TWENTY-THIRD INTERNATIONAL CONFERENCE ON COMPOSITE MATERIALS (ICCM23)

Probabilistic evaluation of filament-wound composite pressure vessel under material uncertainty

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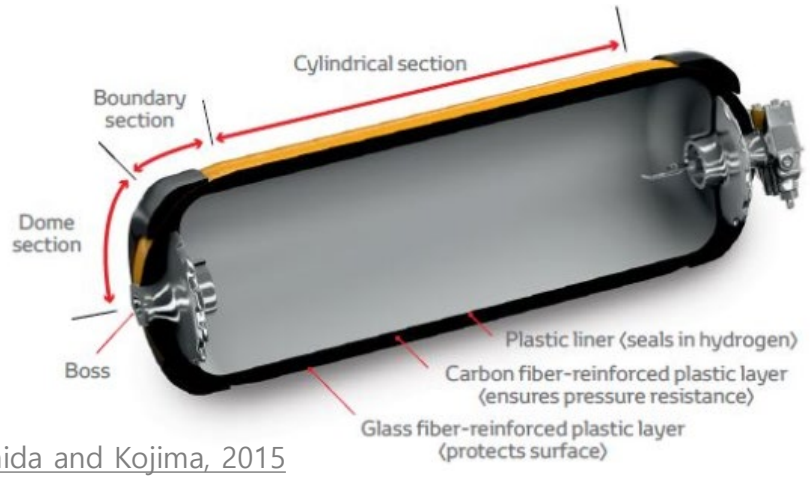
Composite pressure vessels for fuel cell vehicles

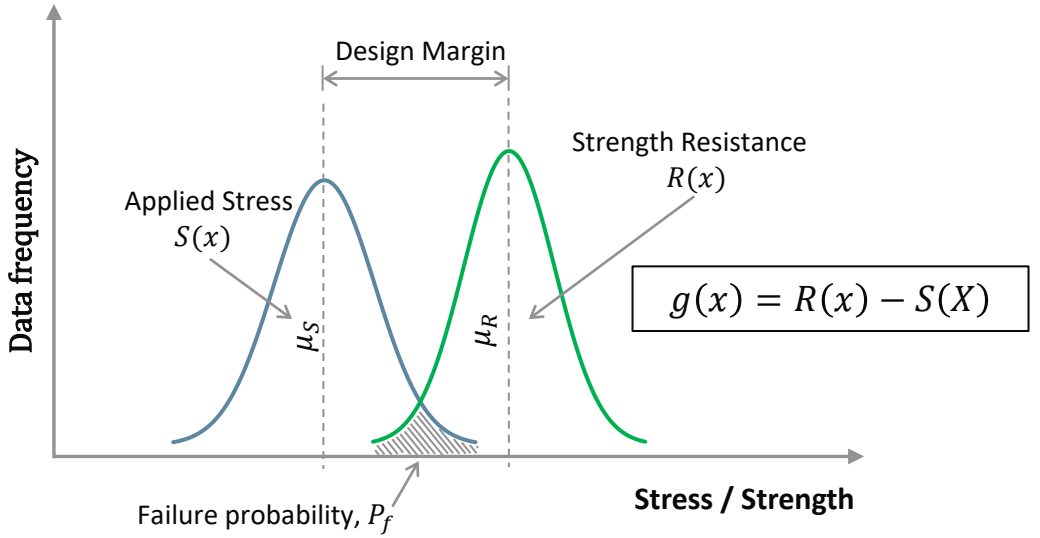


Yoshida and Kojima, 2015

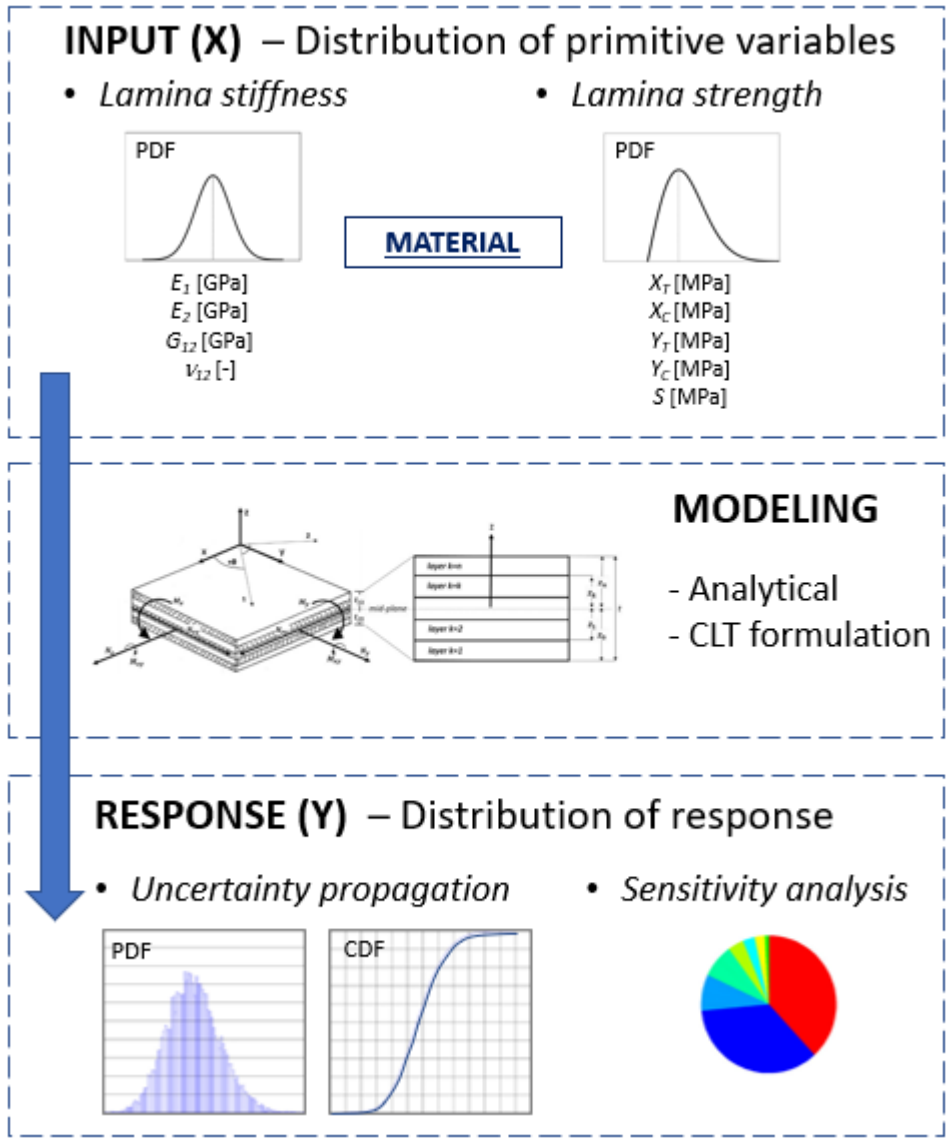
- ✓ Hydrogen fuel cell technology: clean and emissions-free
- ✓ Motors powered by electricity: hydrogen-powered vehicles complementing battery electric cars
- ✓ Hydrogen storage: safe, lightweight and cost-competitive
- ✓ Type IV pressure vessels: thin polymer liner overwrapped with carbon fibers wound layers

Probabilistic structural design

- ✓ Reliability analyses are vital to quantify and evaluate structural safety
- ✓ Stress-strength reliability approach
- ✓ Distributions compared: applied stress to strength



PROBLEM STATEMENT



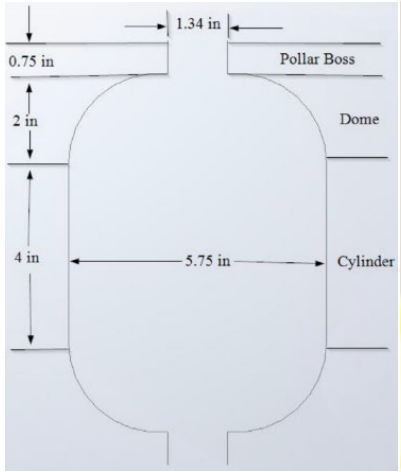
This work investigates:

- ❑ Effects of uncertainties on structural performance
- ❑ Filament-wound pressure vessels
- ❑ Burst pressure
- ❑ Type IV composite pressure vessels (COPV)
- ❑ Variability in material properties
- ❑ Probabilistic design: uncertainty and sensitivity analyses

METHODOLOGY

Case study and general guidelines

- Based on the work from Alam *et. al* (2020)
- Type IV: CF/Epoxy
- Layup: [-13°/+13°/+88°/-13°/+13°]
- $t_{helical}$ = 0,8382 mm; t_{hoop} = 0,2286 mm



Alam et. al, 2020

Strength analysis

- Static, linear elastic
- Design: burst pressure
- First Ply Failure (FPF)
- Classical Laminate Theory
- Failure criterion: Max Stress

Probabilistic evaluation

- Monte Carlo Simulation with random sampling: 1,000 simulations
- Random input variables: material properties
- Normal distribution
- Uncertainty propagation: PDF + CDF
- Sensitivity analyses: Pearson's coefficients + One-factor-at-a-time investigation

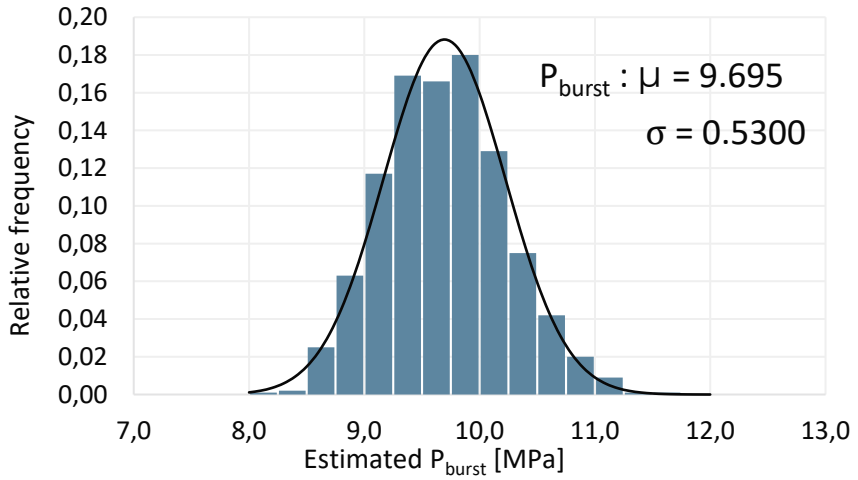
T800/epoxy

Parameter	Mean	Std. deviation
E_1 [GPa]	176.8	8.0
E_2 [GPa]	10.336	0.519
ν_{12} [-]	0.3300	0.0208
G_{12} [GPa]	4.895	0.296
X^T [MPa]	3364.8	112.0
X^C [MPa]	1723.75	137.9
Y^T [MPa]	96.53	3.99
Y^C [MPa]	289.59	16.11
S [MPa]	96.53	0.59

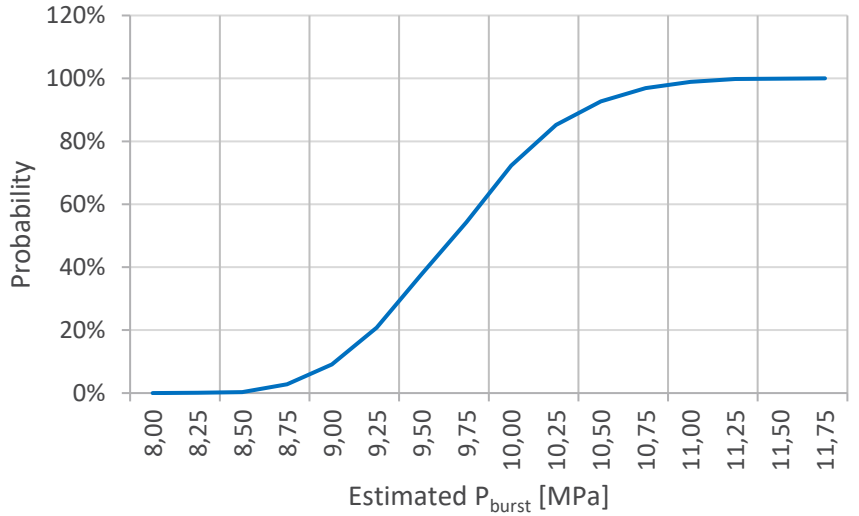
RESULTS – Estimated Burst Pressure

Uncertainty Analysis

Histogram



Cumulative density function - CDF



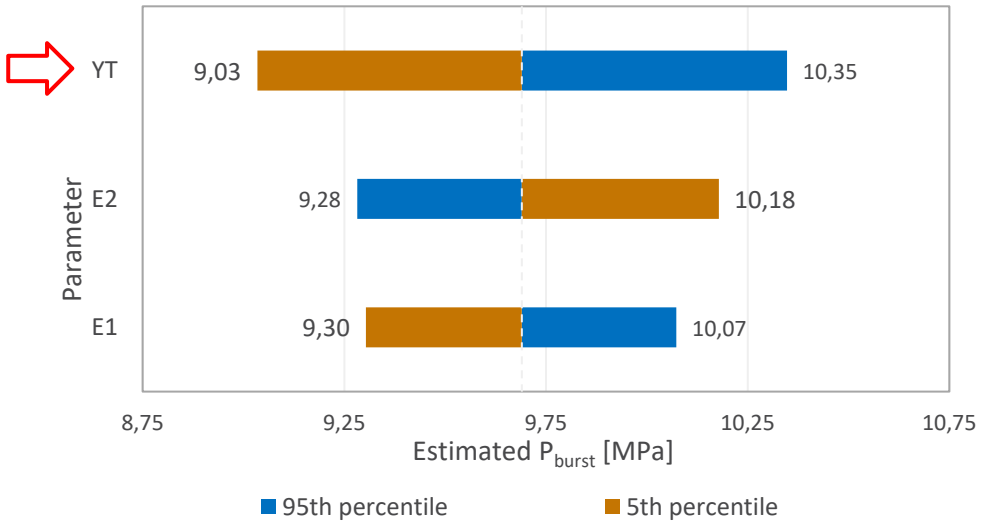
- P_{burst} from Alam *et al.* (2020)
  → FEM: 15.64 MPa;
  experiments - mean: 16.09 MPa
- Different hypotheses:
  → Non-linear geometry and material, dome modeling

Sensitivity Analysis

Pearson's correlation coefficients

Parameter	Correlation coefficient
E_2	**-0.4909**
Y^C	-0.0589
X^C	-0.0540
S	-0.0447
X^T	-0.0263
ν_{12}	+0.0290
G_{12}	+0.0291
E_1	**+0.3883**
Y^T	**+0.7485**

Tornado plot: One-factor-at-a-time analysis

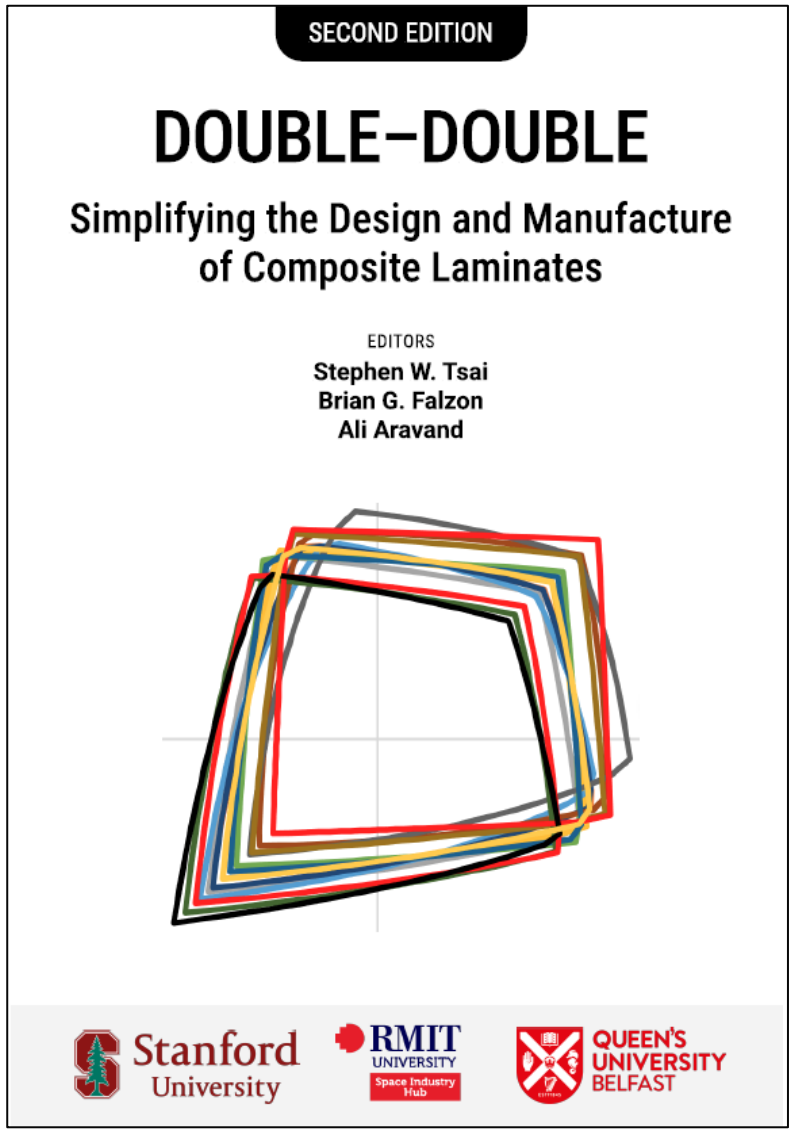


- Y^T,E_1,E_2: stronger correlations
- Y^T: dominates the burst pressure
  → Its variation will reflect in a wider fluctuation of P_{burst}

CONCLUSIONS

- Probabilistic investigation of strength of COPV conducted
- Simplified analytical methodology able to describe the effect of uncertainties of material properties on structural performance
- Uncertainty propagation and sensibility analysis
- Allowable burst pressure of COPV more sensitive to Y_T (most), E_2 and E_1
- Design may vary with changes in vessel geometry (such as layup, thickness), failure criteria, among other
- Better understanding of limitations of current deterministic design strategies

Got book?



Thank you