Fibre-Reinforced-Plastic (FRP) Wheel Developing and Testing at LBF

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Structural Durability on Fibre-Reinforced-Plastic Wheels
Questions for LBF: from the 70’s up to now

„Structural Durability“ → How to proof?
Lesson Learned from the 70’s Rotating Bending Test

Measurement of displacement in 2 directions

Rotating mass \( m \)

\[ \Delta d = d_N - d_0 \]
\[ \Delta d = 0.1 \text{ mm} \]

Failure Criteria of FRP-Wheels is different compared to Metal Wheels.

Test criterion: Stiffness loss \( \leq 10\% \) \( \equiv \Delta d = 0.1 \text{ mm} \)

\( M_b = 2.2 \text{ kN} \)
Lesson Learned from the 70’s
Procedure for a Rotating Bending Test

Test criterion: stiffness loss of $\leq$10 %, corresponding to an increase of the displacement $\Delta d = d_N - d_O = 0.1$ mm with

- $d_N = \text{displacement at the test end}$,
- $d_O = \text{displacement at the test initiation}$

Needed Tests:

3 Tests with $M_b = 2.2$ kNm $\Rightarrow$ Cycles: $N_4 = 1.8 \cdot 10^5$; $N_3 = 2.4 \cdot 10^5$; $N_2 = 2.5 \cdot 10^5$

2 Tests with $M_b = 2.0$ kNm $\Rightarrow$ Cycles: $N_5 = 5 \cdot 10^5$; $N_6 = 2 \cdot 10^6$

1 Test with $M_b = 1.75$ kNm $\Rightarrow$ Cycles: $N_1 > 6 \cdot 10^6$ without stiffness loss

Load levels $M_b$ for the S-N-curve: 80%, 75%, 65% of $M_{b,100\%}$

Loading moment used for fatigue approval based on existing rules for steel and aluminium-alloy passenger car wheels: $M_{b,100\%} = 2 \cdot F_{z,\text{stat}} (r_{\text{dyn}} \mu + e)$.

With $\mu = 0.9$ it corresponds to a bending moment $M_{b,100\%} = 2.64$ kNm
Lesson Learned from the 2010’s ZWARP Test’s on Hybrid Wheels

Result:
After the first 10,000 ZWARP km the metal part fails.

After the second 10,000 ZWARP km the second metal part fails.

There was no failure occur in the FRP Rim.

Wheel Load 650 kg
Lesson Learned from the 2010’s ZWARP Test’s on Hybrid Wheels

Failure at 4643 ZWARP km → Pressure Lost

Result:
The metal part fails first.
After changing, the ZWARP-Test generate a failure in the FRP-Part.

Required Design Rule for FRP:
Damage Tolerance

Wheel Load 650 kg
Pre-Damage and 30% higher Wheel Load

Lesson Learned from the 2010’s ZWARP Test’s on Hybrid Wheels

Failure at 4643 ZWARP km → Pressure Lost

Result:
The metal part fails first.
After changing, the ZWARP-Test generate a failure in the FRP-Part.

Required Design Rule for FRP:
Damage Tolerance
Open Points:
• Design philosophy – „safe life“ versus „Damage Tolerance“
  How do you prove damage tolerance?
  How do you prove the structural durability of safety components?
• Design Concept – one- or multi-axial
  How do you design components in FRP?
• Quality assurance/Evaluation of damages
  Effects of defects considering reliability?
• Evaluation of Components in used – SHM
  How do you evaluate used components in praxis? – NDT, Monitoring
Developed Test Procedure for FRP Wheels

6 Wheels

Stiffness Measurement (Reference)

Preconditioning:
- Radial Impact Level 2
- Overpressure (12bar 60 sec with 0.5bar/3sec)
- High-Temperature (10 Times 20°C/+5°C for 10 min)
- Small Impact Damages (DIN EN ISO 20567-1 Verfahren B)
- Small Surface Damages (DIN EN ISO 17872)
- Steam Jet Test (DIN 55662)
- Environmental Conditioning – 6 Weeks based on SEP1850

1 Wheel

Measurement of the Wheel Conductivity WDK 110
1 Unaged Wheel

Evaluation

Stiffness Measurement (Reference after Preconditioning)

Rotating Bending Test
5 Unaged Wheel

ZWRAP 7500 km
AK-LH08
Aged Wheel

Radial Impact Level 3
1 Unaged Wheel

STiffness Measurement (after ZWRAP)

Evaluation

13th Impact
1 Unaged Wheel

Evaluation

Partners: Audi, BMW, Carbon Revolution, CarboTec, Daimler, Fraunhofer LBF, Leichtbauzentrum Sachsen, Otto Fuchs, Porsche, Ronal, TÜV Nord&Süd, VW

One Goal of the Test Procedure is the Proof of „Damage Tolerance“
Stiffness Measurement

for comparable results with a defined test rig and test procedure is needed.

**Assumption:**
Damages in the FRP-Parts caused a Stiffness Lost.
# Acceptable and Inacceptable Failures

## Acceptable  →  Stiffness Lost < 20%

### Inacceptable:
- Stiffness Lost > or = 20%,
- Sudden Death
- Sudden Air Lost
- Nut Loose(*)
- Loose of Parts or Fracments
- No plastic Deformations

(*) No Nut Loose after the Rotating Bending Test or the ZWARP test or after the Temperature Test with more than 30% of the tightening torque

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Rotating Bending Test

**Two load level until failure or fracture**

1. \( M_{b_{\text{max}}} \geq 75\% \) - one wheel until fracture or \( N > 200,000 \)

2. \( M_{b_{\text{max}}} \): to be define – three wheels until fracture

\[ M_{b_{\text{max}}} \geq 95\% \text{ or } \leq 55-60\% \]
(at least 20% higher or lower than 1)

**Objective:**
Estimation of the slope \( k \) of the estimated SN-Curve with \( \geq 5 \) measurements points.

If there is no fracture visible, the slope \( k \) must be agreed together with “technischen Dienst”.

After 10,000 load cycle tighten Screws!
ZWARP – Test with One Predamaged Wheel

“Standardize Load Spectre” based on AK-LH08

Calibration over axle load

Testing Distance: 7500 km

Objective:
Proof of the „Damage Tolerance“
In 2012: Multifunctional Design of a FRP Wheels

LBF: Development of a FRP Car Wheel with an Integrated Electric Motor

1. CAD-Design

2. Identification of Critical Areas

3. Optimization considering Load Cases

Requirements:
Loading, Space, Weight, Integration of the Electrical Drive

4. Mold design & fabrication

Load Case: Braking

5. Component Manufacturing

6. Testing

LBF: Development of a FRP Car Wheel with an Integrated Electric Motor
Design and Prototyping - Composite Wheel with Motor

15”
3.5 kg
Common Product Development Process at Fraunhofer

**Diagram Overview**

- **Requirements**
  - Brainstorming
  - Morphological method
- **Concept**
  - Development of structures and mechanisms
  - Design
  - Material-definition
  - Engineering, design
- **Material, Compound**
  - Material Design
  - Material development
  - Chemical analysis
  - Additivation
  - Stabilisation
  - Compatibilisation
- **Specimen**
  - Sample Preparation
  - Injection molding
  - Extrusion
  - Hand lay-up
  - RTM
- **Simulation Result-Files**
  - Mashing
  - Definition of load cases
  - Simulation isotropic and anisotropic
  - Simulation, Calculation
- **Components**
  - Injection molding
  - Extrusion
  - RTM
  - Compression molding
  - Manufacturing at ICT
- **Assembly/System**
  - Definition of load cases
  - Definition of test procedure
  - Test rig design and build up
  - Testing and evaluation
- **Product**

**Legend:**
- LBF
- ICT

**Materials Tested:**
- All materials
- Plastics / compounds

**Simulation Methods:**
- Cyclic (S/N curve, Gassner)
- Static (strength, stiffness, poisson’s ratio)
- Dynamic
Special Equipment – Fraunhofer ICT

Manufacturing Technologies - compression molding technology
Development of new Process Techniques

Dieffenbacher Presse Typ Compress Plus

- Pressure Load: 3.200 t
- Clamping Surface: 2.900 x 2.000 mm
- Minimal tooling height: 755 mm
- Maximal tooling height: 1.500 mm
Project CARIM

“Commercialization of a full carbon wheel manufactured with automated high-volume process for the automotive market”

Key data CARIM:
H2020-FTIPilot-2015-1 – 690915

Budget: 2.44 mio. €
(1.93 mio. € funded by EU)

Duration: 01.01.2016 – 31.12.2017

Partners:
- Fraunhofer ICT
- RI-BA Composites Srl (I)
- TÜV SÜD Product Service GmbH
- Alpex Technologies GmbH
- Alma Mater Studiorum - Bologna University (I)

Supported by Fraunhofer LBF: Calculation and Testing

Project coordinator: Philipp Rosenberg (Fraunhofer ICT), Tel. +49 721 4640 417, philipp.rosenberg@ict.fraunhofer.de
In the 80’s LBF made Load Measurement on Aircraft Wheels
Cumulative Frequency Distribution of Stresses

Airbus A300B

Resulting Cumulative Frequency Distribution of Stress Amplitudes

- Taxi (2)
- Landing Impact, Spin-Up, Spring-Back (1)
- Turning (4)
- Braking (3)

Strain Time Histories

Cumulative frequency H (log)
In the 80’s LBF made Load Measurement on Aircraft Wheels
Test’s on Main Landing Gear of an Airbus A300B
CFRP AIRCRAFT WHEEL (A320)
WEIGHT: 38KG; WEIGHT REDUCTION approx. 40%

Manufactured by Röder Präzision

First Prototyp in RTM

Designed by Fraunhofer LBF
CFRP Aircraft Wheel (A320)
Weight: 38kg; Weight Reduction approx. 40%

Manufactured by Röder Präzision
2017: Development of a composite aircraft nose wheel

Objectives:

- Development of an A320 nose wheel made from CFRP with following basic requirements:
  - significant reduction of weight
  - resistance against mechanical and environmental loads
- Development of a LP-RTM manufacturing process (CFP)
- Validation by manufacturing and testing of prototypes (CFP)
Vielen Dank für Ihre Aufmerksamkeit!!!

Im LBF entwickelte Primärkomponenten in FKV

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Other Examples of FRP products by LBF

Lower Control Arm
Weight reduction of 30%

Rear axle
Weight reduction of 37%