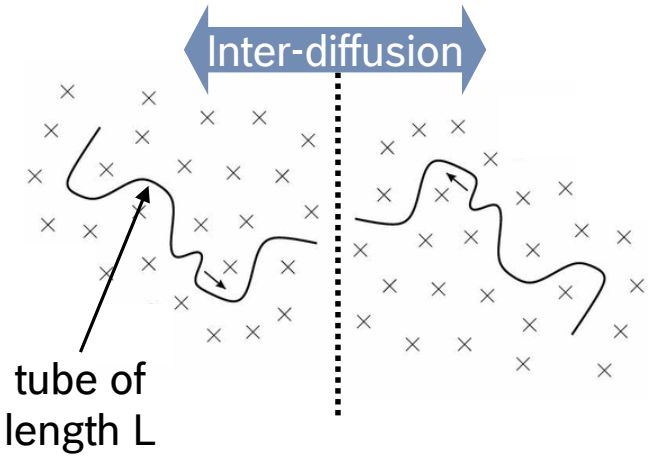


Source: S.G. Kim and N.P. Suh. Polym. Eng. Sci. 26, 17 (1986)

* De Gennes, Doi & Edwards

Lifetime assessment of weld lines under fatigue loading
Degree of bonding at the interface (weld line quality)

- Polymer healing depends on molecular mobility guaranteed mainly by temperature.
- Healing domains:
  - $T > T_{crystallization}$ for semi-crystalline polymers.
  - $T > T_g$ for amorphous polymers.
- The inter-diffusion process of the polymer chains at the weld line surface can be described by the reptation theory.



- For a non-isothermal process at the weld line interface (typical case in injection molding) we can describe the local quality of matrix healing as follows:

$$Q_{local} = \int_{t_{contact}}^{t_{solidification}} \frac{d\tau}{t_R\left(T(\tau), P(\tau)\right)}$$

Criterion

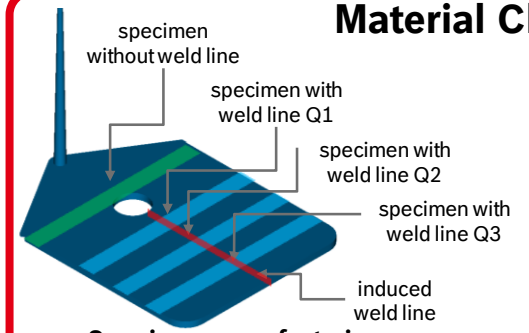
$Q \geq 1$ **Bulk**

$Q < 1$ **Incomplete healing**

Lifetime assessment of weld lines under fatigue loading

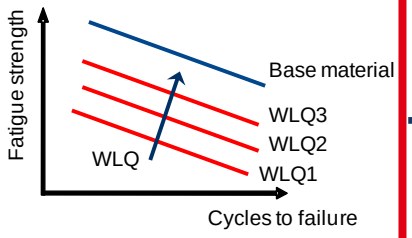
Approach

Material Characterization



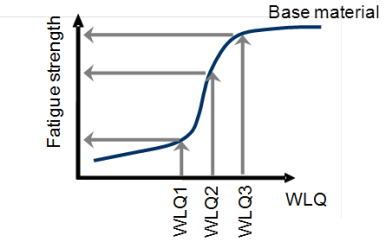
Specimen manufacturing

Fatigue testing in fuel



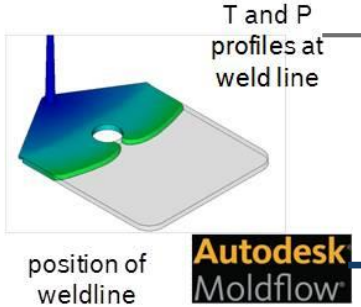
Fatigue behavior

Lifetime Assessment

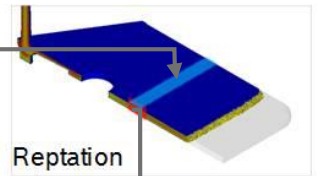


Calibration curve for WLQ

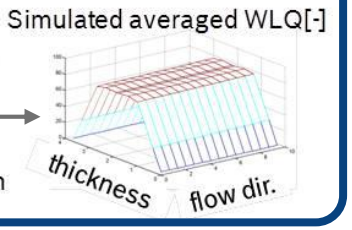
Injection Molding Simulation



Weld line quality computation



WL quality field



healing quality estimation

Struct. Analysis

Mapping (FO, WLQ)

WL as node set

SIMULIA ABAQUS ANSYS

Focus of the presentation

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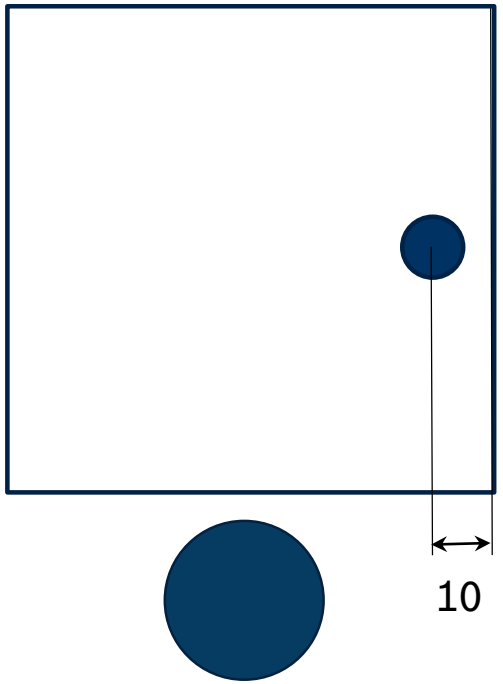
Lifetime assessment of weld lines under fatigue loading

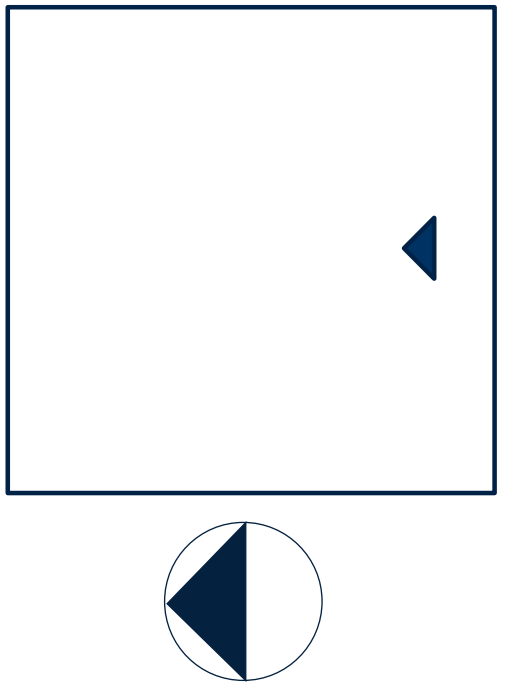
Characterization of weld lines: plates

Plate MI1



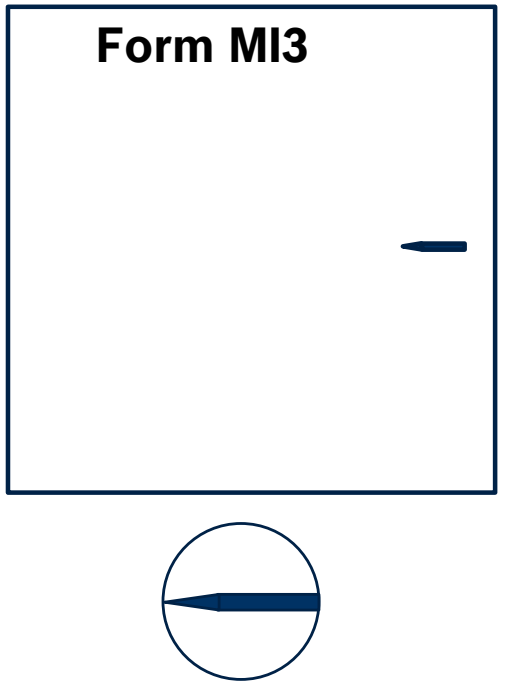
Diameter: 10
Angle: 180°

Plate MI2



Width: 10
Angle: 90°

Plate MI3



Width: 1
Angle: 10°

Plate dimensions:
80x80x2 mm

New mold plate + inserts available at CR/APP

All dimensions in mm

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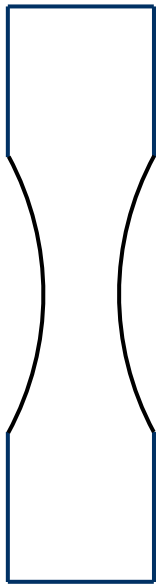
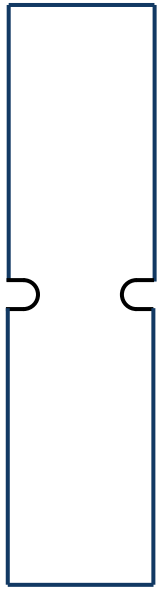
Lifetime assessment of weld lines under fatigue loading
Characterization of weld lines: specimens

Plain (PL)



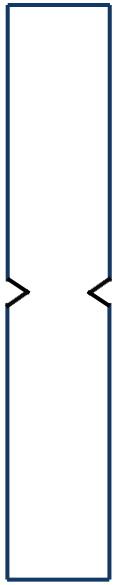
Gross width: 20
Radius: 40

Mildly Notched (MN)



Gross width: 20
Radius: 2
Opening angle: 0°

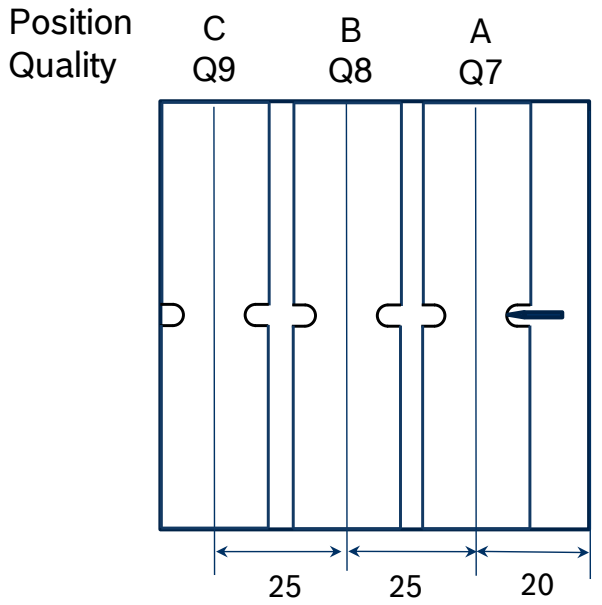
Sharply Notched (SN)



Gross width: 14
Radius: 0.1
Opening angle: 60°

Dimensions (in mm)
Length: 80
Thickness: 2
Net width: 10

Example of specimen extraction:



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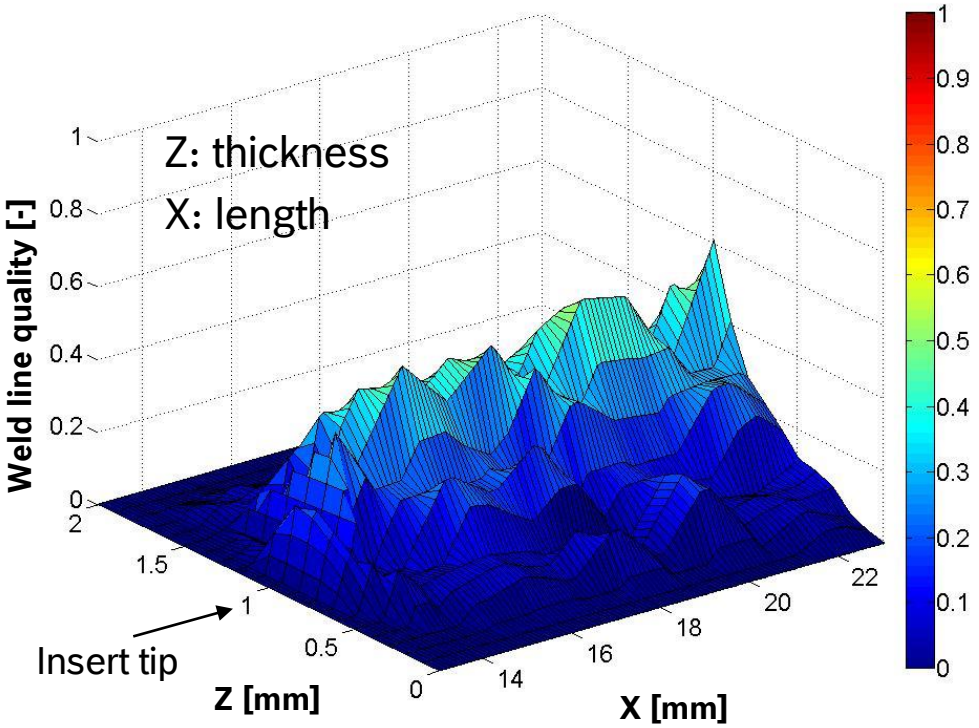
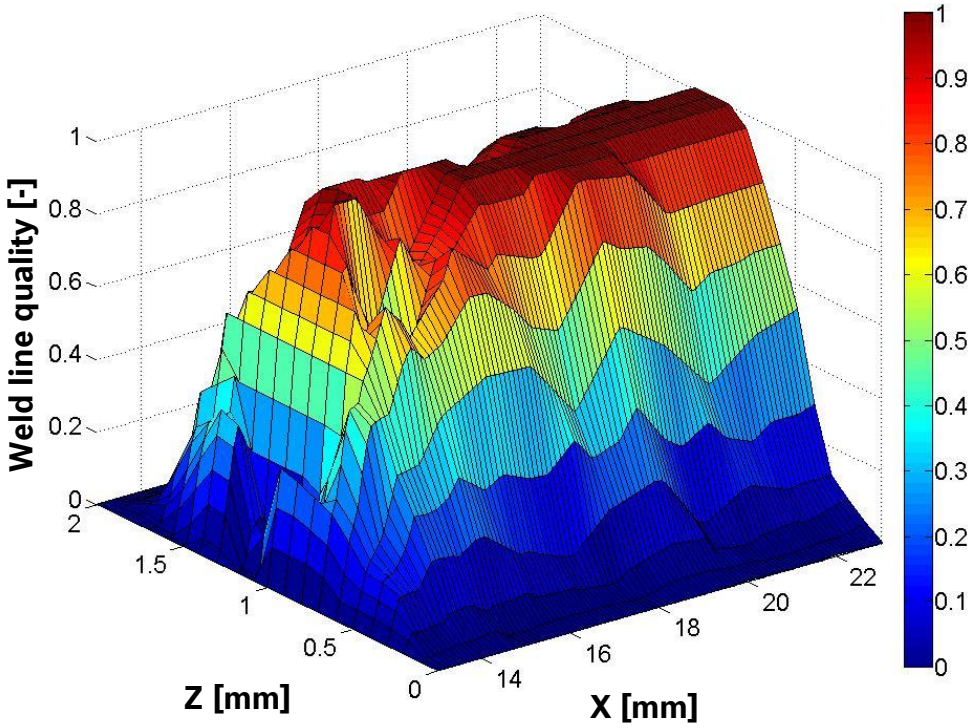
Lifetime assessment of weld lines under fatigue loading

Weld line quality: influence of process parameters

Poor process parameters



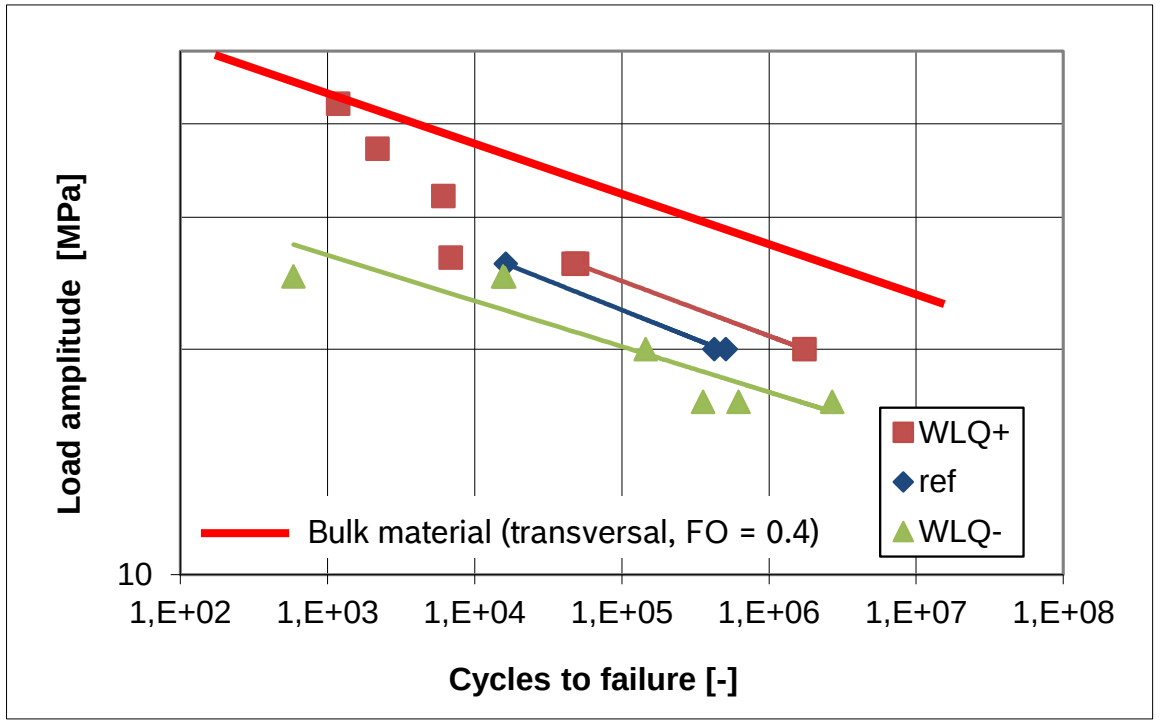
Optimal process parameters



Process parameters significantly affect weld line quality field
In the proximity of the insert tip weld line quality has very low values (close to zero)

Lifetime assessment of weld lines under fatigue loading
Influence of weld line quality on fatigue strength

RT, R=0, PPA-GF40 weld line, air, plain



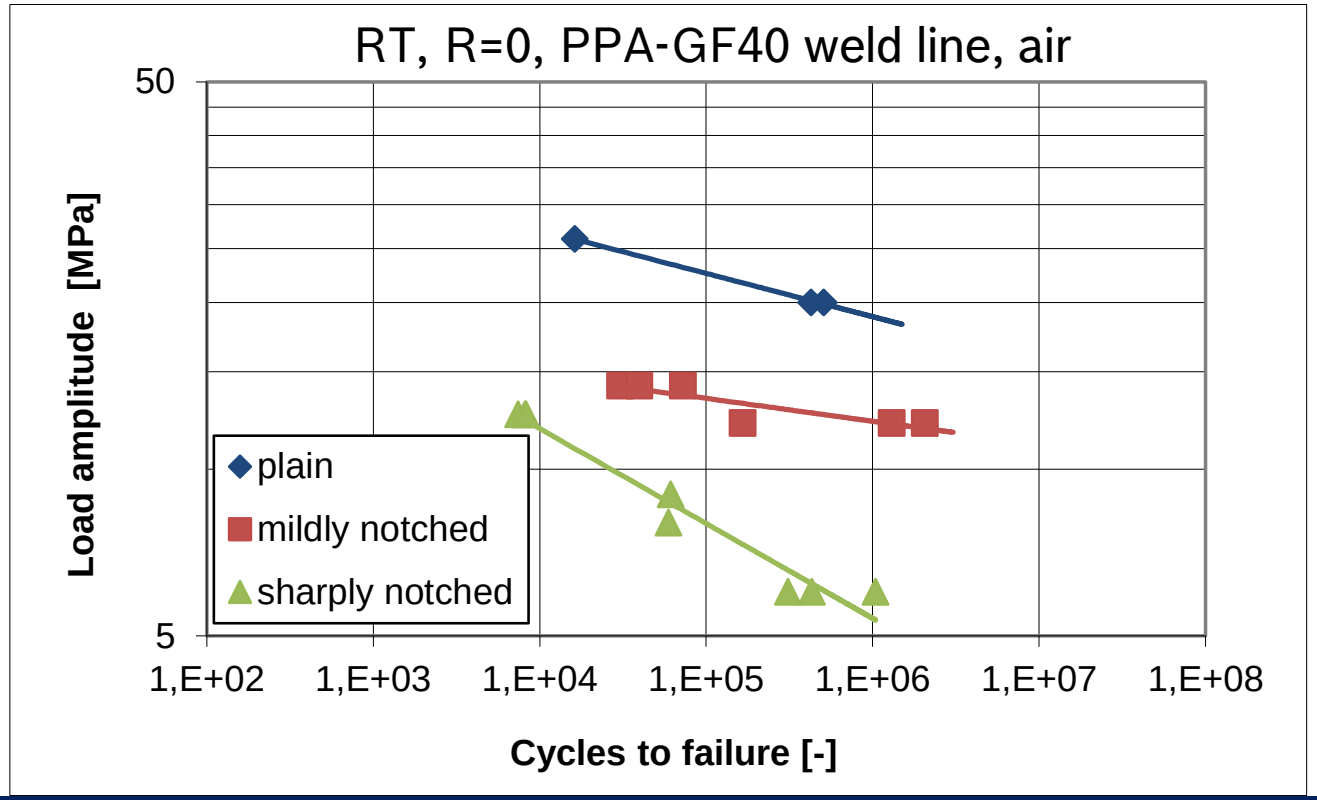
- Data scatter significantly larger than for bulk material
- Lower weld line qualities result in lower fatigue strength
- Influence of weld line quality seems to affect stronger the low cycle fatigue behavior
- Fatigue strength of weld line reaches in the best case the strength of a transversally aligned bulk specimen

Increased data scatter compared to bulk material
Weld line quality affects resulting fatigue strength, especially in the low cycle regime

FO: Fiber Orientation (1st component of the tensor)

Lifetime assessment of weld lines under fatigue loading

Notch sensitivity of weld line under fatigue loading



- S-N curve of weld line material strongly affected by the presence of notches
- Bulk material: notch sensitivity factor (ration between strength of sharply notched and plain specimen) at RT, R=0: **0.4 – 0.5**
- Weld line: notch sensitivity factor at RT, R=0 in the range **0.2 – 0.3**

The presence of notches strongly affects the S-N curve of weld lines (both strength and slope)
Increased notch sensitivity of weld line material compared to bulk

Lifetime assessment of weld lines under fatigue loading

Correlation between fatigue strength and weld line quality

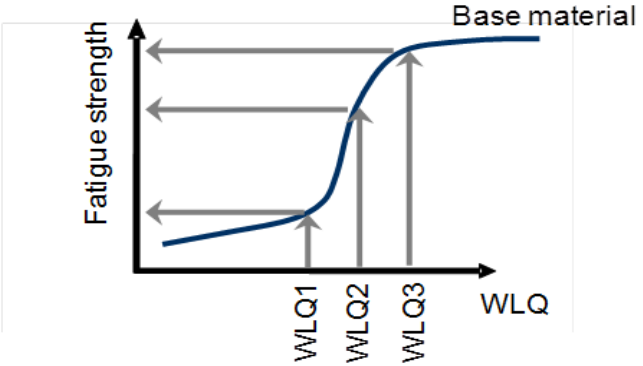
HYPOTHESIS

The weld surface:

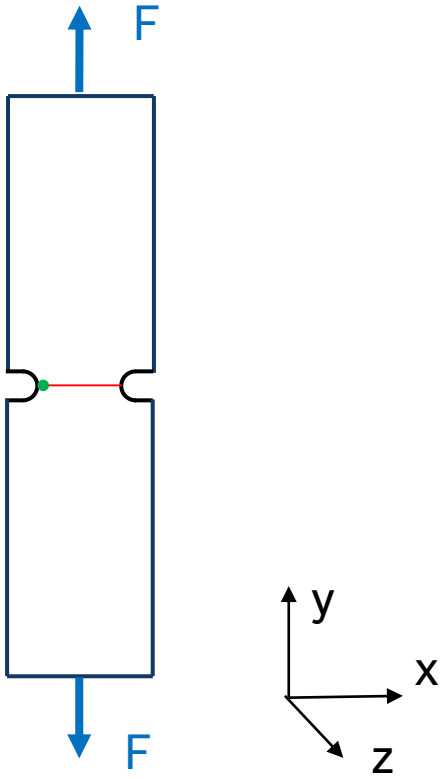
i. has no thickness

ii. is planar

iii. is made of polymer only



Calibration curve for WLQ

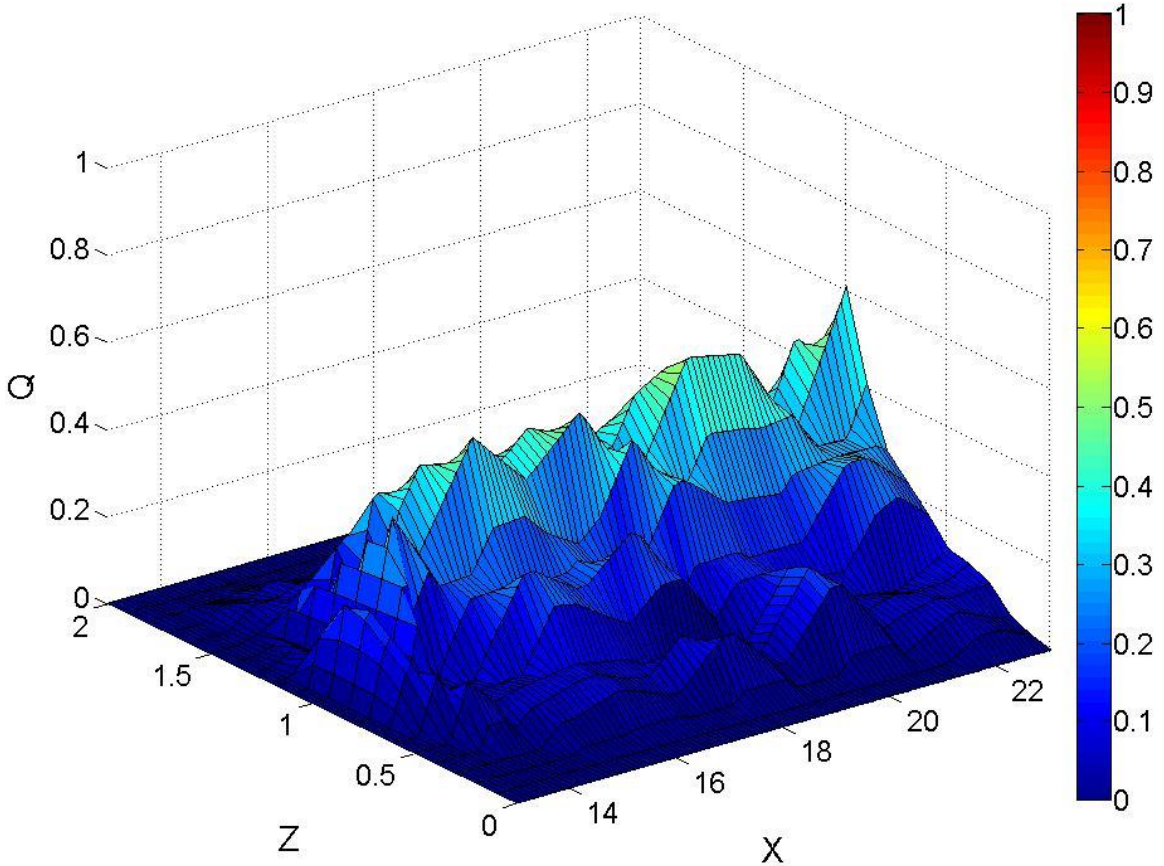


IDEA: the points on the weld line that contribute to the global strength are localized at the notch tip region.

$$\widehat{Q}_{avg} = \frac{\iint_{local\ area} WLQ(x,z)\,dx\,dz}{A_{local\ area}}$$

Lifetime assessment of weld lines under fatigue loading

Correlation between fatigue strength and weld line quality



Challenge: at notch tip (free surface) WLQ=0 results

Even in the proximity of notch tip (here at X=13 mm) WLQ is very low and numerical noise is very large

Consequence: large control volume necessary to get robust average quality

WLQ: Weld Line Quality

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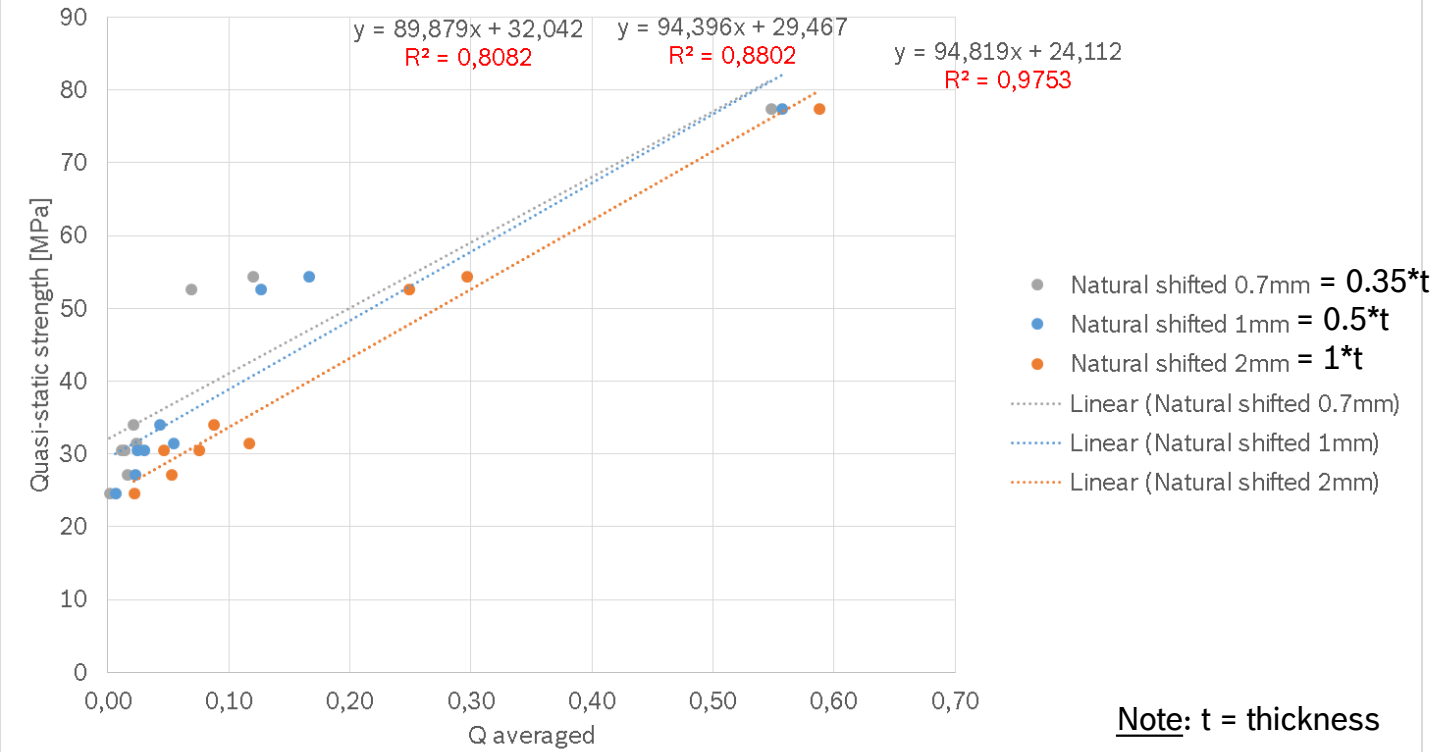
Lifetime assessment of weld lines under fatigue loading

Correlation between fatigue strength and weld line quality



- Example: quasi-static strength of mildly notched specimens
- With a sufficiently large control area a linear correlation between strength and average quality can be obtained
- Extension to fatigue strength ongoing

Quasi-static strength correlates with weld line quality
An averaging area over a length equal to the specimen thickness shows the best correlation

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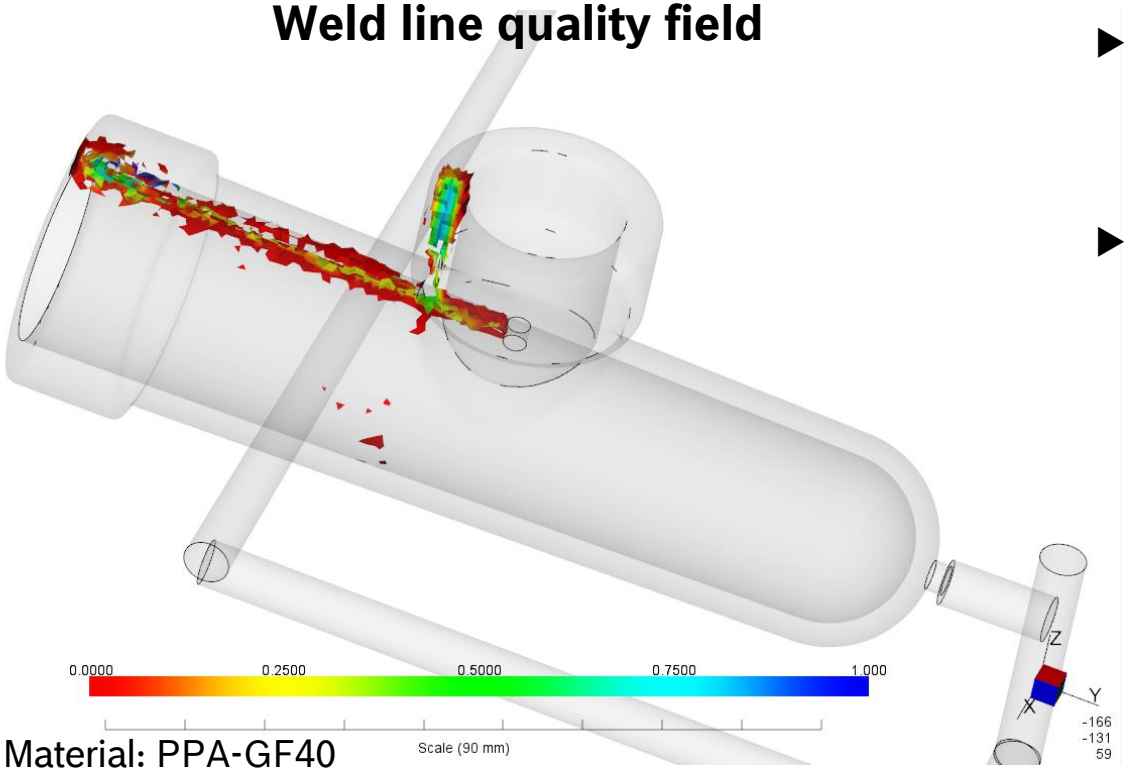
Lifetime assessment of weld lines under fatigue loading

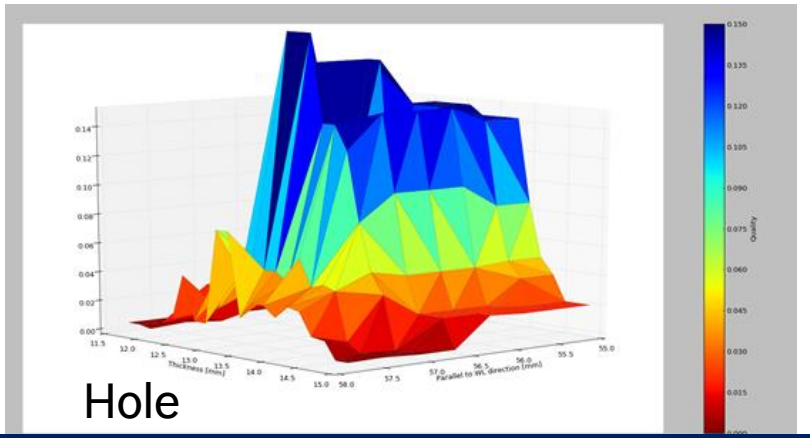
Weld line quality computation: influence of process parameters

Weld line quality field



Material: PPA-GF40

- Recommended process parameters already cause very low values of weld line quality field at the hole connecting the 2 tubes
- Sensitivity study on the influence of process parameters on weld line quality at the hole ongoing



Hole

Low weld line quality often occurs on parts, even at recommended process conditions

* Weld line quality computation within the PhD of M.B. Baradi

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Lifetime assessment of weld lines under fatigue loading
Summary and Outlook

- Integrative simulation chain for lifetime assessment of reinforced plastics
  - Simplification of simulation chain and interchangeability of software packages highly desirable
- Weld line quality
  - 3D prediction of weld line position within commercial tools partly possible; further improvements needed
  - Computation of weld line quality as post-processing step to process simulation
  - Robustness of weld line quality field to be improved (increase spatial resolution, reduce numerical noise)
- Influence on fatigue strength
  - Quality of weld line affects fatigue strength up to factor of two
  - Weld line fatigue strength below the S-N curve of bulk material, transversally oriented
  - Increased notched sensitivity of weld lines compared to bulk materials
- Correlation between strength and weld line quality
  - Concept to compute average weld line quality on part available
  - Validation on a semi-complex part ongoing

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