
Durability by Design
New Results on Load Carrying Silicone Bonding
Anneliese Hagl

Structure of the Presentation

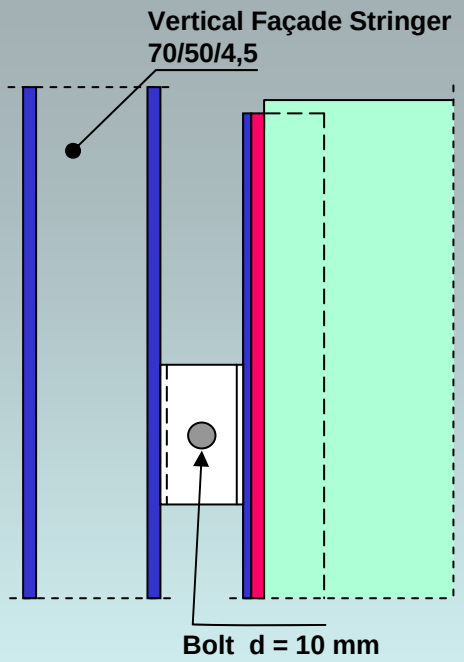
- ➔ **Application of U-type Bonding Geometry**
- ➔ Material Tests
- ➔ Bonding Geometry and Durability
- ➔ Conclusions of Bonding Geometry Analysis

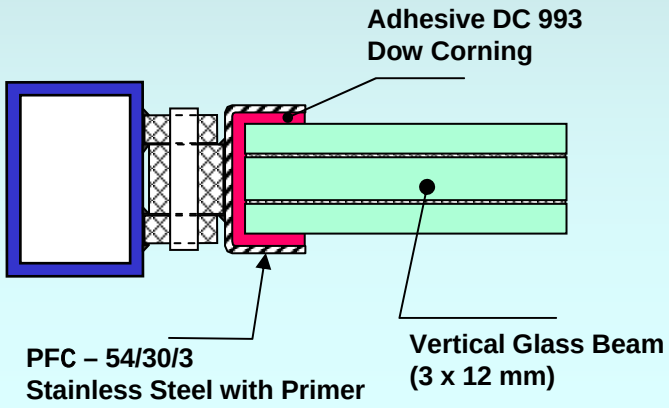
Example: Herz Jesu Church, Munich

Architectural objective: Minimum of visible load carrying structures

- **Horizontal and vertical glass beams for support of the glass façade**
- **Load carrying bonding by Silicone adhesives applied to glass beams**

Glass Beam Attachment





Design Idea:

- Selection of parallel flange channel (PFC)
- Three sided bonding design
  - one front region
  - two side regions

Question:

How to assess durability of such a bonding geometry or similar designs?

Critical Parameters affecting Joint Durability

(Kinloch, A. J. „Durability of Structural Adhesives“)

Environment	**Presence of moisture identified as most hostile environment, especially in combination with high temperature**
Adhesive type	**Chemical type of structural adhesives important for joint durability, depending on physical and chemical attack mechanisms**
Adherend, adherend surface pretreatment	**Application of primers helpful in producing durable joints by stabilizing surface layers e.g. oxides**
Applied stress	**Increased rate of strength loss by presence of externally applied or internal stress by lowering energy barrier unbroken/broken**
Joint design	**Emphasized durabilitiy effects by high stress distributions on interface between adhesive and adherend (interfacial failure typical after environmental attack)**

Focus in this presentation:

- **Adhesive: see material test results**
- **Applied stress: see discussion on bonding geometries**

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Test Procedures for Material Tests

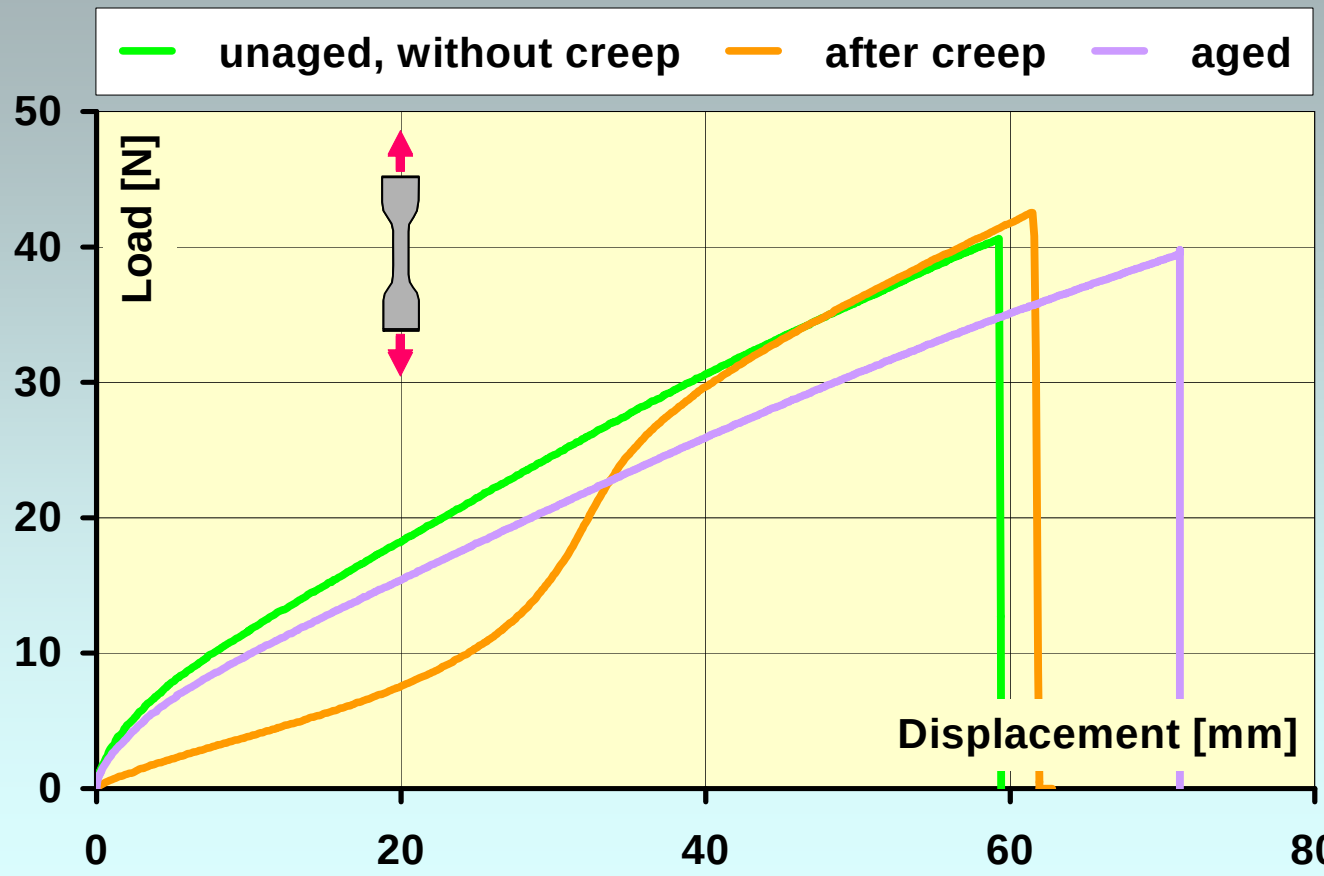
Aging

- 3 days — 80° C temperature
- 10 days — 45° C temperature de-mineralized water with cleaning agent (5%)
- 3 days — 80° C temperature
- 10 days — 45° C temperature de-mineralized water, UV radiation 50 +/-5 W/m^2
- 1 day — 23° C temperature - baseline laboratory conditions
- 8 days — 45° C temperature salted water (50 g salt/l), UV radiation 50 +/- 5 W/m^2
- 2 days — - 30° C temperature
- 1 day — 23° C temperature - baseline laboratory conditions

Creep

- Creep duration 105 days continuous loading
- Creep load corresponding to 20% of fracture strain
  - Tension 16.5 N
  - Shear 115.0 N
- Tension test within 24 hours after unloading

Tension Tests Including Aging and Creep

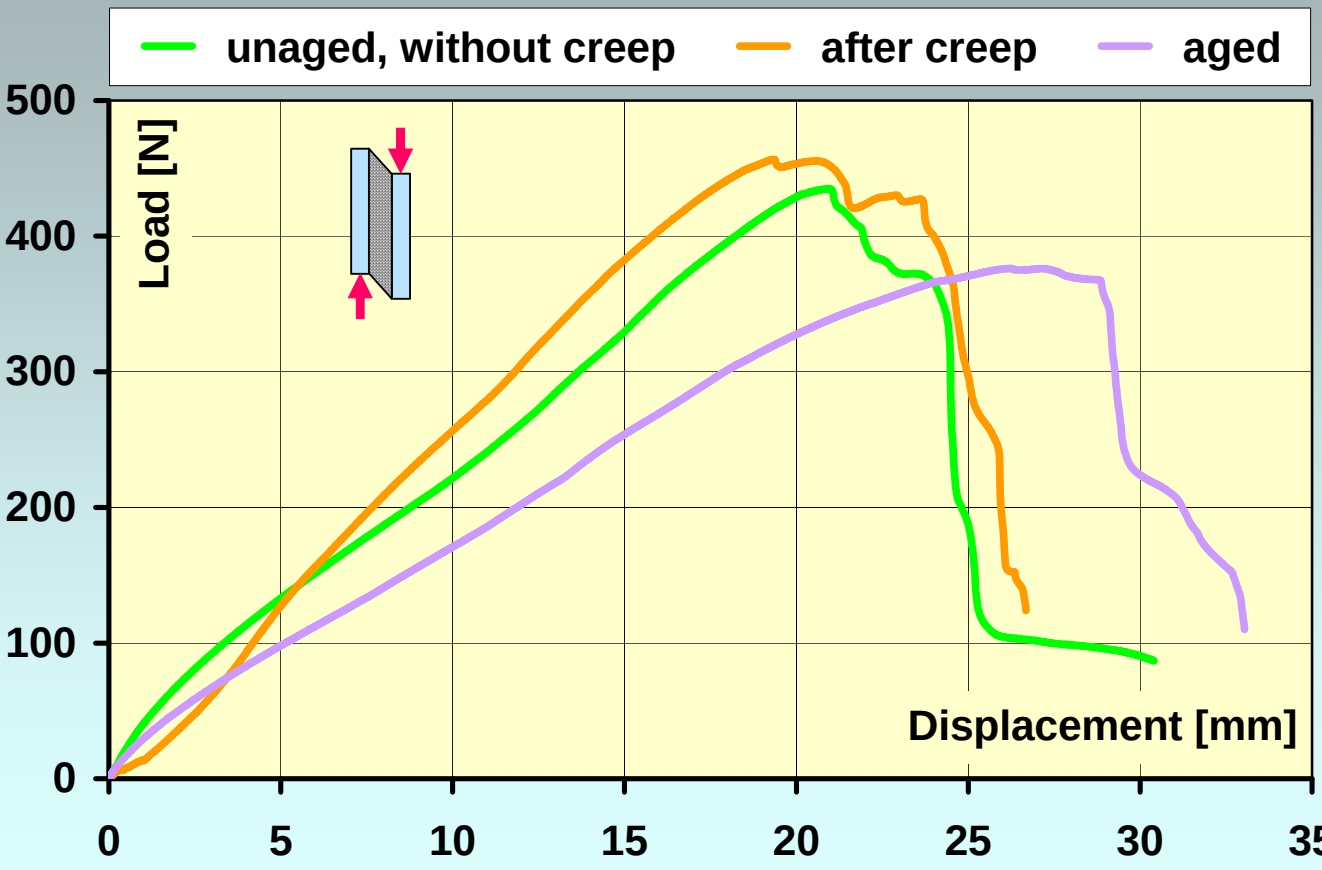


Tension test database

- 10 specimens in baseline conditions
  5 aged specimens
  5 specimens exposed to creep
- Strength of the specimens is slightly affected by aging or creep (load history)
- Stiffness of specimens is affected by aging only
  ↳ increased flexibility for aged specimens

Source: Fachhochschule München, FB02, Geklebte Verbindungen im Konstruktiven Glasbau, Final Research Report, BMBF Projekt, AIF-Nr.: 1755X04, 2007

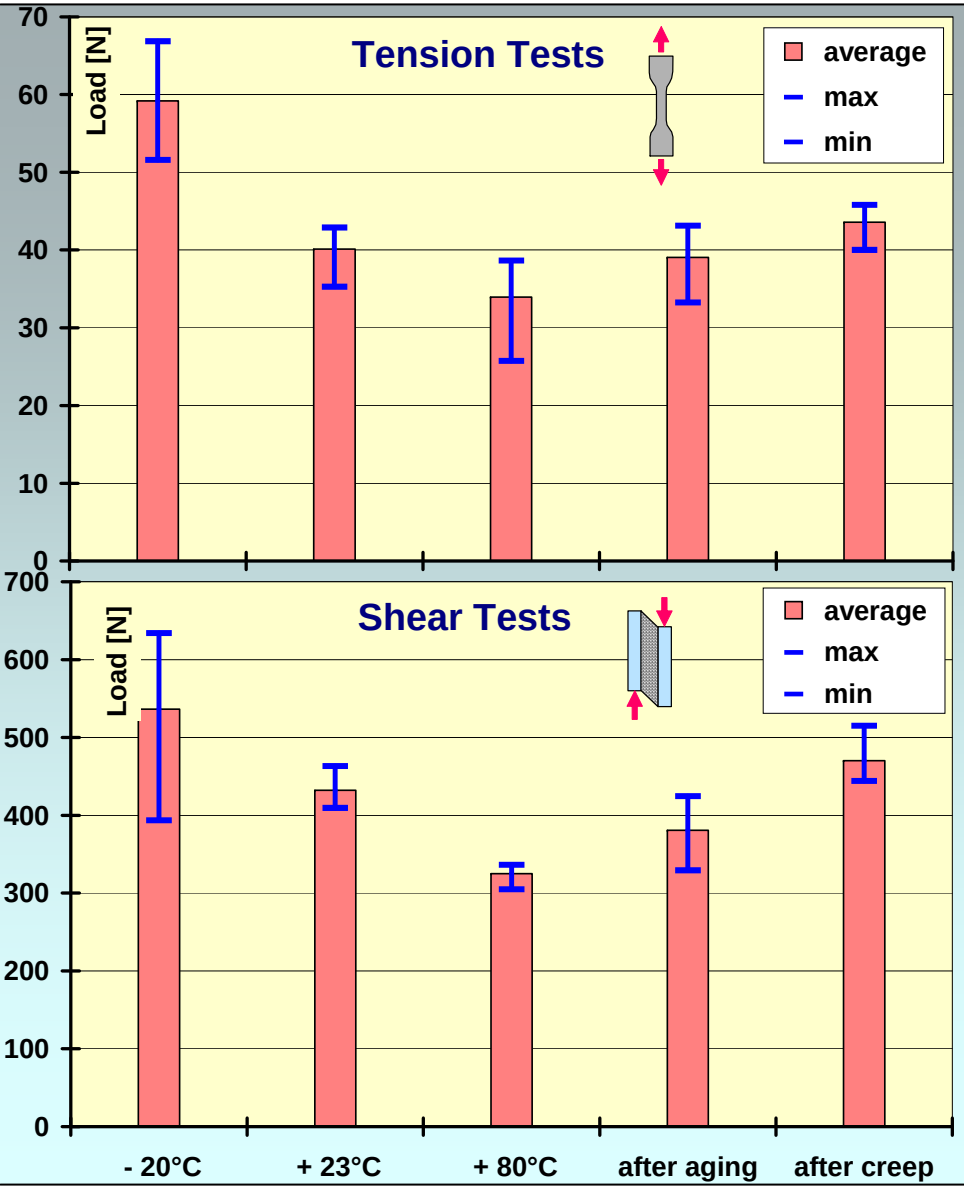
Shear Tests Including with Aging and Creep



Shear test database

- 5 specimens in baseline conditions
  5 aged specimens
  5 specimens exposed to creep
- Strength of the specimens is slightly affected by aging or creep
- Stiffness of specimens is mainly affected by aging
  ↳ increased flexibility for aged specimens
- Results generally similar to tension tests

Source: Fachhochschule München, FB02, Geklebte Verbindungen im Konstruktiven Glasbau, Final Research Report, BMBF Projekt, AIF-Nr.: 1755X04, 2007



Overview of Test Results

- Strength of specimens is slightly affected by aging or creep in comparison with 23°C - tests
- Specimen strength is significantly affected by temperature – strength is much lower for increasing temperature
- Results between tension and shear are in general agreement

Conclusions are:

In case of strength requirements:
↳ critical case is high temperature

In case of stiffness requirements:
↳ critical case is aging

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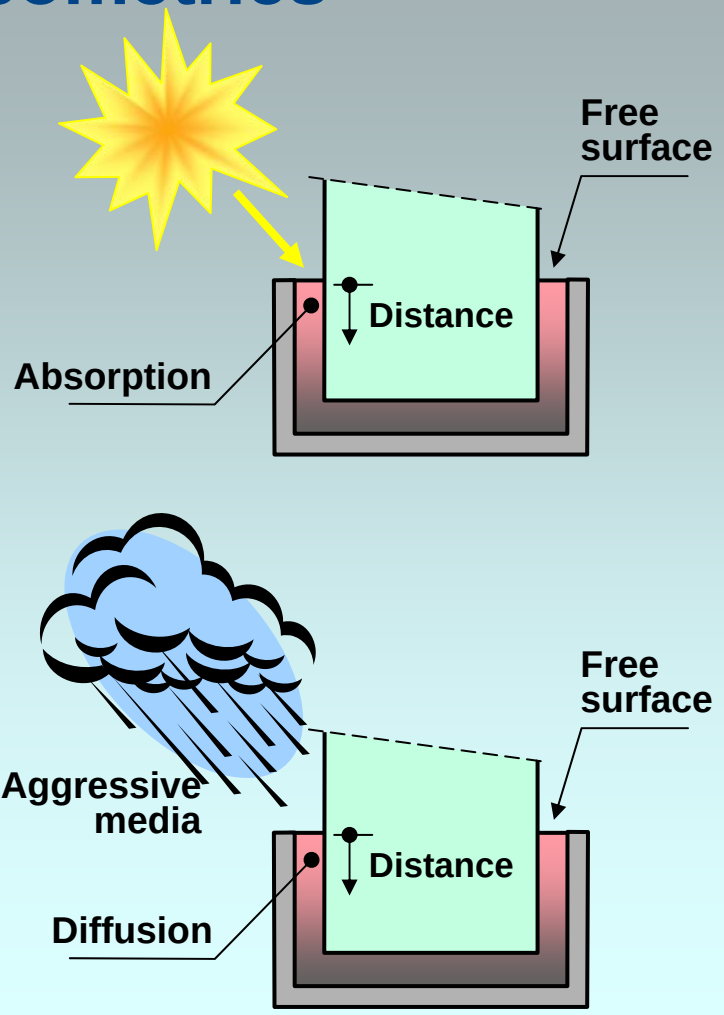
Assumptions for Assessing Durability of Different Bonding Geometries

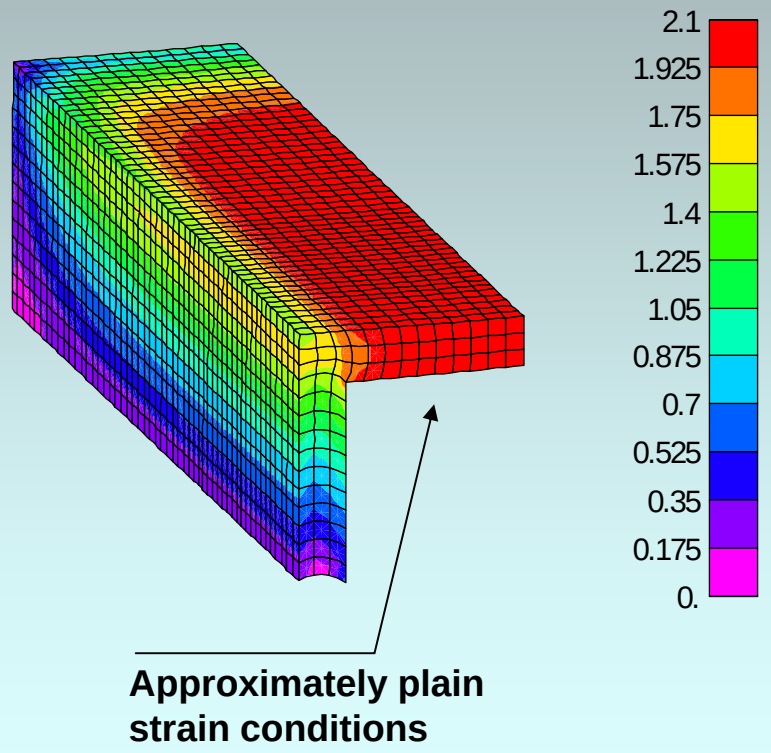
- Environmental impact of aggressive media and solar radiation is a function of distance below the free surface of adhesive
- Physical principles are:
  - Absorption of radiation
  - Diffusion of aggressive media
- Highest impact on damage is expected for the free surface and will decrease with increasing distance inside the adhesive
- Maximum principal stress level in vicinity of free surface is assumed to be a measure of durability



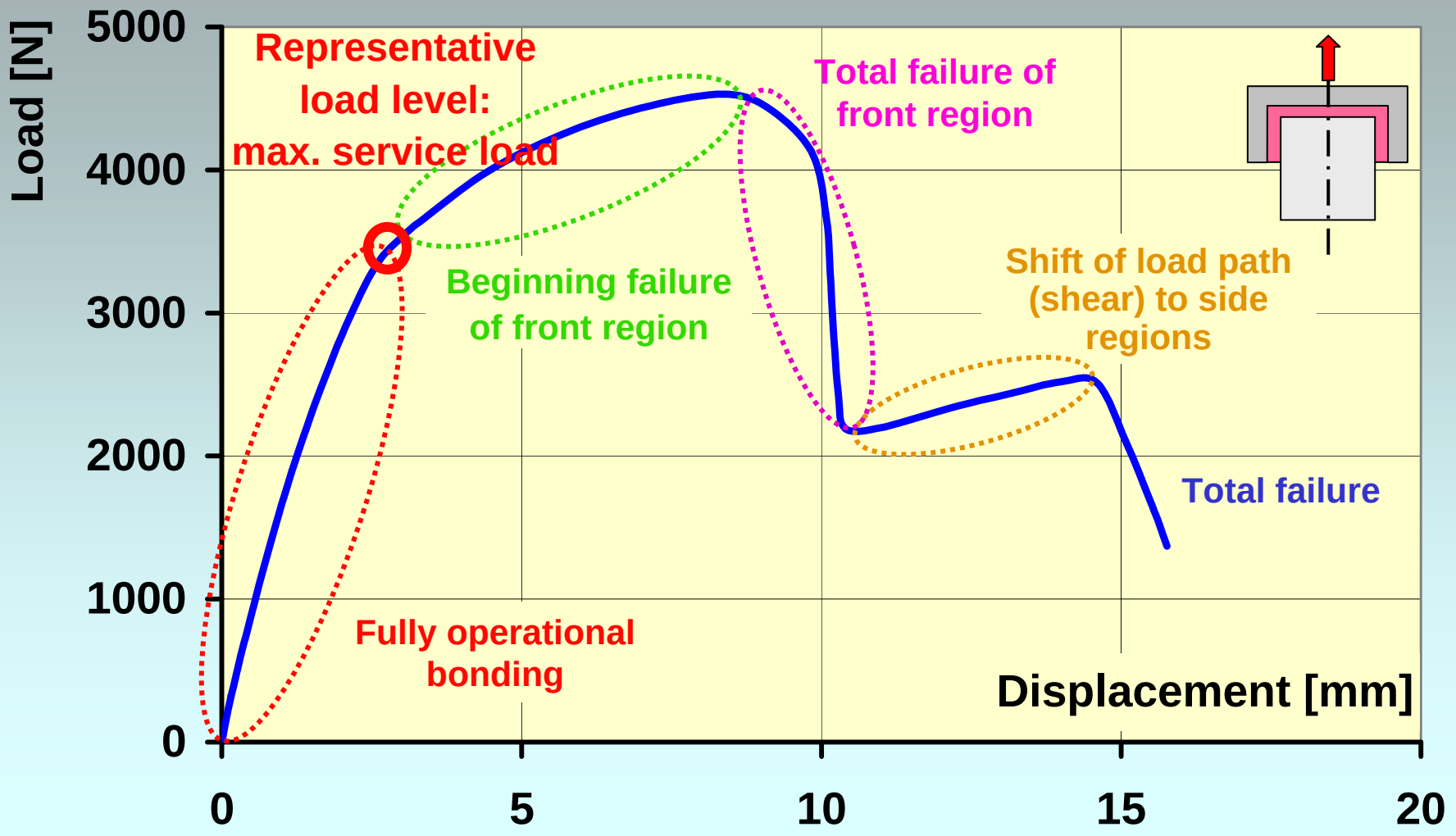
Stress Investigations by Numerical Models

- Application of Finite Element Analysis (FEA) is useful
- Hyper-elastic material laws used for representation of Silicone adhesives
- For the following studies a 2D plain strain state is considered
- Critical load case for bonding is tension
- Loading of models adjusted to 2.1 N/mm² maximum principal stress (based on experimental results)

Example of a quarter model of a U-type bonding with finite length

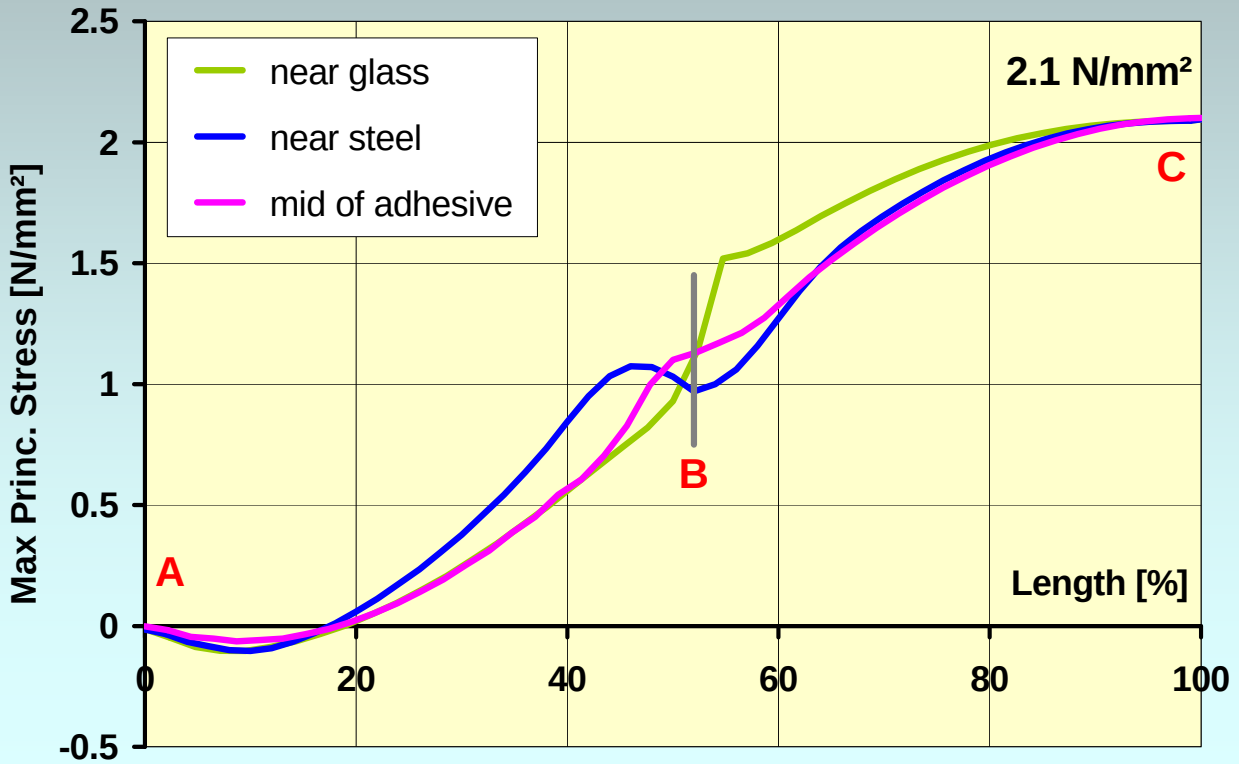


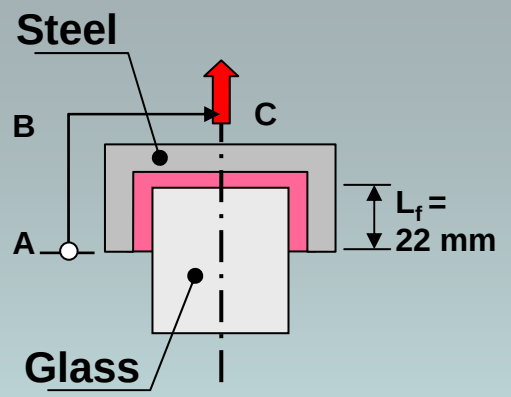
Experimental Results: Failure of U-type Bonding

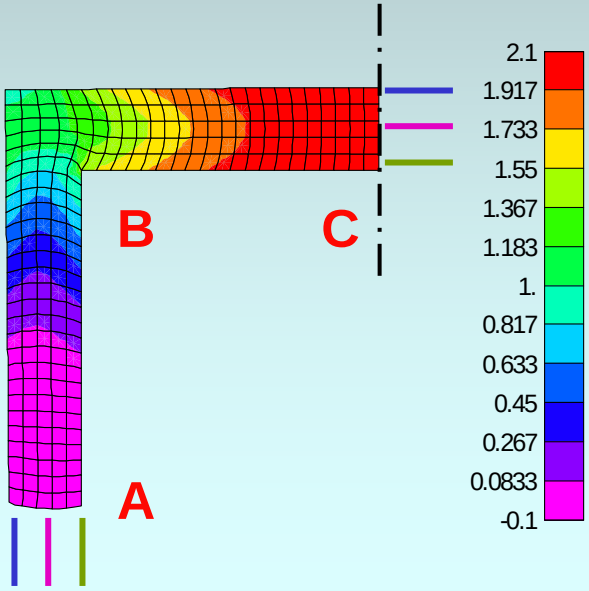


Stress Distribution of U-type Bonding Geometry

- Half 2D model taking into account symmetry conditions
- Plotting of max principal stresses for three different levels
- Stress level in vicinity of point A relevant for durability aspects

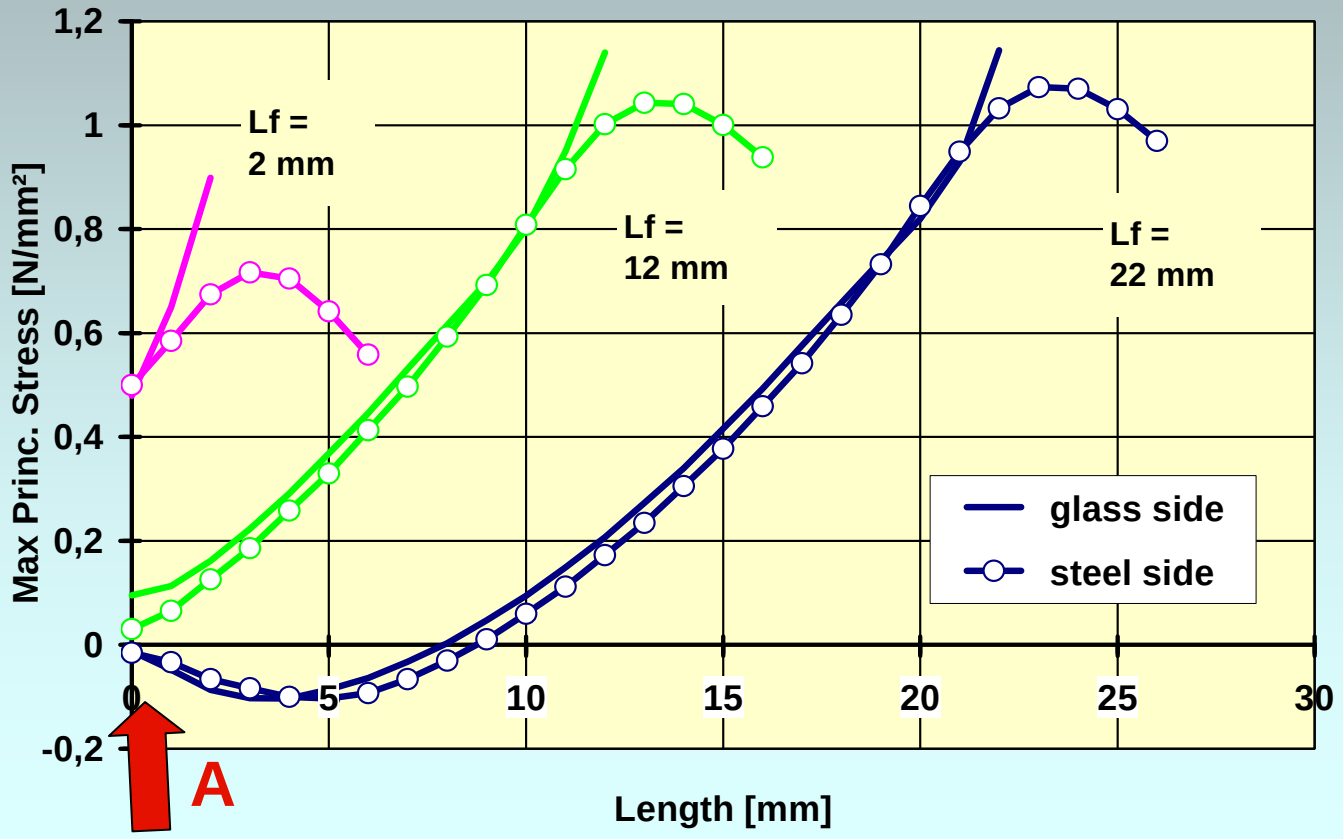


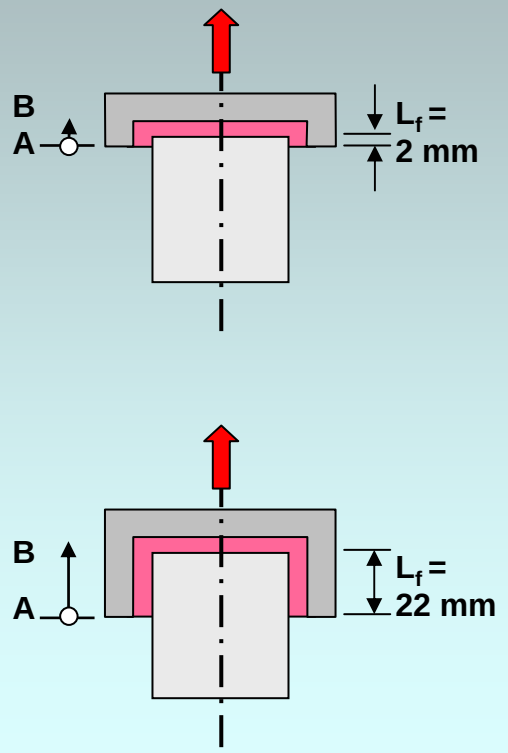




Stress Distribution at Flanges for Different L_f

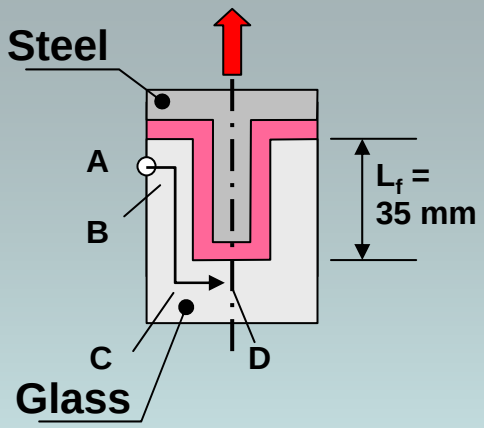
- Results presented near glass or steel: values in middle of adhesive less critical
- Small stress levels at free surfaces (A) observed for L_f > 12 mm
- Therefore adequate durability behavior is expected for these designs

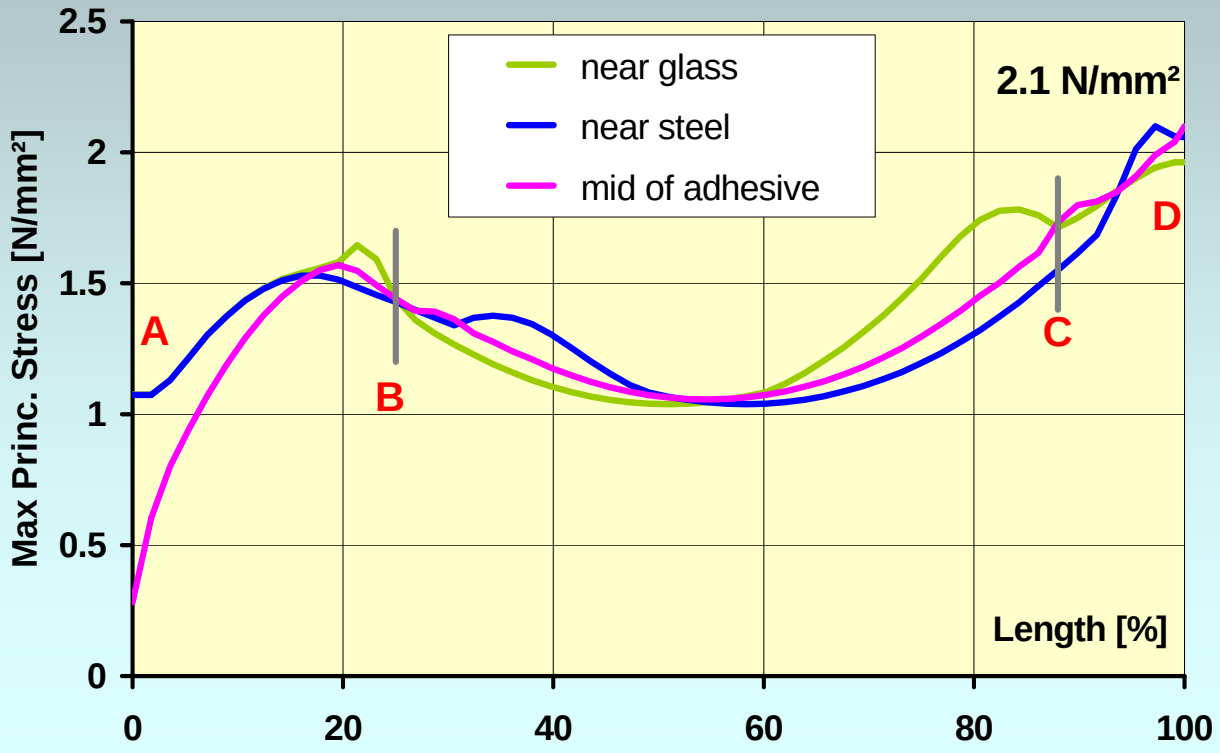


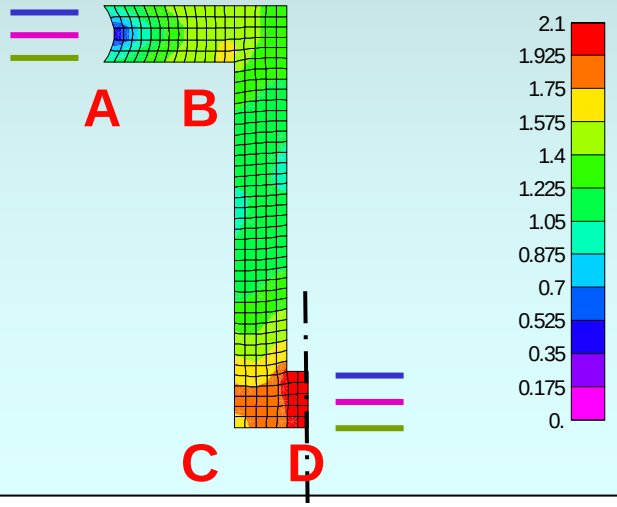


Stress Distribution of T-type Bonding Geometry

- Half 2D model taking into account symmetry conditions
- Plotting of max principal stresses for three different levels
- Stress level near point A relevant for durability aspects

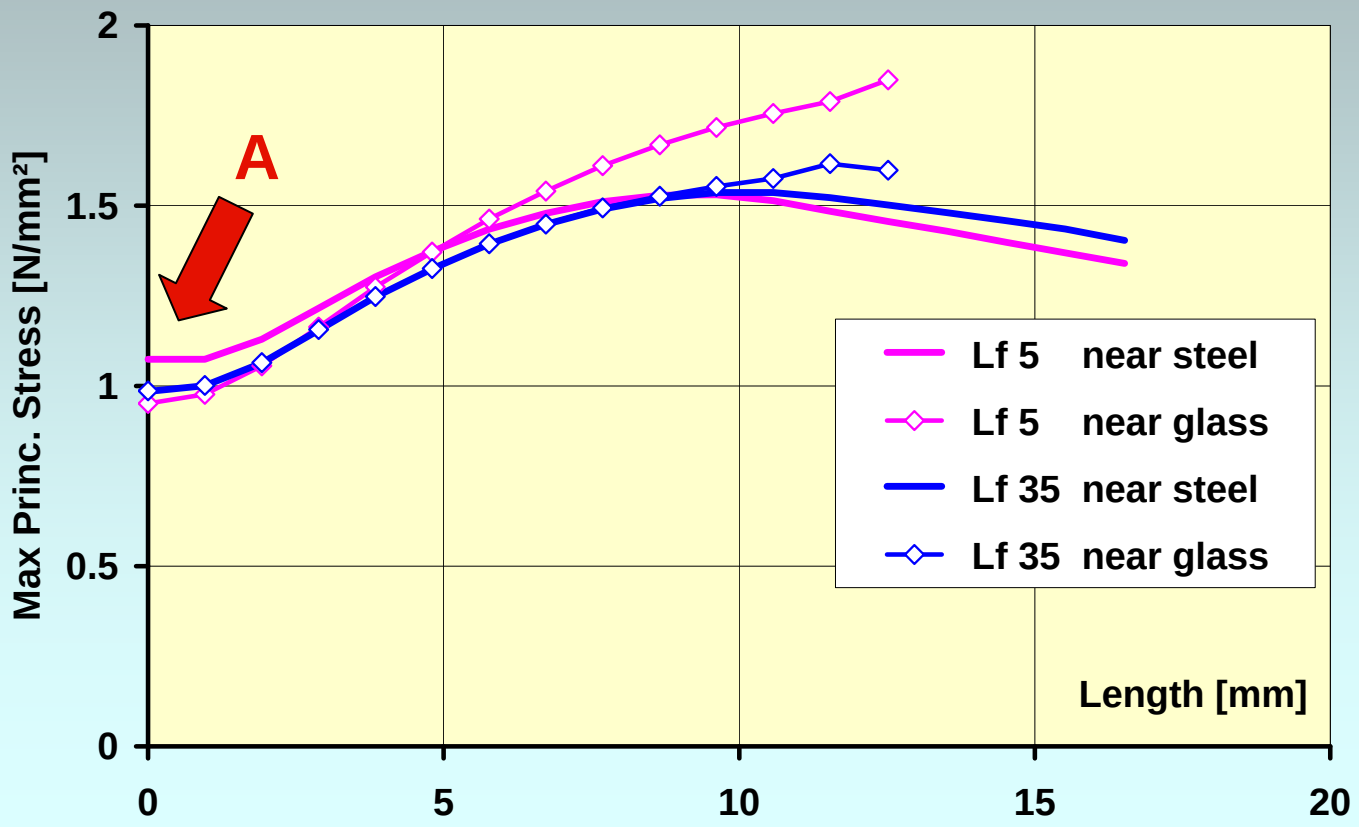


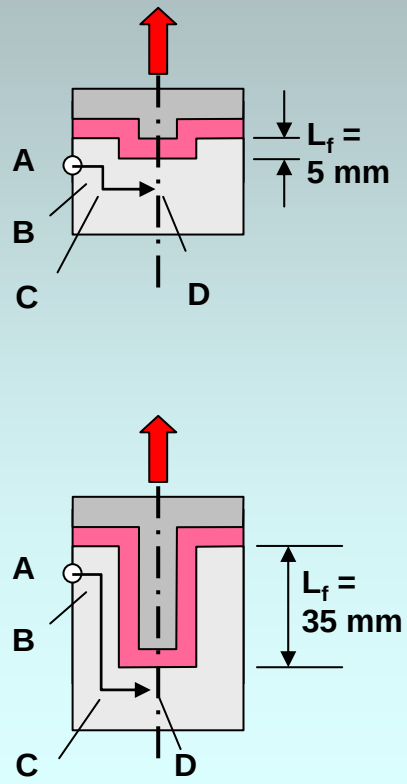




T-Type Bonding Stress Distributions for Different L_f

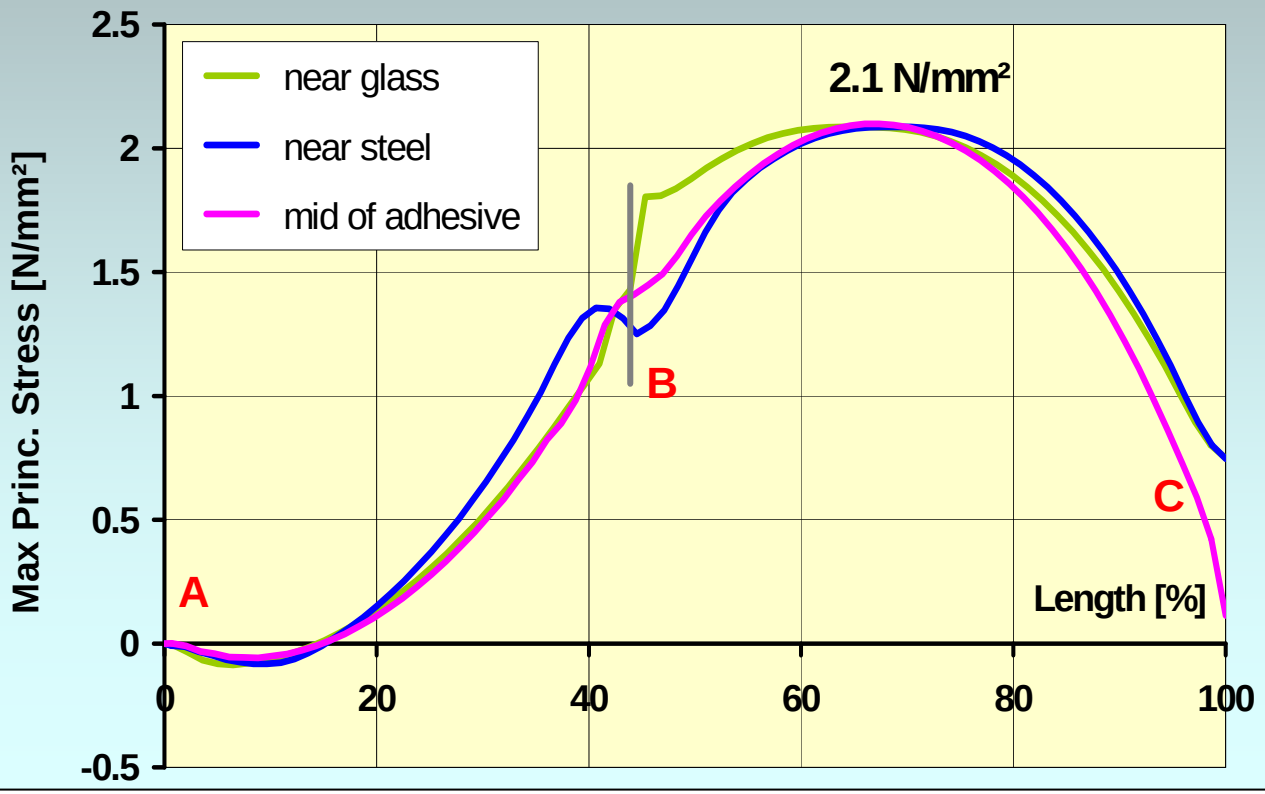
- High stress levels near point A compared to U-type bonding
- T-type bonding ranked lower concerning durability
- Variation of L_f without major impact on stress levels near point A

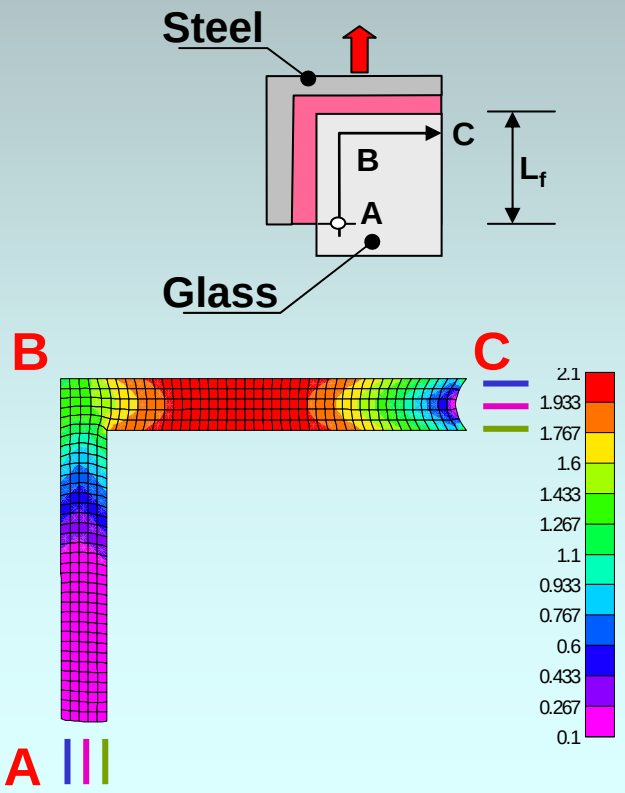




Stress Distribution of L-type Bonding Geometry

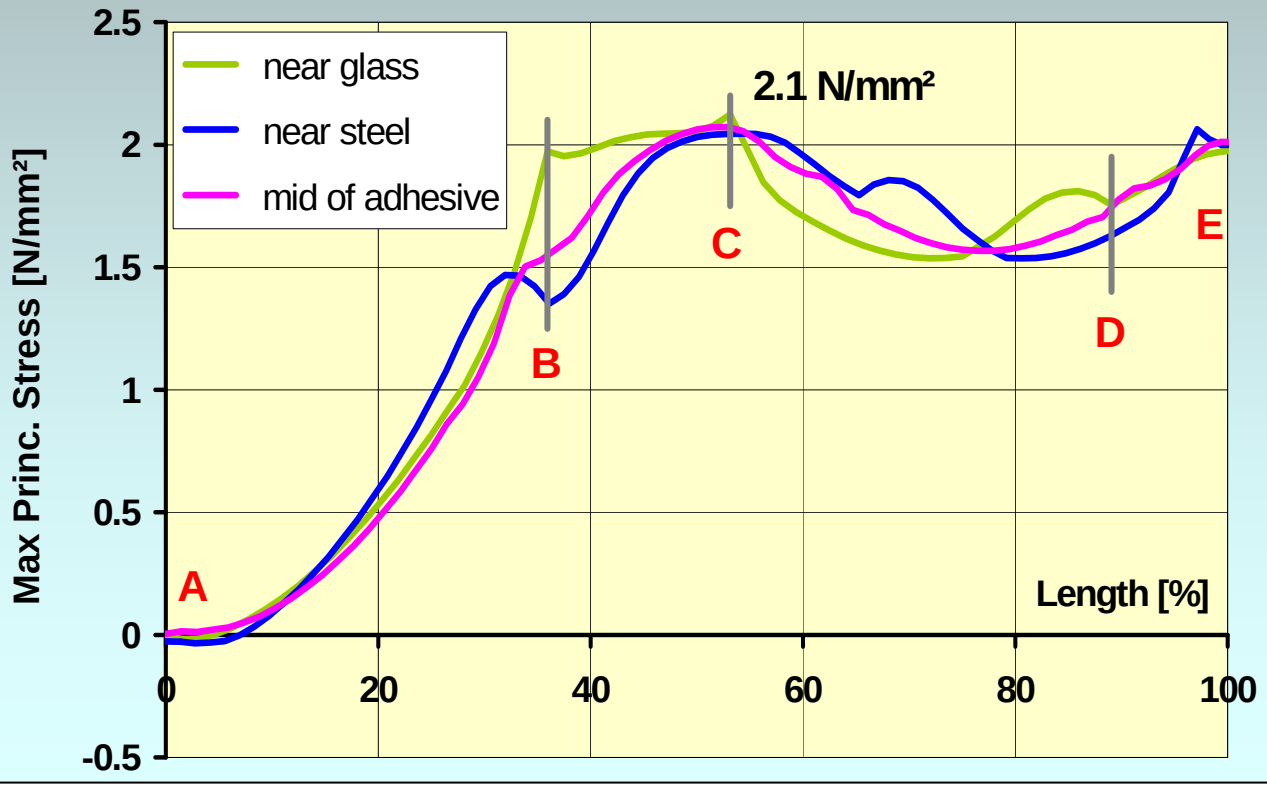
- Full 2D model due to missing symmetry
- Stress levels near points A and C relevant for durability aspects
- Stress behavior near point A corresponding to U-type bonding geometry
- Stress behavior near point C corresponding to T-type bonding geometry

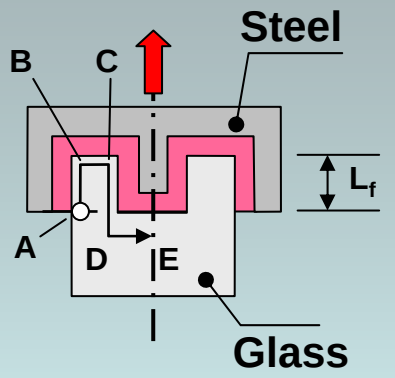


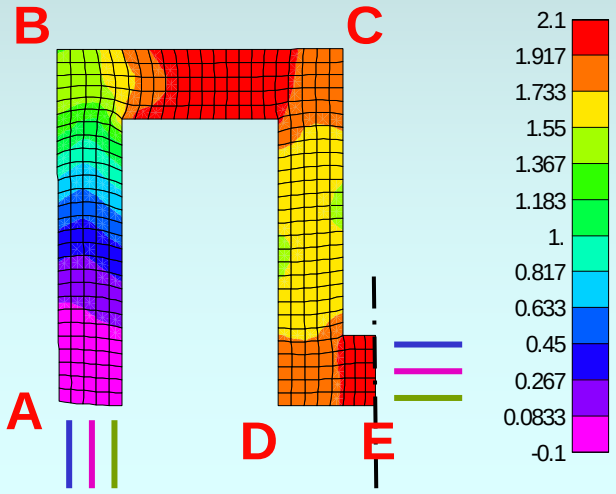


Stress Distribution of E-type Bonding Geometry

- Half 2D model taking into account symmetry conditions
- Stress levels near point A relevant for durability aspects
- Stress behavior corresponding to combination of U-type and T-type bonding geometry







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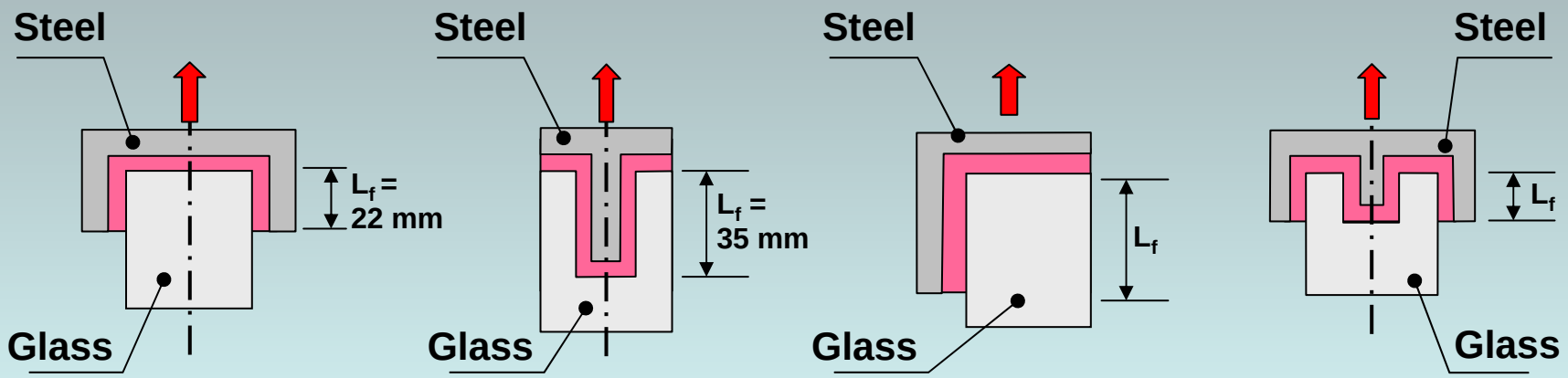
Conclusions of Bonding Geometry Analysis

- Different bonding geometries investigated for tension load case: U-type, T-type, L-type and E-type

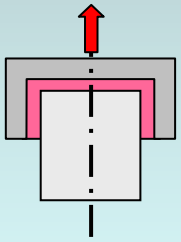


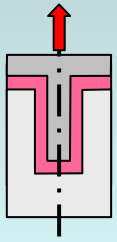
- U-type and E-type bonding geometries favorable with respect to durability aspects
- T-type and L-type bonding geometries less favorable with respect to durability aspects

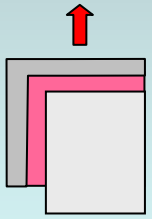
Comparison of Stress Distributions

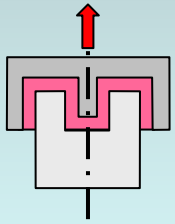
Similar bonding geometries show similar stress distributions on comparable parts of their geometries

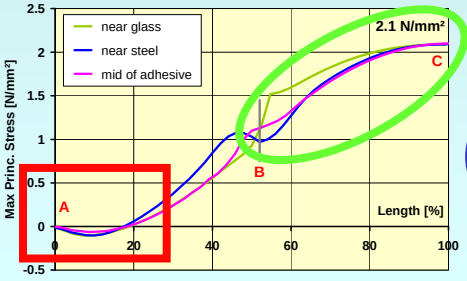
- Side region with a free edge: U, L, E
- Front region with free edges: T, L
- Front region with an encapsulated flange: T, E
- Encapsulated front region: U, L

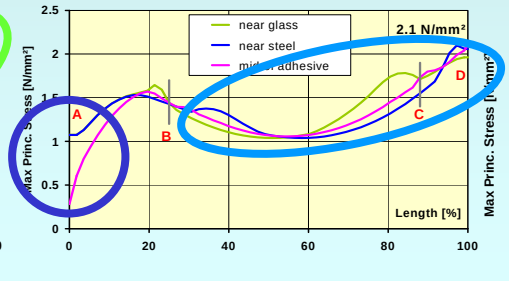


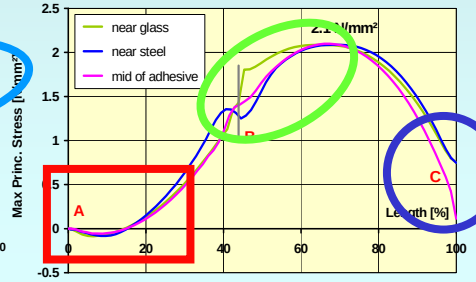


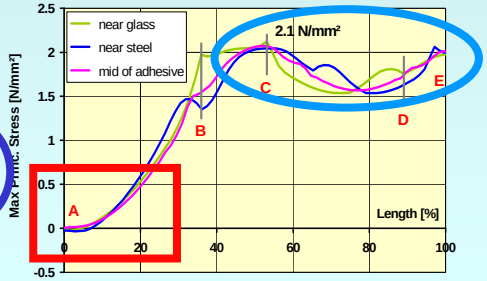






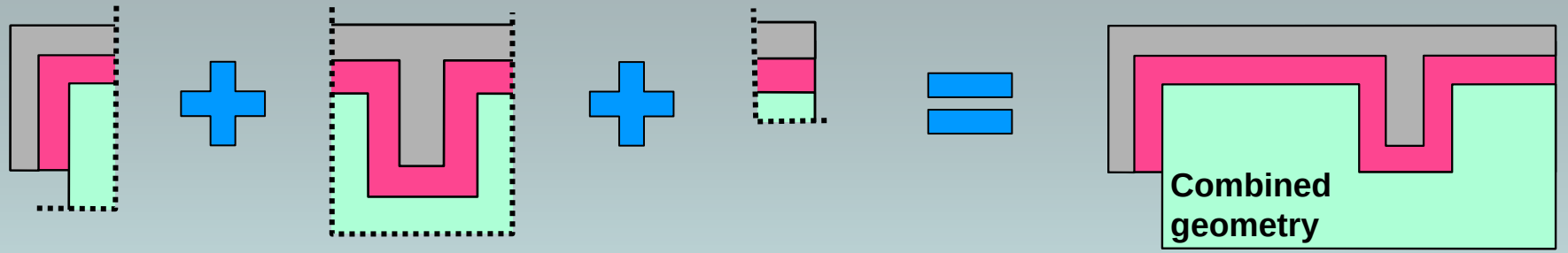






Generalization of Results

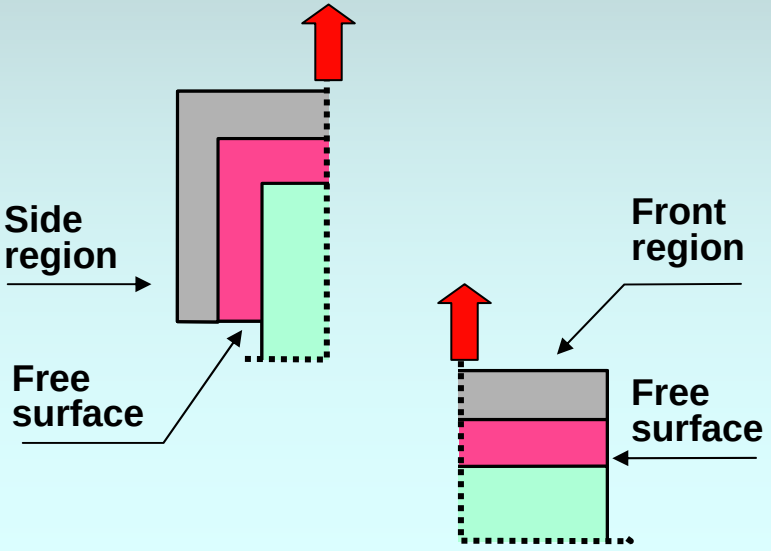
- Results can be applied for a class of bonding geometries with planes parallel and perpendicular to tension loading. Example:



- Durability assessment depending on free surface configuration

- For bonding geometries with free surfaces located at end of the side region: good durability property expected

- For bonding geometries with free surfaces located at end of front region: lower durability expected




Questions ?