Infusion Technology for Bonded CFRP Repairs

(for Aircraft Primary Structures)

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Hochleistungsleichtbau
anpassungsfähig – effizient – tolerant

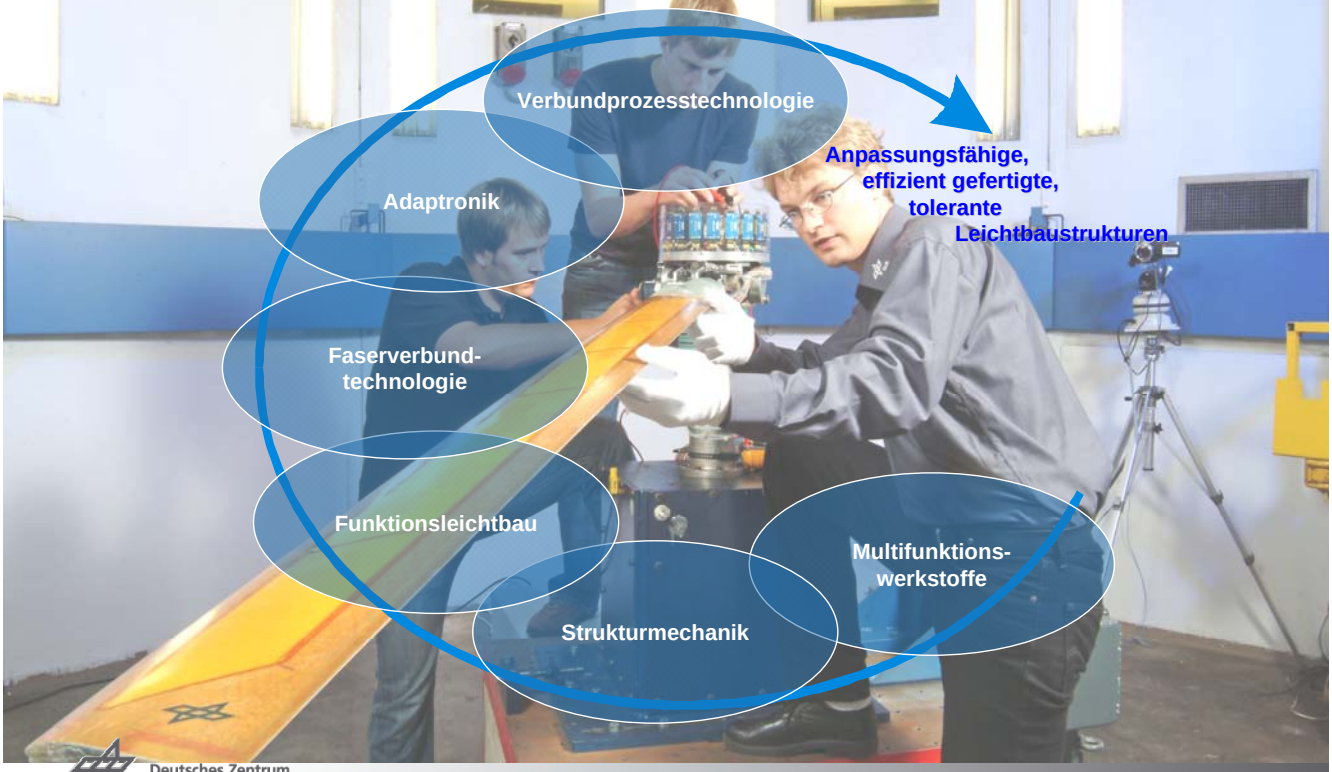
Wir sind die Experten für Entwurf und Realisierung anpassungsfähiger, effizient gefertigter, toleranter Leichtbausysteme.

Unsere Forschung dient der Verbesserung von

- Sicherheit
- Kosteneffizienz
- Funktionalität
- Komfort
- Umweltverträglichkeit

Wir schlagen die Brücke zwischen Grundlagenforschung und industrieller Anwendung

Die Prozesskette des Hochleistungsleichtbaus

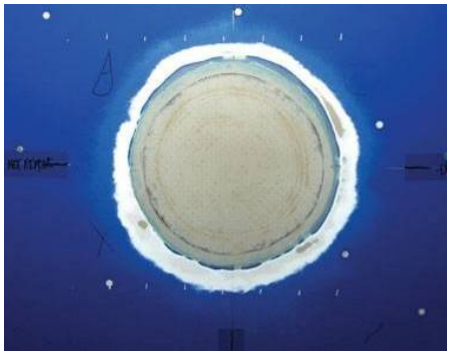


Infusion Technology for Bonded CFRP Repairs

Outline

- Repair environment
- State-of-the art of CFRP repair
- Repair concepts
  - Design and automation
  - Infusion repair
- Summary
- Outlook

Damage by Lightning Strike



Boeing Demonstration of (cosmetic) Patch Repair

Repair Environment (EASA)

- **Primary structure**
  - Safety relevant, failure causes total loss
    e.g. centre wing box, VTP bearings, rudder, fuselage
- **Secondary structure**
  - Structure relevant for normal operation, failure does not cause total loss
    e.g. aerodynamic fairings / flaps, slats
- **Tertiary structure**
  - Remaining structure, failure has low impact on operation
    e. g. maintenance covers

→ **Repaired by OEM or certified Company**
  - Redesign and certification of repair necessarry
    e. g. new frame coupling

→ **Repaired by Operator**
  - By *structural repair manual* (SRM)

→ **No immediate Repair necessary**
  - Part may be temporarily removed
  - Failure cascade has to be prevented

State-of-the-art : Bolted Repair

Bolted Repair

- Bypass of original load path by riveting of one or two doublers

Advantage

- Good recovery of strength
- Slight
- Fast application
- Easy certification because of Fail-Safe-Concept

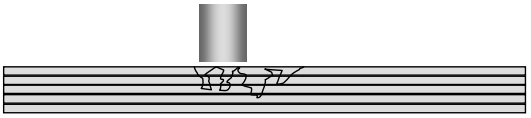
Disadvantage

- Minimum skin thickness necessary
- Steps in aerodynamic shape
- Complex at edges and pressure vessels
- High weight, two sided access required

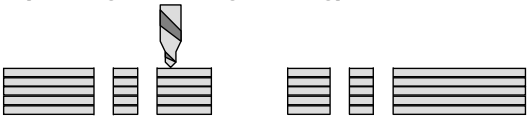
Examples

- Thick aircraft structures (>3mm)

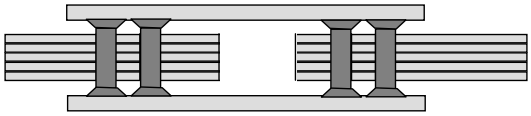
1. Damage Detection by NDT



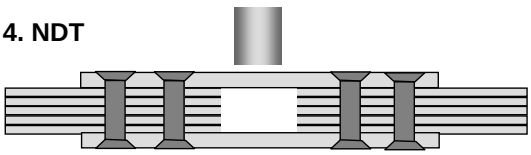
2. Removal of Damage (Drilling, Grinding, Milling)



3. Riveting of Doublers



4. NDT



State-of-the-Art : CFRP-Patch Repair

Scarf Repair

- NDT, removal of damage, manual grinding of scarf, co-curing of wet prepreg layup or co-bonding of hard patch (separate tooling necessary), prepreg technology favoured.
- Ramp of scarf 1:20 – 1:60

Adavantage

- Original structural behaviour nearly restored
- Flush repair
- Excellent mechanical performance

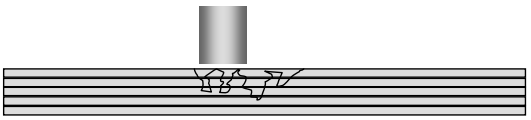
Disadvantage

- Extremely complex and time consuming
- Quality management complex (fellow coupons)
- Much of healthy material has to be removed by the scarf → Weakening of Structure?

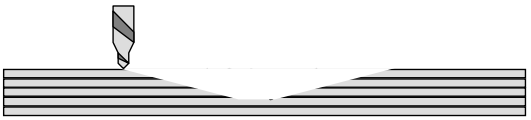
Examples

- Repair of flaps (A320)

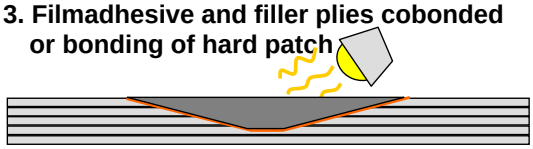
1. Damage detection by NDT



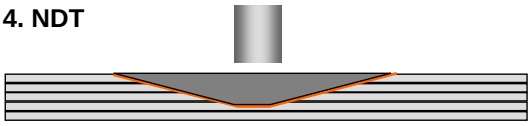
2. Removal of damage by grinding or milling



3. Filmadhesive and filler plies cobonded or bonding of hard patch

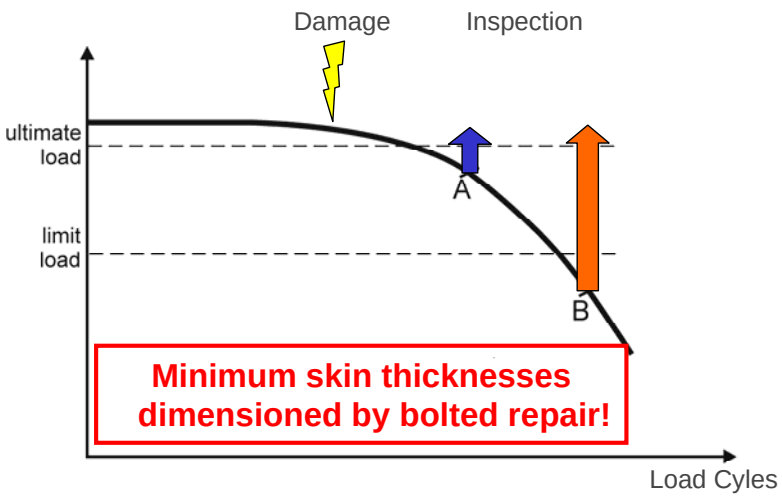


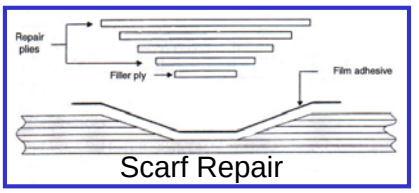
4. NDT



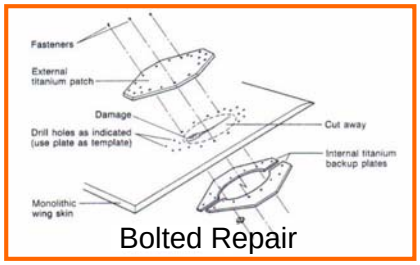
Repair Environment

- **Repair scenario for primary structures**
  - Scenario A: Bonded repair allowed
  - Scenario B: Restricted to bolted repair





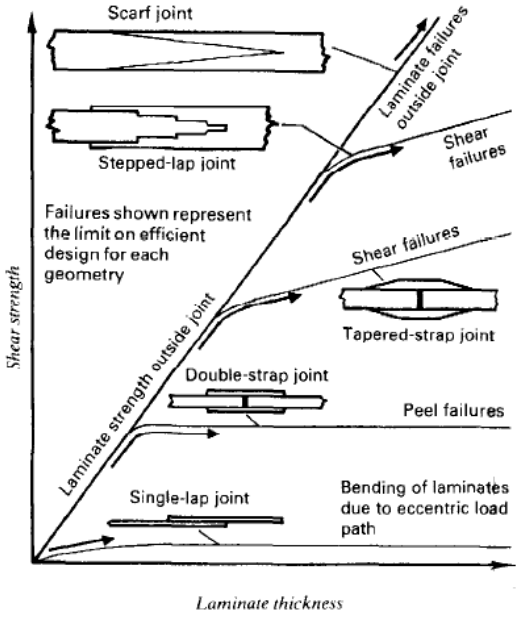
Scarf Repair



Bolted Repair

State-of-the-Art: CFRP-Patch Repair

Structure Mechanical Background



State-of-the-Art: Bonded CFRP-Patch Repair

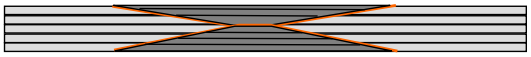
Patch Repair Variation by Baker (*Composite Materials for Aircraft Structures*)

Standard Scarf

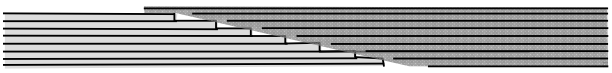
Scarf Repair with Overply + Integrated Filler Plate

Scarf Repair with Overply + Bonded Plate

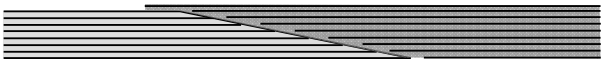
Double Scarf



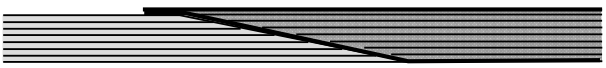
Stepped Repair with Overply (Ply-by-Ply)



Scarfed Repair with Overply (Ply-by-Ply)



Scarfed Repair with Continuous Ply

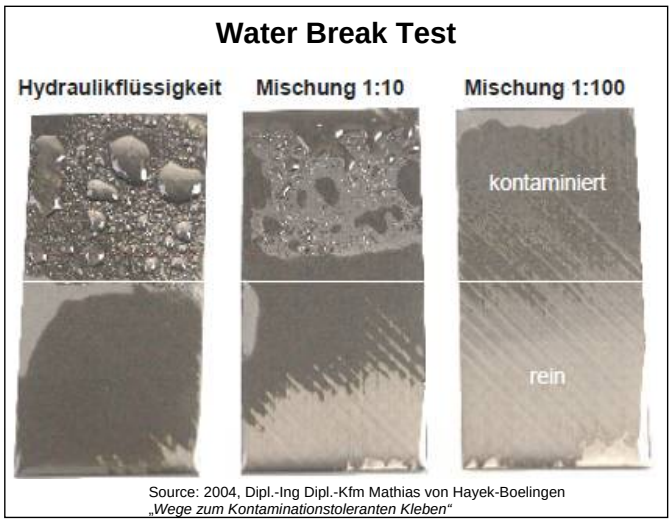


Scarfed Repair with Cupped Plies

State-of-the-Art: Surface treatment CFRP-Patch Repair

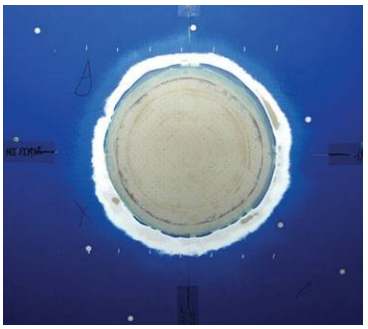
- **Contaminated Surfaces**
  - Fuel, hydraulic oil, gear oil, silicone oil, lubrication grease, organic grease, de-icing fluids, mould release (silicone based or fluor-carbon hydride based), soot, water / moisture
  - Risk of a „Kiss Bond / Slip Bond“ (contact of boundary layer without shear strength)

- **Preparation of Repair Surface**
  - Moist structure / dry patch
    - complex drying of surface
  - Grinding/Milling of scarf, laser
  - Testing of surface
    - Waterbreak test
  - Preparation of bondline surface
    - Grinding, blasting, wet peel ply (patch), corona, plasma pyrolysis (glass fibre)
  - Fellow coupon tests



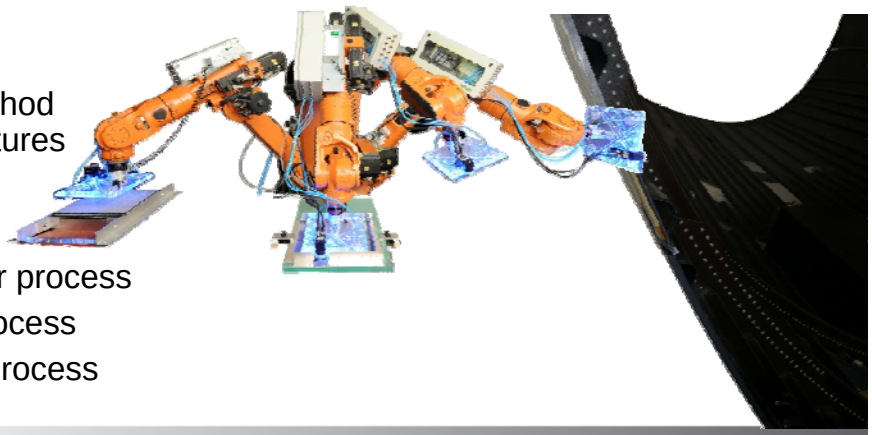
Source: 2004, Dipl.-Ing Dipl.-Kfm Mathias von Hayek-Boelingen
„Wege zum Kontaminationstoleranten Kleben“

DLR – Concepts for Bonded Repair


Repairs done today
Repairs done tomorrow
Demonstration of Boeing 787 Repair

- **Challenges**
  - Reduction of maintenance time
  - Reduction of maintenance costs
  - Certification of bonded repairs
  - Reproducibility / human factor
  - Structural performance

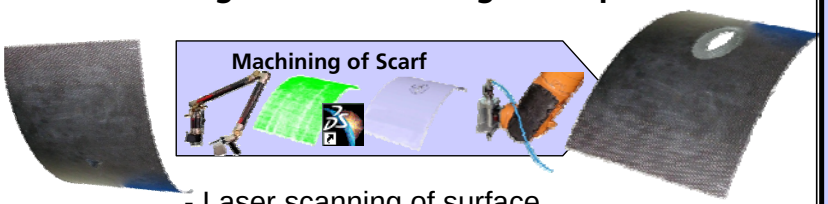
- **Aim**
  - Depot repair method for primary structures



- **Solutions**
  - Automated repair process
  - Robust repair process
  - Fail-safe repair process

DLR - Concepts

Design and Machining Concept



- Laser scanning of surface
- Surface reconstruction of real geometry
- Design of scarf
- Generation of machining data
- Milling of scarf (3-axis or 7-axis)

Advantages

- Digitized geometry for automation of repair process
- Digitized geometry for tooling generation (hard patch)
- Digitized geometry for documentation
- Automated milling/grinding of scarf for minimization of human factor
- automated milling/grinding of scarf for maintenance time reduction

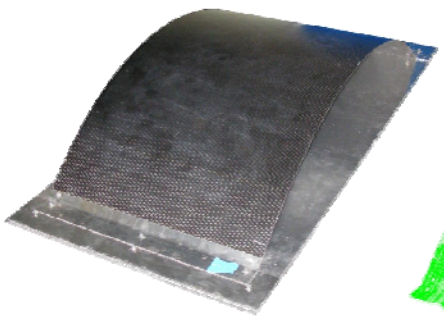
DLR - Design Concept

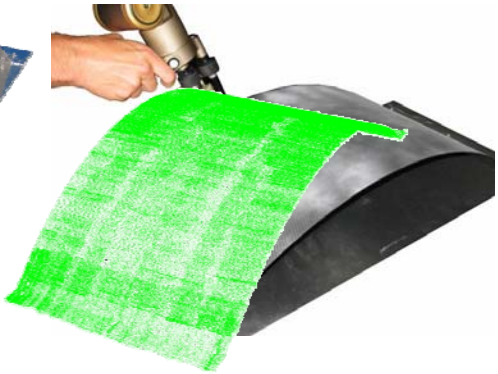
- **Removal of Damage / Scarfing**
  - Laserscanning of 3D-Surface

Scanning by Perceptron V5 Laserscanner

or

ATOS 3D-Scanning System*
Manufacturer: GOM

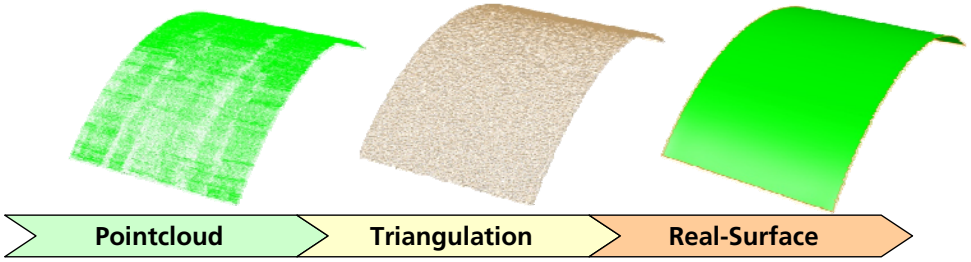




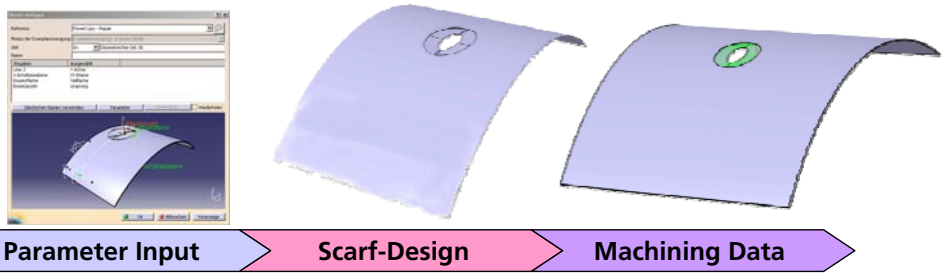
*Source: EADS

DLR - Design Concept

- **Virtual Design of Repair**
  - Surface reconstruction in CATIA V5



  - Design of Scarf by parameterized construction



Infusion Repair

Advantages

- Easy repair process via infusion of patch
- No patch tooling required
- Flexible patch for repair of double curved structures
- High mechanical performance
- Single sided access only

Design and Machining Concept

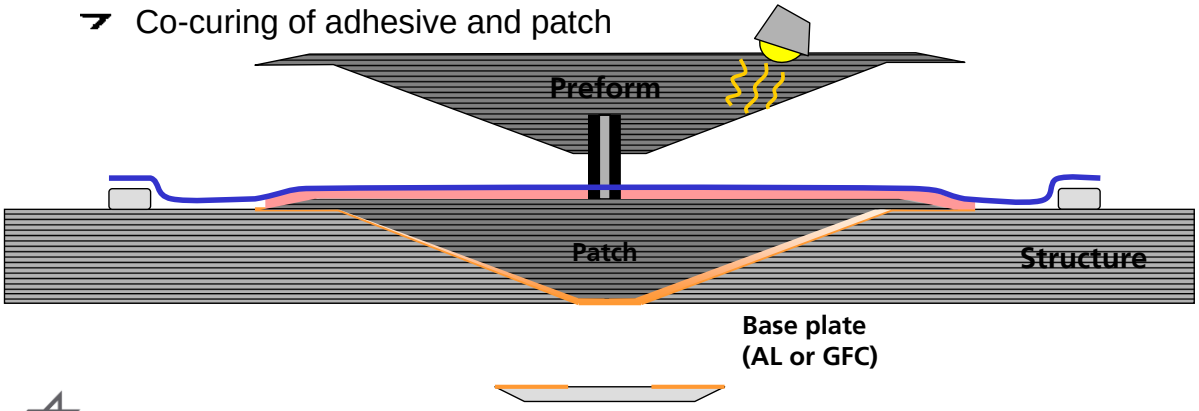
- Laserscanning of surface
- Surface reconstruction of real geometry
- Design of scarf
- generation of machining data
- Milling of scarf (3-axis or 7-axis)

Repair Concepts

- Infusion of Positioned Preform
- Cobonding of Patch and Adhesive
- One Sided Access only
- Low Assembly Tolerances

Infusion Repair

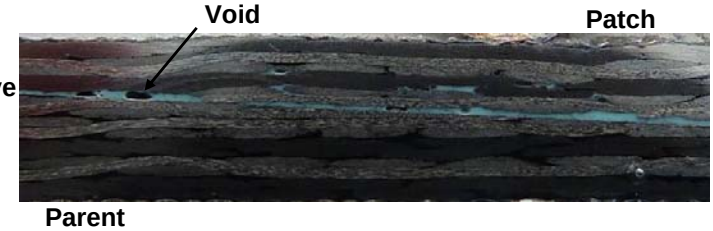
- **Cobonding infusion repair concept**
  - Bonding of filler plate
  - Insertion of film adhesive
  - Insertion of preform (with overplies)
  - Single sided vacuum bagging
  - Infusion of preform
  - Co-curing of adhesive and patch

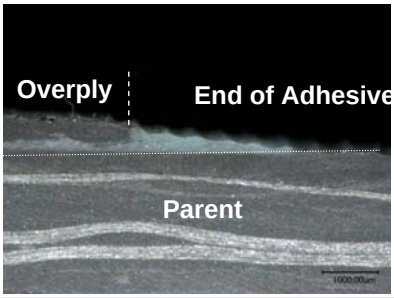


Infusion Repair

- **Evaluation of Mechanical Performance**
  - Coupon specimen EN6066
    - Easy manufacturing
    - Easy testing (1-axis tension)
    - Testing of scarf not adhesive
    - Quantative evaluation of joint
    - Surface analysis of broken surface

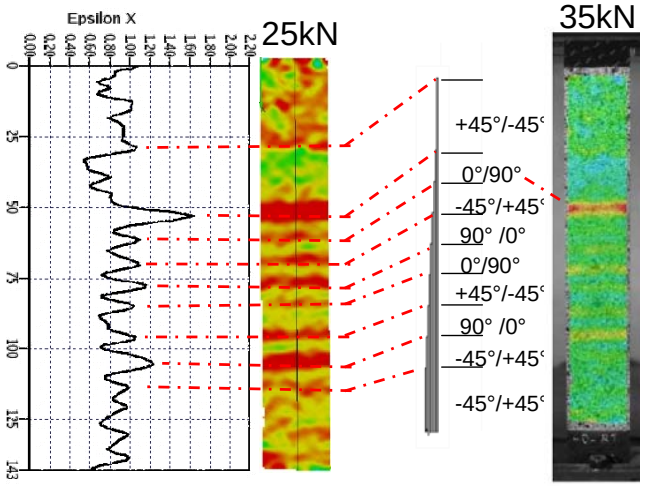
Standard Set of
En6066 Coupons





Infusion Repair

- **Investigation of mechanical performance**
  - ARAMIS
    - Evaluation of surface strainfield
  - Strain gauges for local strains

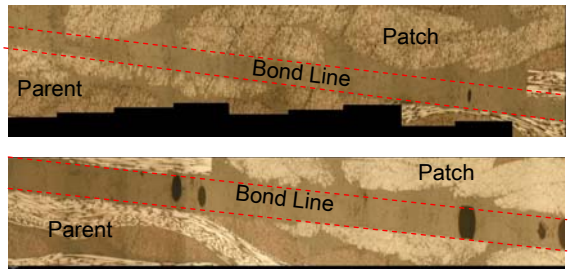


Infusion Repair

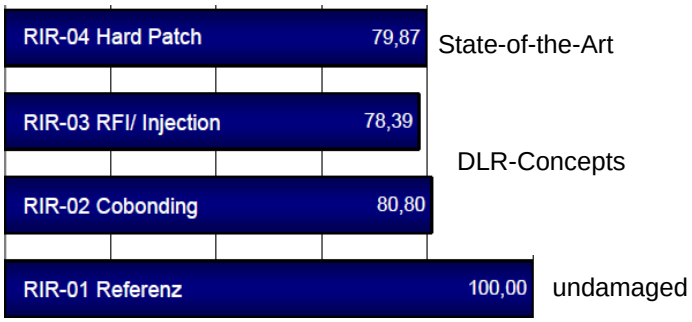
- **Detail testing**
  - Quantification of geometry influence
    - Scarf angle, elliptic repairs
  - Evaluation of repair process
  - Verification of concepts
  - Validation of patch lay-up
    - Ply-by-ply / cupped
  - Validation of machining concept
  - Validation of handling concept

Infusion Repair

- **Microscopic Evaluation**
  - Cobonding
    - Good bond line, no voids
  - Hard patch (state-of-the-art)
    - Good bond line, some voids

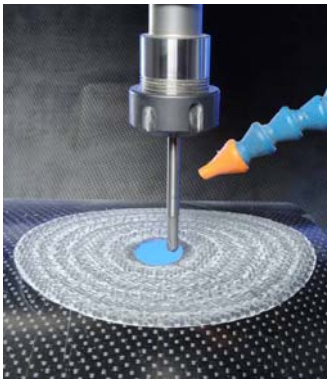


- **Mechanical Evaluation (Coupon)**
  - Infusion repair has equal mechanical performance compared to hard patch
  - About 80% total load recovery has been achieved

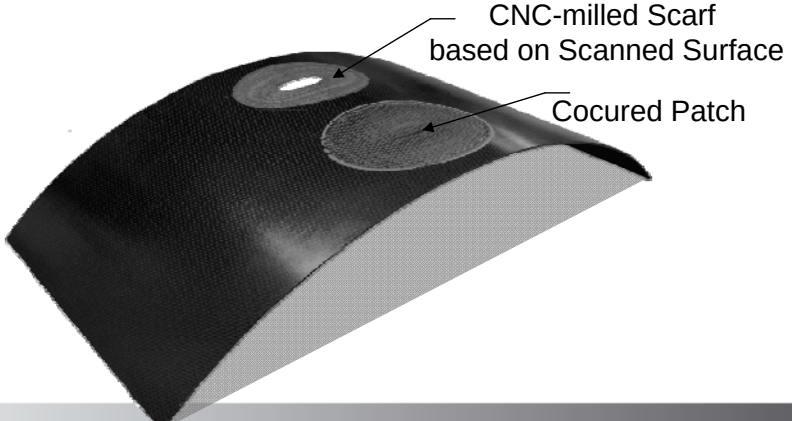


Proof of Concept

- **Design and Machining Concept**
  - Milling of a 3D Scarf



- **Infusion Patch Repair**
  - 3D-Demonstrator



Summary

- State-of-the art lacks a bonded repair solution for primary structures to overcome „designed for bolted repair“- design-rule
- Repair is strongly driven by certification requirements
- Design and machining concept improves repair quality, documentation and allows process automation as well as new geometries
- Infusion repair reduces process complexity for curved parts drastically by equivalent mechanical performance

Outlook

- **Improvement of machining concept**
  - Miniaturization
  - Making it movable
- **Investigation of alternate load scenarios**
  - Compression
  - Load combinations
  - Fatigue
- **Developement of a 3D Repair Standard Detail Specimen**
  - Aim: Comparison of repair processes, investigation of load shifts around 3d-patchrepairs
- **Simulation and optimization of 3D-patch repairs**

Vielen Dank für Ihre Aufmerksamkeit

Contact Data

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