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Safety of High Pressure Hydrogen Tank - Approach to Carbon Neutral Society -

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1. High Pressure Hydrogen Management
2. Types of Tank
3. How to Ensure Reliability of Tank
4. Applicability of Fracture Mechanics
5. Application of Health Monitoring System

We have several options for energy supply chain to realize carbon neutral society.

Hydrogen is the most promising.

Mobile Application of Fuel Cell

https://www.intelligent-energy.com/our-products/uavs/

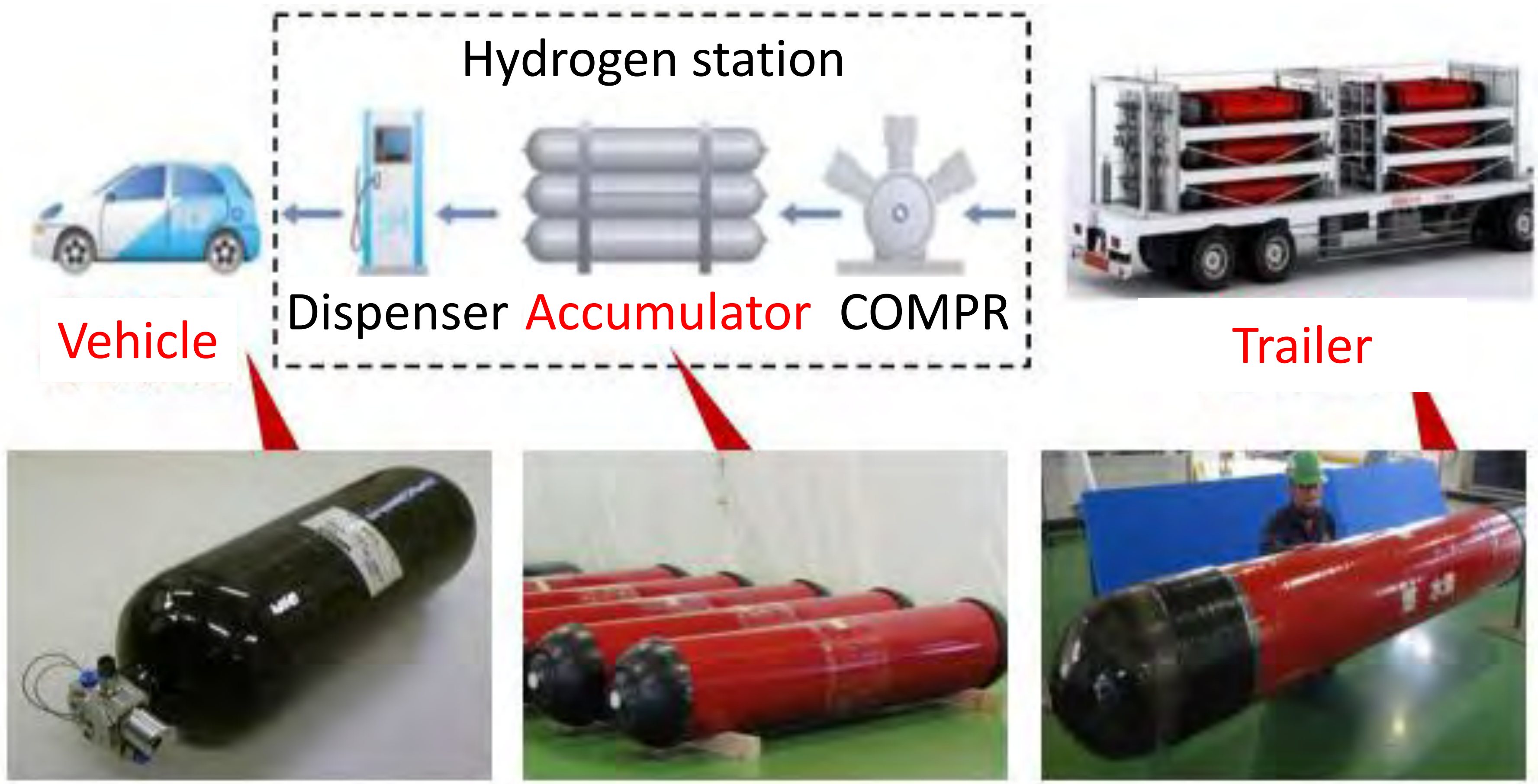
https://www.toyota-shokki.co.jp/news/release/2016/07/26/001318/index.html

Alstom’s Coradia iLint

https://www.globalrailwayreview.com/news/77191/hydrogen-fuel-cell-train-tour/

Bike with Cartridge Tank

Hydrogen Tank to Support Fuel Cell Vehicle



http://www.samtech.co.jp/products/hpc.html

Types of tank

Type4 for FCV

Four Types of Hydrogen Tank

Type1
all metal cylindrical pressure vessel

Type2
a hoop wrapped cylindrical pressure vessel with a load sharing metal liner and composite reinforcement on the cylindrical part only

Type3
fully wrapped cylindrical pressure vessel with a load sharing metal liner and composite reinforcement on both the cylindrical part and dome ends

Type4
a fully wrapped cylindrical pressure vessel with a non-load sharing liner and composite reinforcement on both the cylindrical part and the dome ends

For FCV Tank or Fueling Station

FCV tank

Normal working pressure	: 70 MPa
Allowable temperature	: 85℃ ～ −40℃
Pressure cycles	: 5500 or 11,000
Design optimization	: Light weight

Accumulator

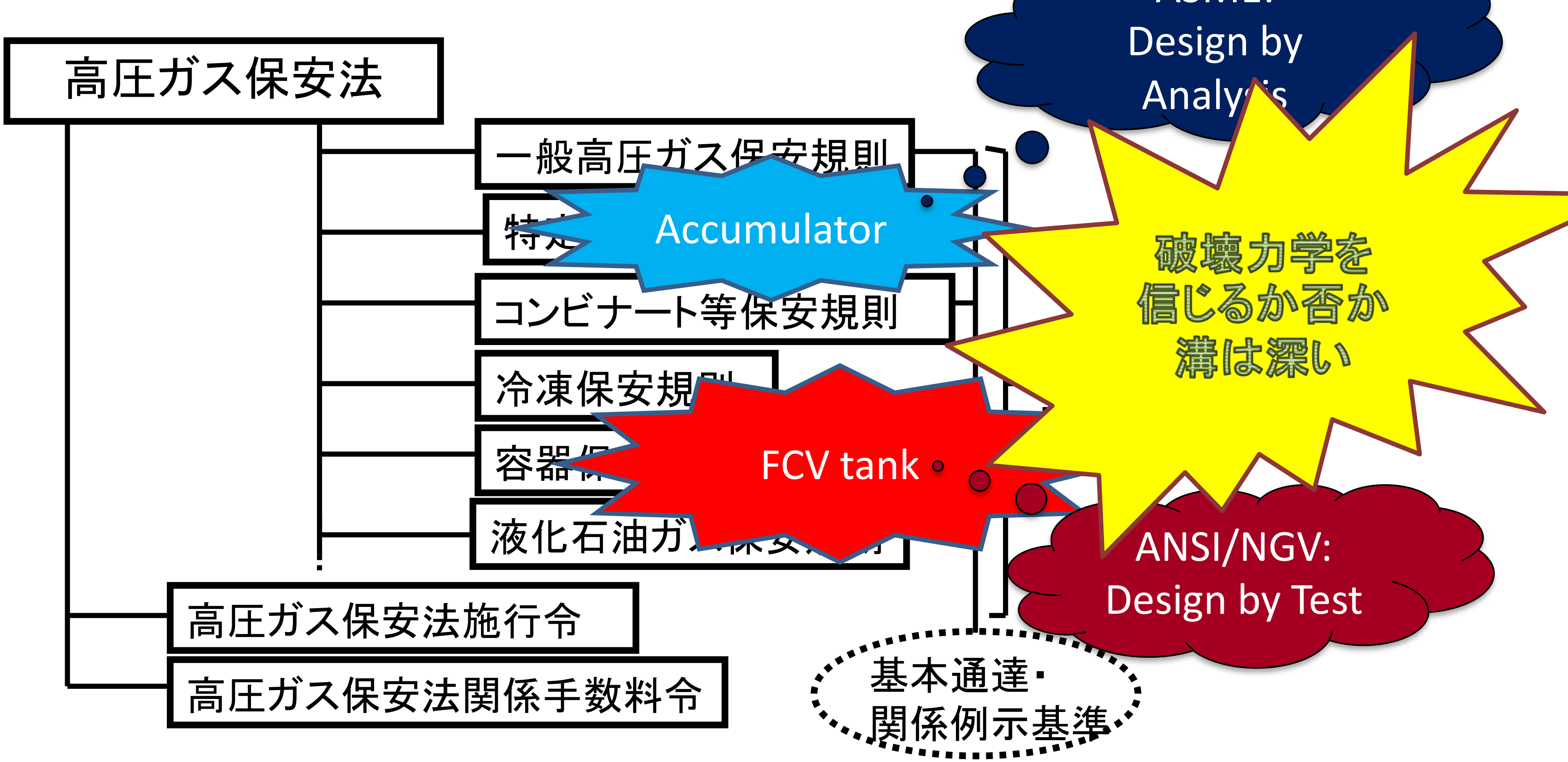
Design pressure	: 100 MPa
Allowable temperature	: Ambient
Pressure cycles	: 100,000
Design optimization	: Cost reduction

How to Ensure Reliability of tank

Fracture mechanics ?

Japanese Regulation of Tank

高圧ガス保安法令等の主な体系



KHKS 0220 Regulation

1．Scope

2．Definition of terms

3．Materials

4．Design

4．1　General

4．2　Basic formulation

4．3　Pressurized cylinder

4．4　Fatigue analysis

4．5　Strength and fatigue evaluation

4．6　Experiment for fatigue analysis

4．7　Leak before break

4．8　Crack propagation

5．Manufacturing

6．Stationary test

7．Leakage

Never require performance test as design standard！

Performance Test for FCV Tank

1. Absence of methodology by specimen test to determine allowable stress for CFRP
2. Reliability by performance tests
3. Origination from compressed natural gas vehicle
4. Design by trial and error

Performance Test for Simulated Life of Tank

Global Technical Regulation No.13（UNR134)

→ Drop test

→ Surface damage test

→ Chemical exposure test

→ Ambient-temperature pressure cycling test

→ 10 cycles by 150 % NWP

→ High temperature static pressure test

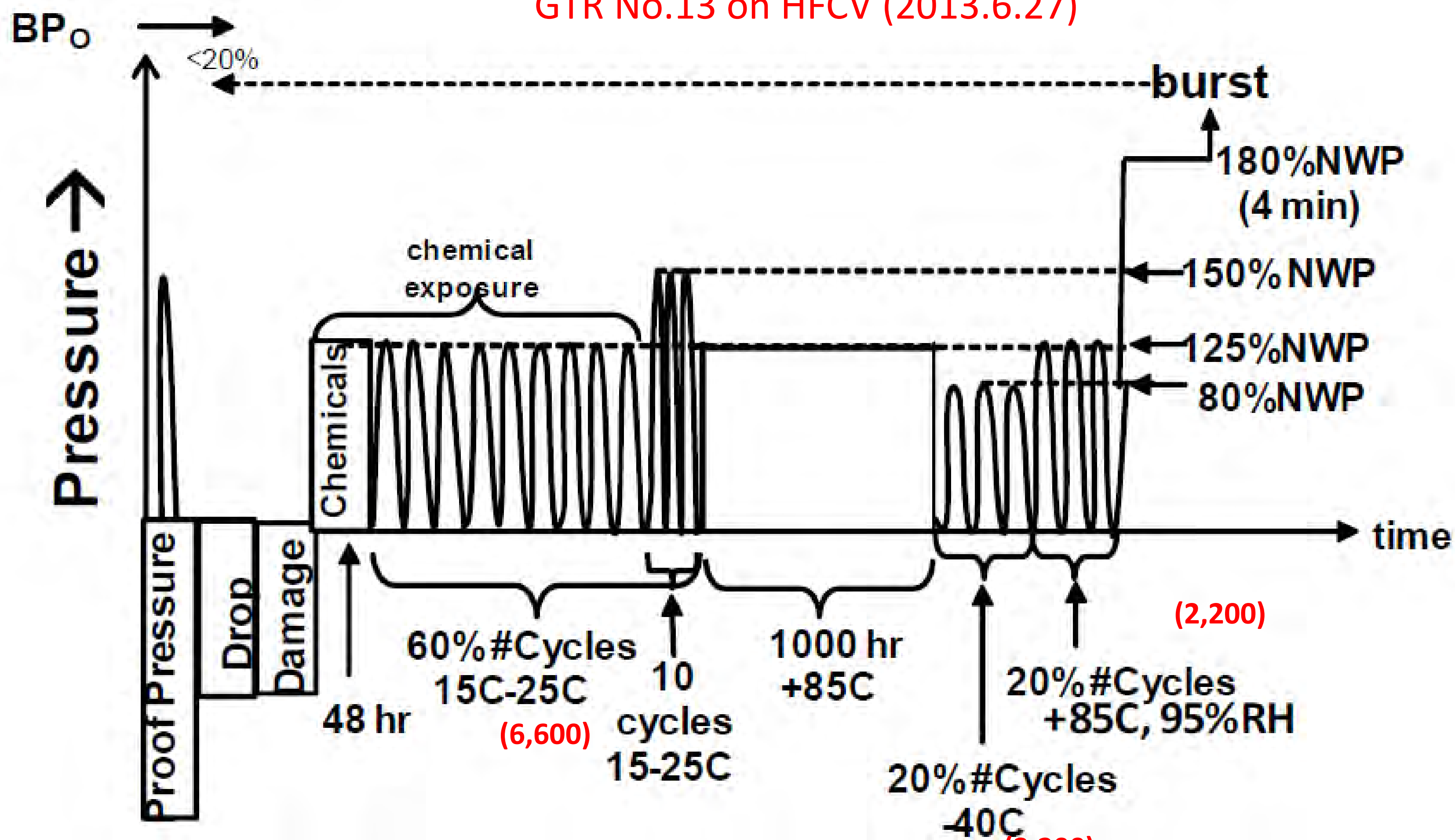
→ Extreme temperature pressure cycling

→ Hydraulic residual pressure test

→ Burst test

Performance Based Test for Type 4 Tank

GTR No.13 on HFCV (2013.6.27)

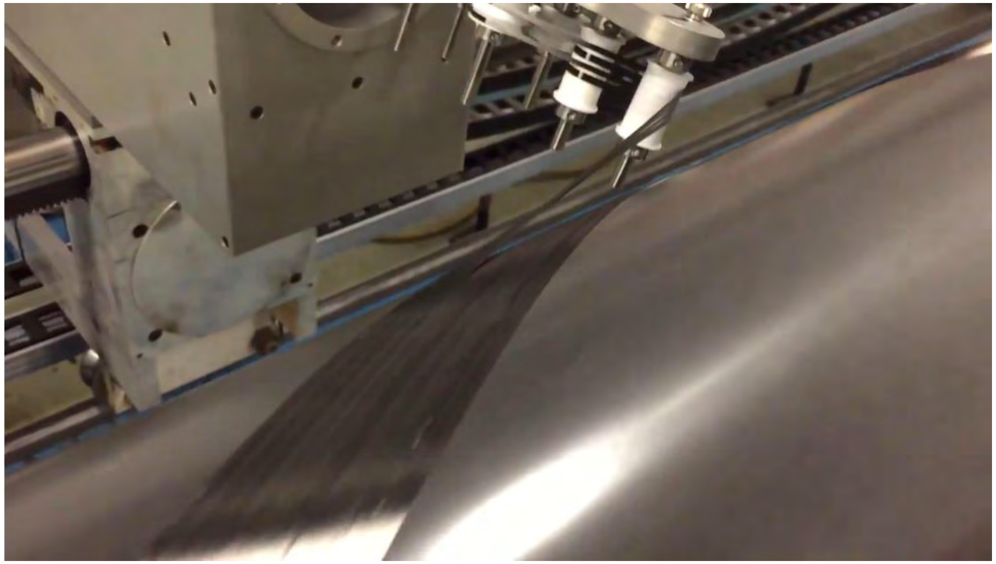


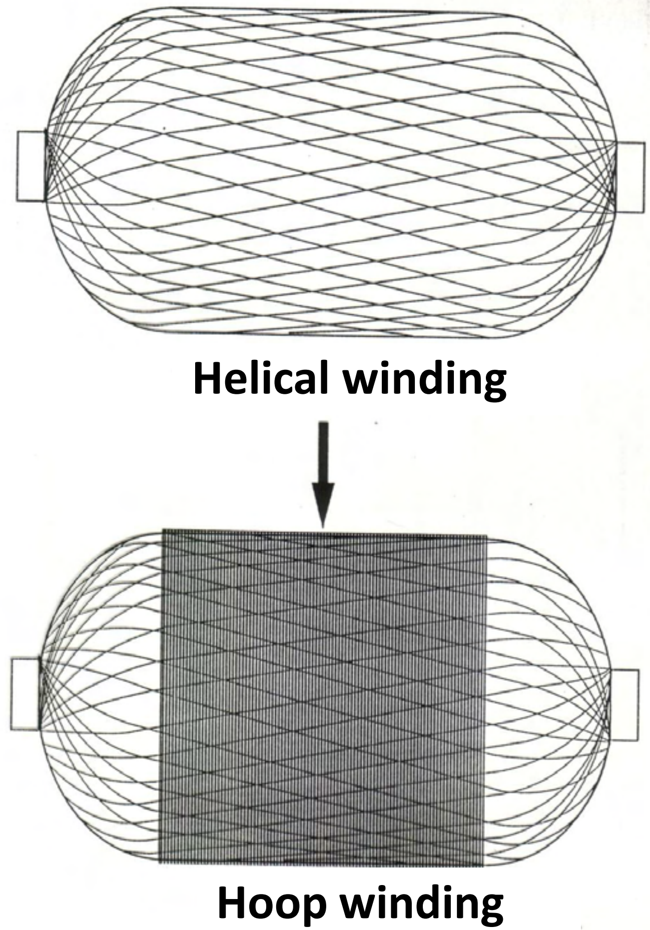
#Cycles = 5,500 or 7,500 or **11,000**

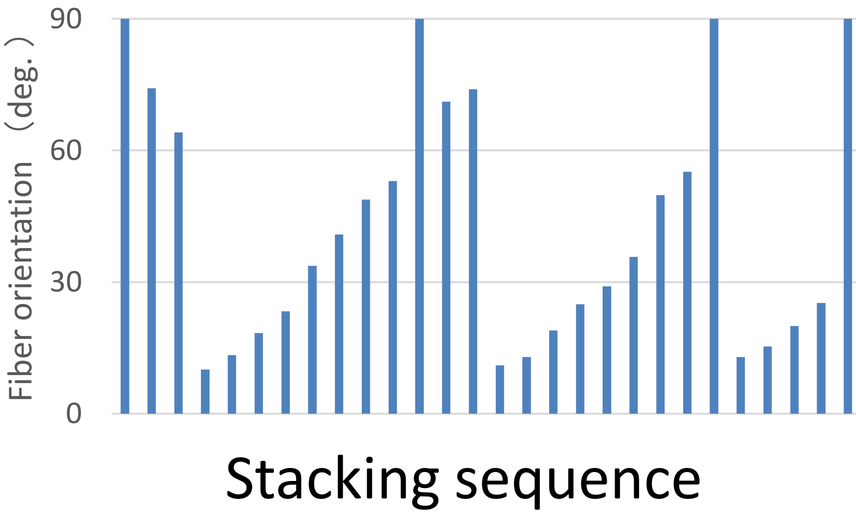
Applicability of Fracture Mechanics

Difficulty by complicated
mechanical field in CFRP

Filament Winding Method





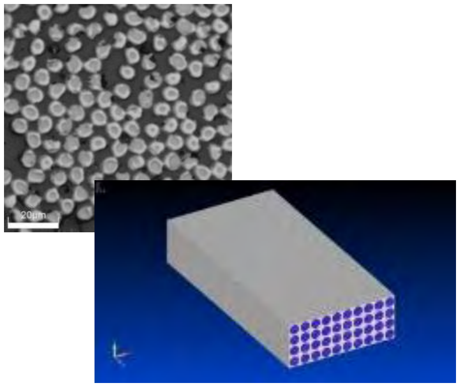


Huge variation of stacking sequence

＝＞Difficulty in stress analysis

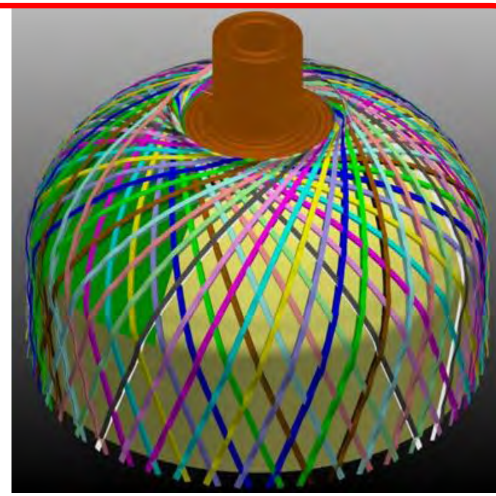
Approach by Meso-scale Modeling of CFRP

Micro-scale



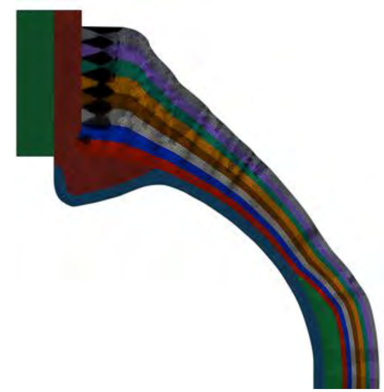
- ✓Solid model
- ✓Carbon fiber: Anisotropic material
- ✓Matrix resin: Isotropic material

Meso-scale



- ✓Solid model
- ✓Carbon fiber bundle: Anisotropic material
- ✓Matrix resin: Isotropic material

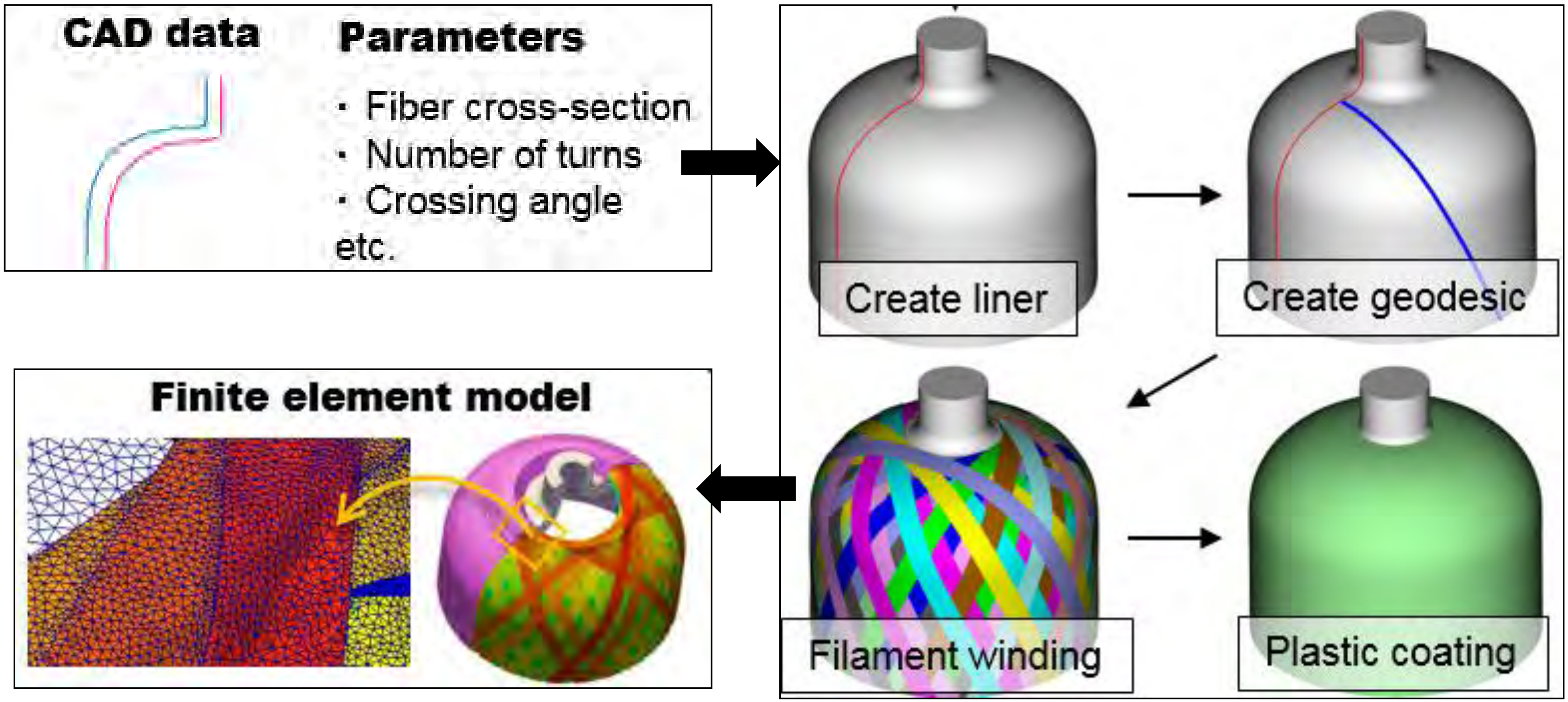
Macro-scale



- ✓Axisymmetric continuum model
- ✓CFRP: Anisotropic material

Carbon fiber bundles and matrix resin are distinguished separately to cope with stress enhancement by fiber bundles crossing in filament winding process.

Meso-scale Modeling of CFRP Tank



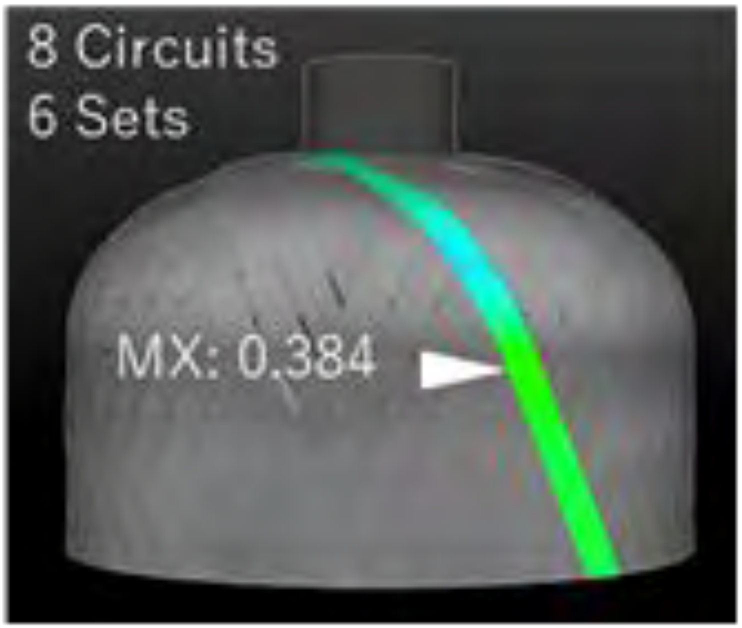
Merit:

➢Direct introduction of nonlinear fracture model of resin

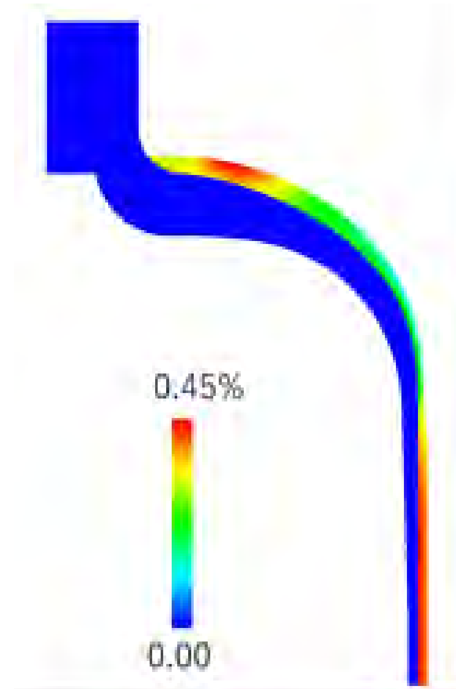
➢Explicit handling winding pass as design parameter

Advanced Meso-scale Model

<u>Meso-scale</u>



<u>Macro-scale</u>



Strain along fiber is incorrectly evaluated by macro-scale model caused by inadequate continuum modeling based on rule of mixture and lamination theory.

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CISS Center for Research on Innovative Simulation Software

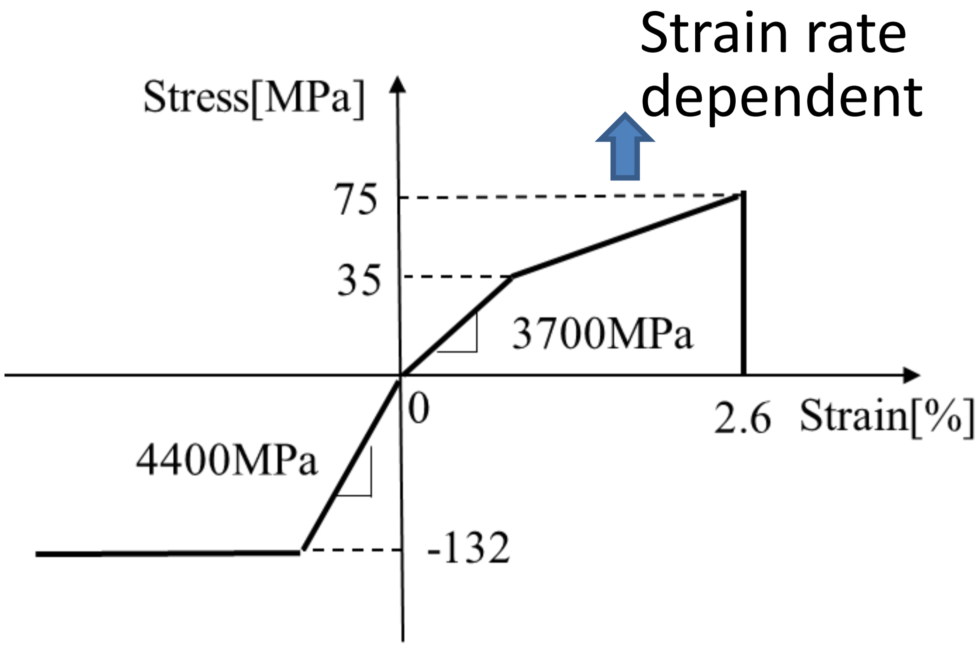
Fracture Model Setting

Matrix resin:

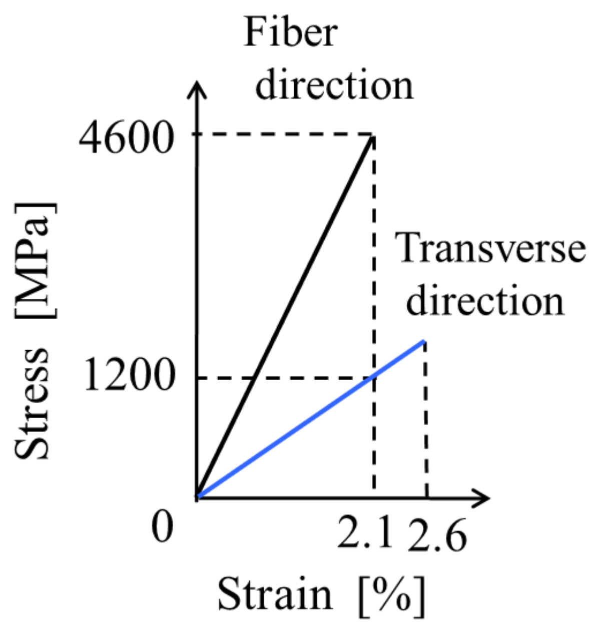
- ✓Plastic behavior depending on strain rate
- ✓Asymmetric fracture model for tension and compression

Carbon fiber bundle:

- ✓Resin fracture criterion for transverse direction

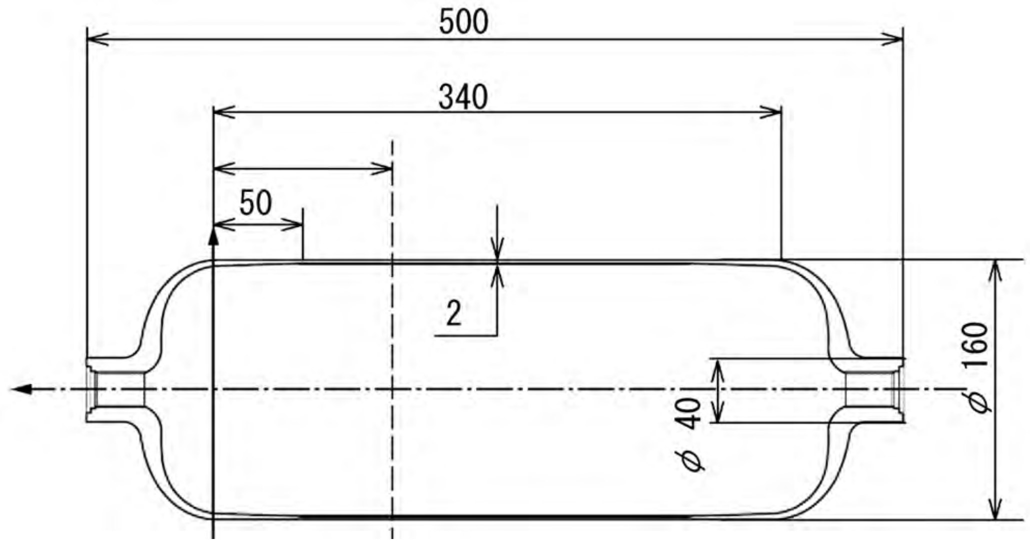


Matrix resin



Carbon fiber bundle

Validation by Pressurizing Burst Test

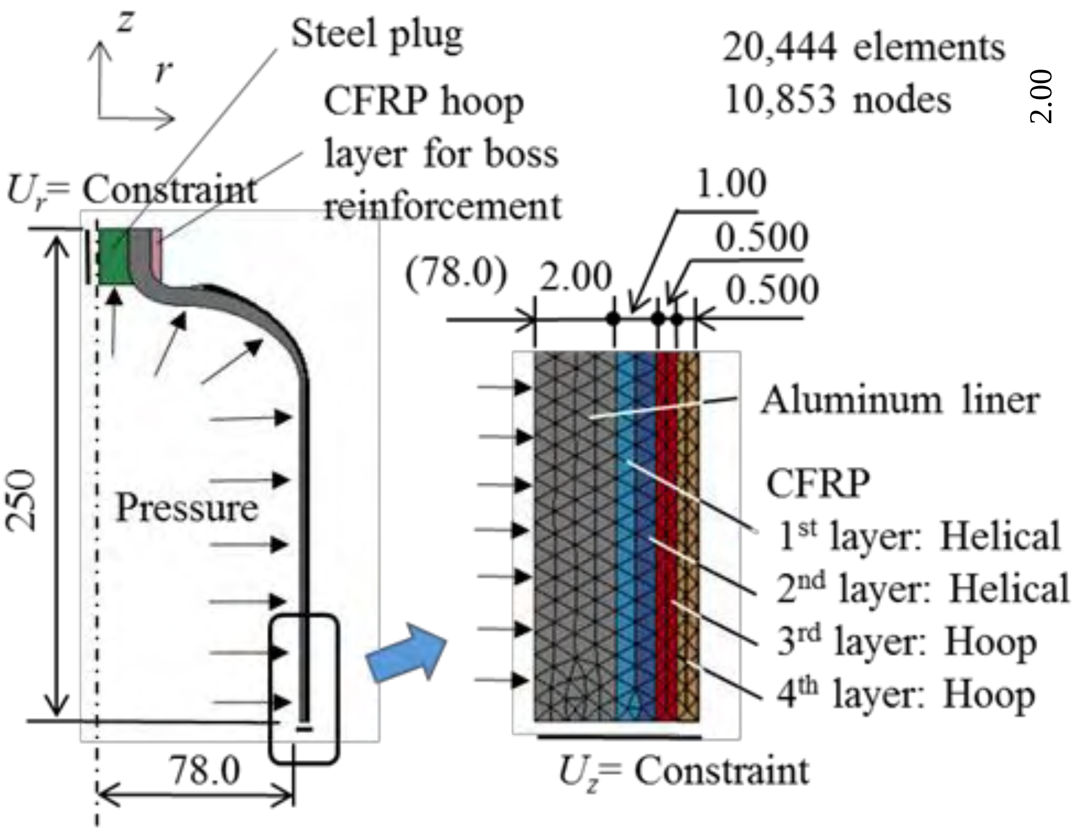


A6061 liner of 7.5 L

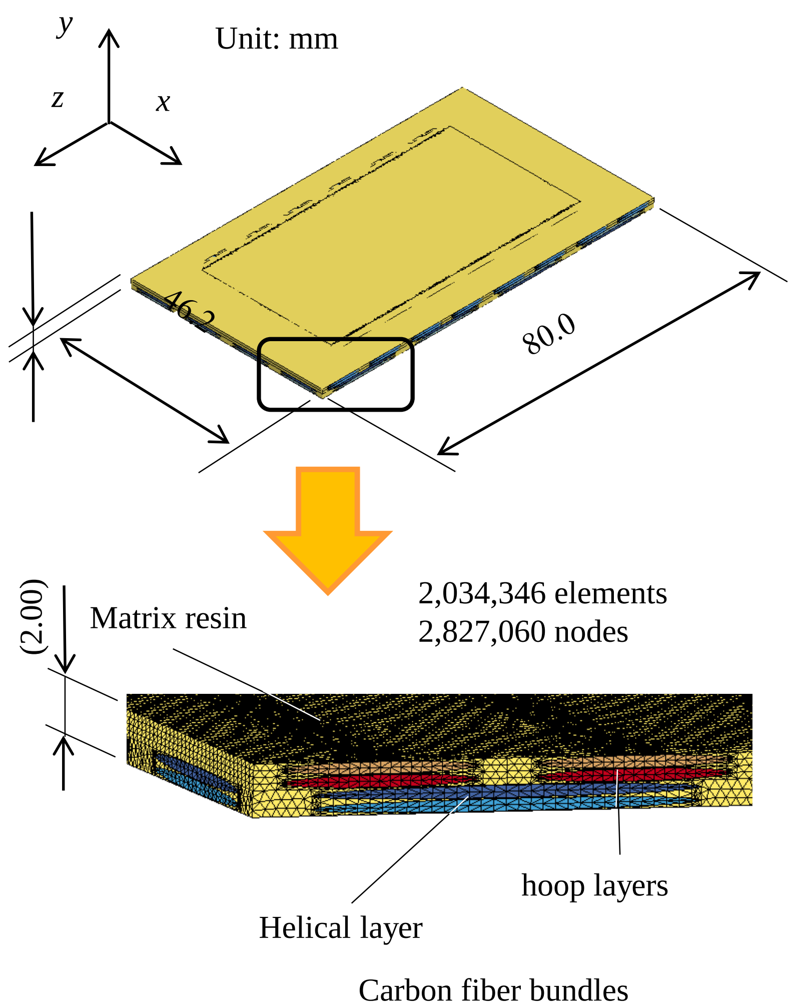
Type 3 mini-tank

After burst test

Zooming Simulation

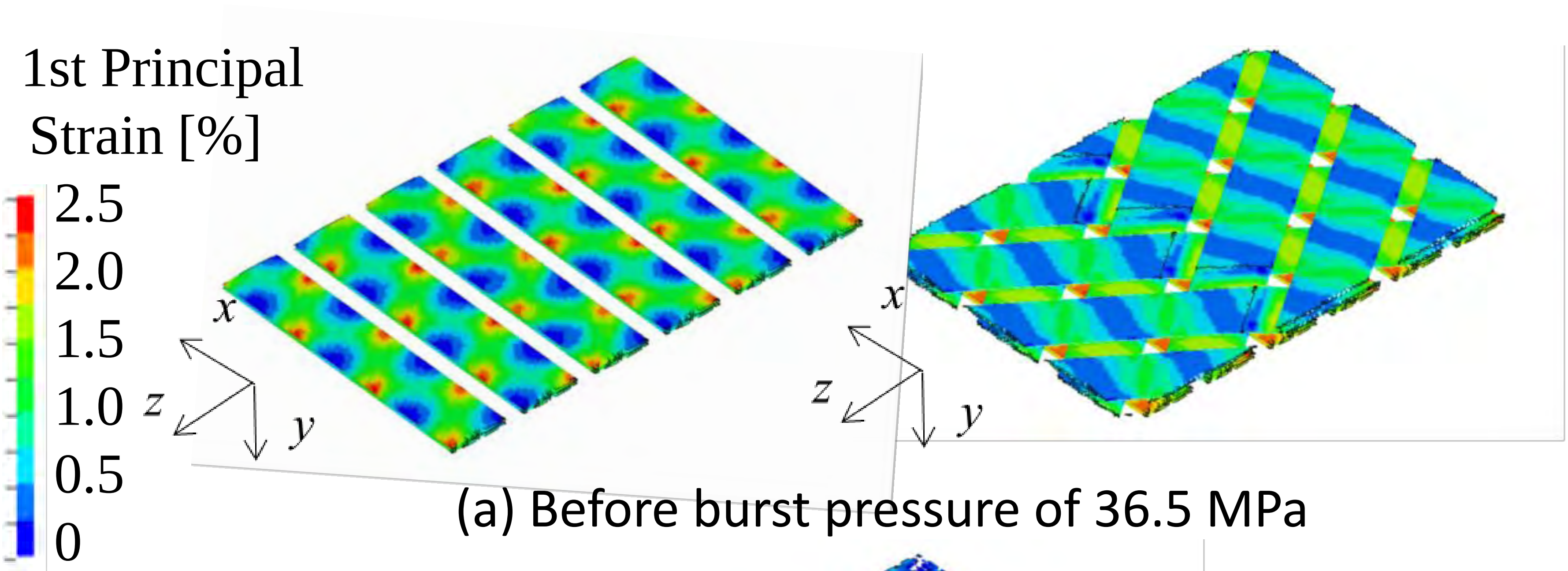


Macro-model

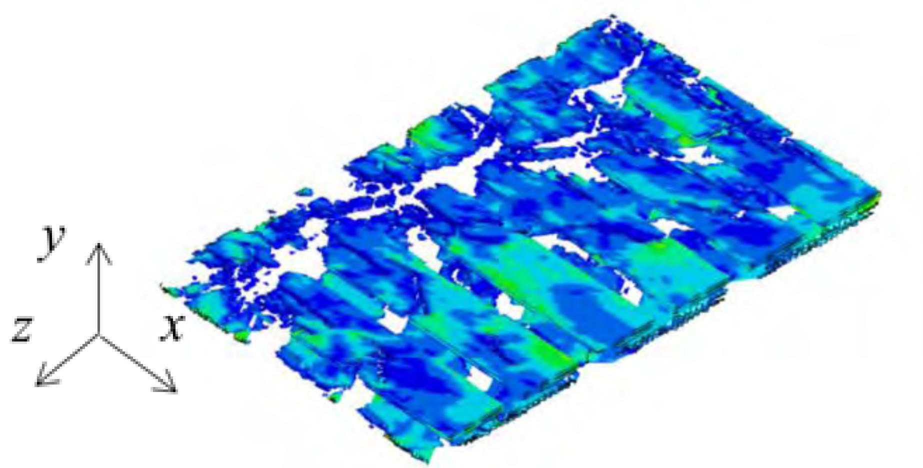


Meso-model

Local 1st Principal Strain Enhancement

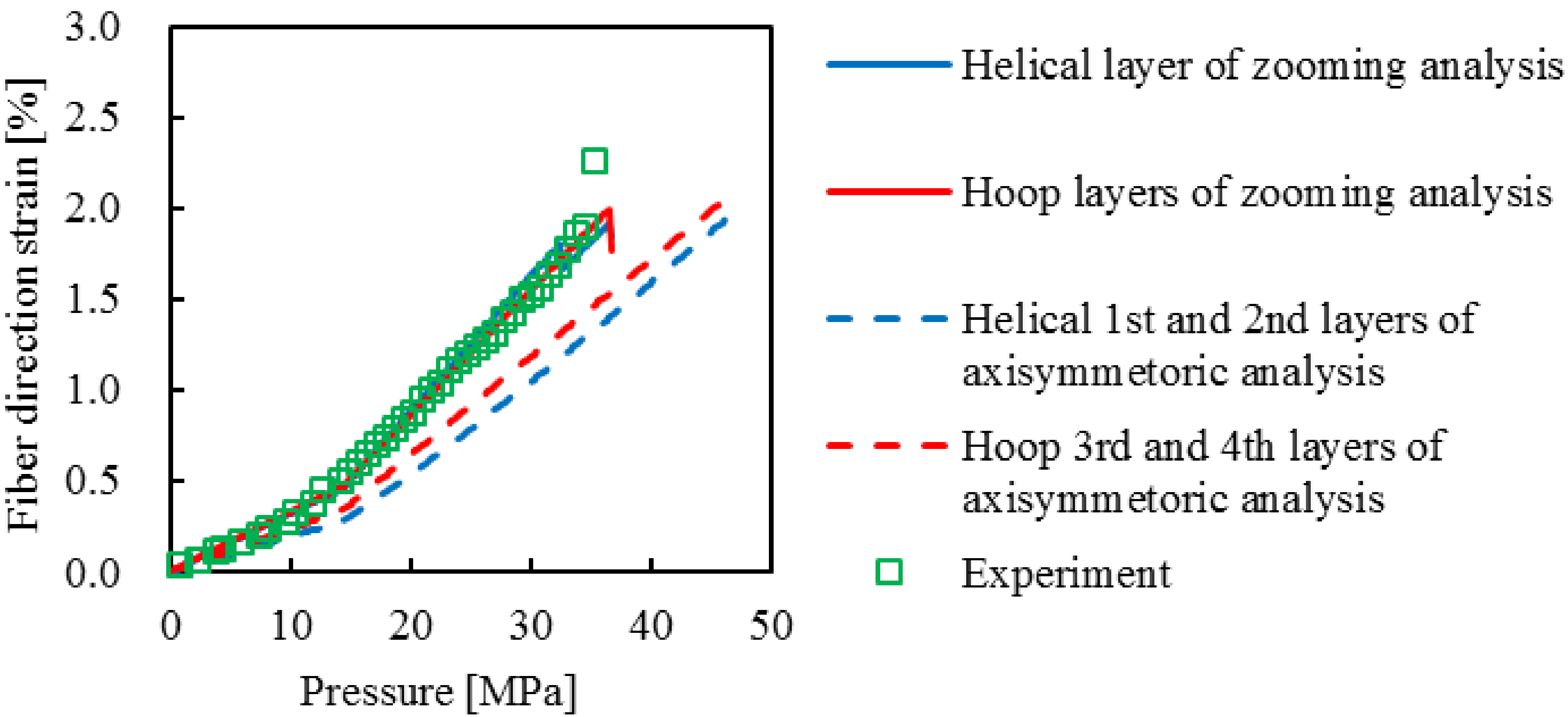


(a) Before burst pressure of 36.5 MPa



(b) After burst pressure of 36.8 MPa

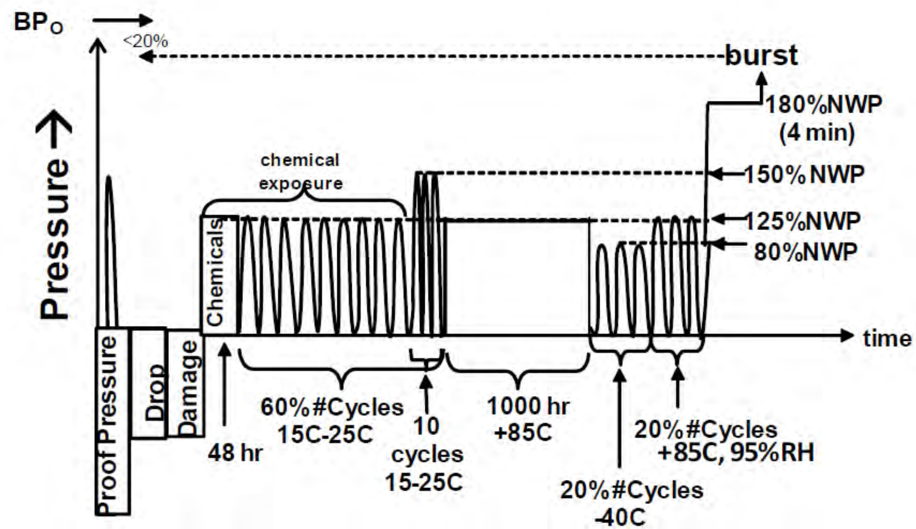
Precise Prediction of Burst Pressure



Application of Health Monitoring System

Condition Based Maintenance
（CBM）

Huge Safety Factor by Performance Test



Irrationalness of performance-based regulation : GTR No.13

- ✓ Stringent test to hold safety for 15 years without inspection
- ✓ Prohibition of use over 15 Years

Rational proposal of condition-based maintenance

- ✓ Health monitoring of CFRP tank
- ✓ Utilizing automotive telecommunication technology
- ✓ Detail inspection after damage signal

Concluding Remarks

- ◆Absence of design methodology based on fracture mechanics
- ◆Complicated micro- and meso-structures of CFRP
- ◆Performance test to ensure reliability of CFRP
- ◆Application of fracture mechanics based on meso-scale simulation
- ◆Condition-based maintenance for CFRP tank