Towpreg

Core Competitive Technology Analysis

Applications in Hydrogen COPVs, Aerospace and AFP

Technology Review: Toray, Mitsubishi Chemical and Teijin

Resin formulation is the key barrier to entry

Integrated Analysis of Cure Cycle, Tg and Toughness

JNC Composites Lab

Core Technologies

01 Resin Formulation

02 Uniform Impregnation

03 Resin Content / Tow Shape

04 Low Tack / Processability

05 Filament Alignment

Five Core Towpreg Technologies

Resin formulation (cure cycle, Tg, toughness) and process/geometry control for hydrogen COPVs

01

Resin Formulation

Resin Formulation
(Cure · Tg · Toughness)

★★★★★

Highest entry barrier / basis of performance

Tg 140–160°C with high G_{IC} and G_{IIC}

02

Uniform Resin Impregnation

Impregnation Control

★★★★★

Directly linked to resin viscosity

Minimize dry spots and voids

03

Resin Content / Tow Shape

RC & Tow Shape

★★★★☆

RC ±1% / Width ±0.2 mm

Consistent winding quality

04

Low Tack / Processability

Tack & Processability

★★★★☆

High-speed AFP and FW

Balance tack and layer retention

05

Filament Alignment

Filament Alignment

★★★★★+

Direct burst-pressure impact: 3–10%

Fatigue-life impact: 10–30%

01

Resin Formulation Design (1/2)

Resin Formulation: Design Factors and Trade-offs | ★★★★★ | Core technology with the highest entry barrier

Resin formulation often presents a higher entry barrier than manufacturing technology. The key is to optimize competing requirements for viscosity, impregnation, storage stability, tack, Tg and toughness.

Viscosity	Impregnation	Storage Stability	Tack
3–80 Pa·s	Minimal dry spots / voids	RT Storage / OOA	AFP / FW balance

Cure Speed	Tg	Toughness	Fatigue Resistance
Fast Cure / OOA	80–250°C by application	Crack / fatigue resistance	Pressure-cycle durability

⚠ Key Trade-offs

High Tg	↔	Lower toughness	→ Higher brittleness
Fast cure	↔	Lower storage stability	→ Shorter pot life
Low viscosity	↔	Resin-rich areas	→ Harder RC control
High toughness	↔	Lower Tg	→ Lower heat resistance
Fast impregnation	↔	Surface quality	→ Bleed-out risk

01

Resin Formulation Design (2/2)

Cure Cycle, High Tg and Toughened Epoxy | Application to 700-bar Hydrogen COPVs

Cure Cycle

Aircraft — 0.6–0.7 MPa (autoclave)

180°C × 2 hr

COPV — FW tension / liner heat limit

110–140°C / 2–8 hr

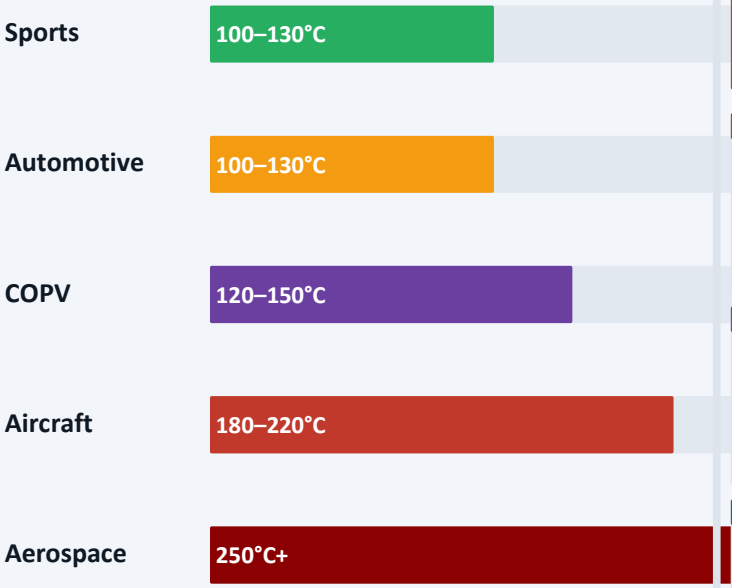
Automotive — Press molding / fast cure

120–150°C / 5–20 min

OOA — Vacuum bag 0.1 MPa / lower capital cost

80–120°C / 30–90 min

Required Tg by Application



Higher Tg → greater brittleness → toughening needed

Toughened Epoxy ★★★★★+

Tens of thousands of 700-bar cycles
→ Crack resistance (toughness) is critical

Core-Shell Rubber	EXL2300 · EXL2314 MBS-type particles	Mode-I G_{IC} ↑
Thermo-plastic	PES · PEI · PEEK Phenoxy Resin	Mode-II G_{IIC} ↑
Nano	CNT · Graphene Nano Silica	Interface / crack arrest

Targets: Tg 140–160°C · $G_{IC} \geq 300$ J/m² · $G_{IIC} \geq 800$ J/m²

02

Uniform Resin Impregnation

Impregnation Control | ★★★★★ | Linked to resin viscosity (Slide 3): Mitsubishi's key 3–80 Pa·s patent

Resin must penetrate uniformly between thousands to tens of thousands of filaments in a tow, while maintaining stable impregnation without resin separation during high-speed winding.

Minimize Dry Spots

Eliminate dry regions
Prevent strength loss

Suppress Voids

Prevent air entrapment
Maintain interlaminar strength

Maximize Stress Transfer

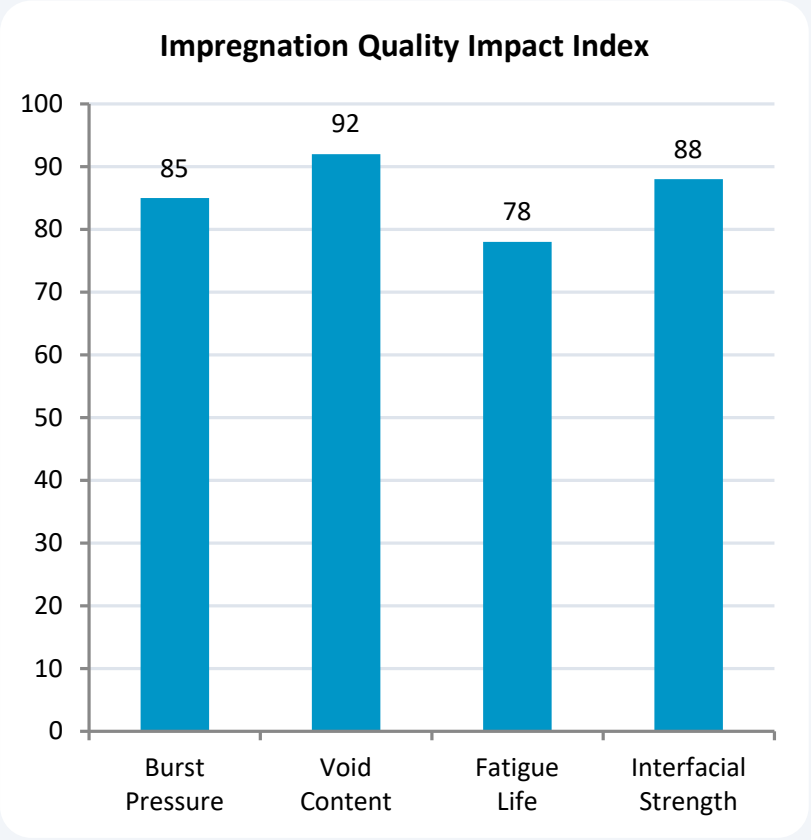
Between filaments
Uniform load sharing

Prevent Resin Separation

During high-speed winding
Maintain stability

📌 **M Company's Key Patent**

Control resin viscosity within 3–80 Pa·s to achieve both impregnation and handling (tack).
Lower viscosity aids impregnation; higher viscosity improves handling. The optimal balance is critical.



03

Precise Resin Content and Stable Tow Shape

Resin Content & Tow Shape | ★★★★☆ | COPV control requirements: RC ±1%, width ±0.2 mm

Target Resin Content by Application

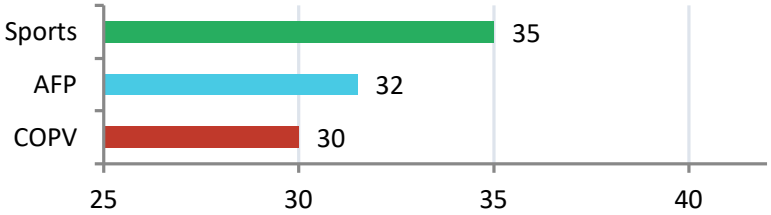
Pressure Vessels (COPV)	Automated AFP	Sports
25–35%	**28–35%**	**30–40%**
Tolerance Within ±1%	Tolerance Within ±1.5%	Tolerance Within ±2%

Tow Shape Control Parameters

Tow Width	±0.2 mm	Precision 1/4-inch AFP control (Toray Advanced Towpreg)
Tow Thickness	±0.02 mm	Uniform ply thickness directly affects winding quality
Tow Tension	Within ±5%	Limit tension variation to preserve filament orientation

⚠ Effects of Resin Content Variation

- ✗ Strength variation
- ✗ More winding defects
- ✗ Uneven cure shrinkage
- ✗ Burst-pressure variation



04

Low Tack and High-Speed Processability

Tack & Processability | ★★★★☆ | Key to AFP / Filament Winding: Toray ‘Low-Tack’ Technology

When Tack Is Too High

- ✗ Sticking to guide rollers
- ✗ AFP head blockage
- ✗ Limited winding speed
- ✗ Poor RT storage stability

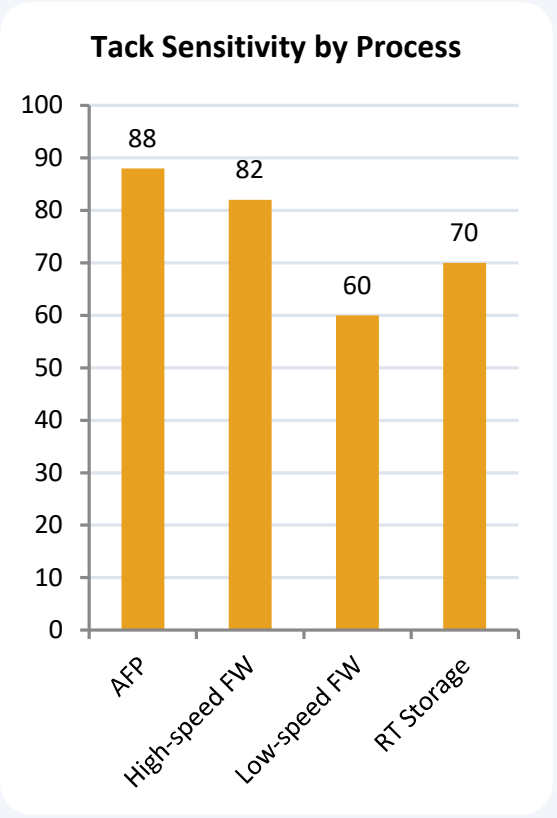
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Balanced Design
Tack ↔ Process

When Tack Is Too Low

- ✗ Insufficient layer retention
- ✗ Delamination risk
- ✗ Winding pattern deviation
- ✗ Slippage during molding

✓ Ideal tack: layer retention without roller sticking, with room-temperature (RT) storage stability



05

Maintaining Filament Alignment

Filament Alignment | ★★★★★+ | Critical know-how for hydrogen COPVs, combined with toughened epoxy

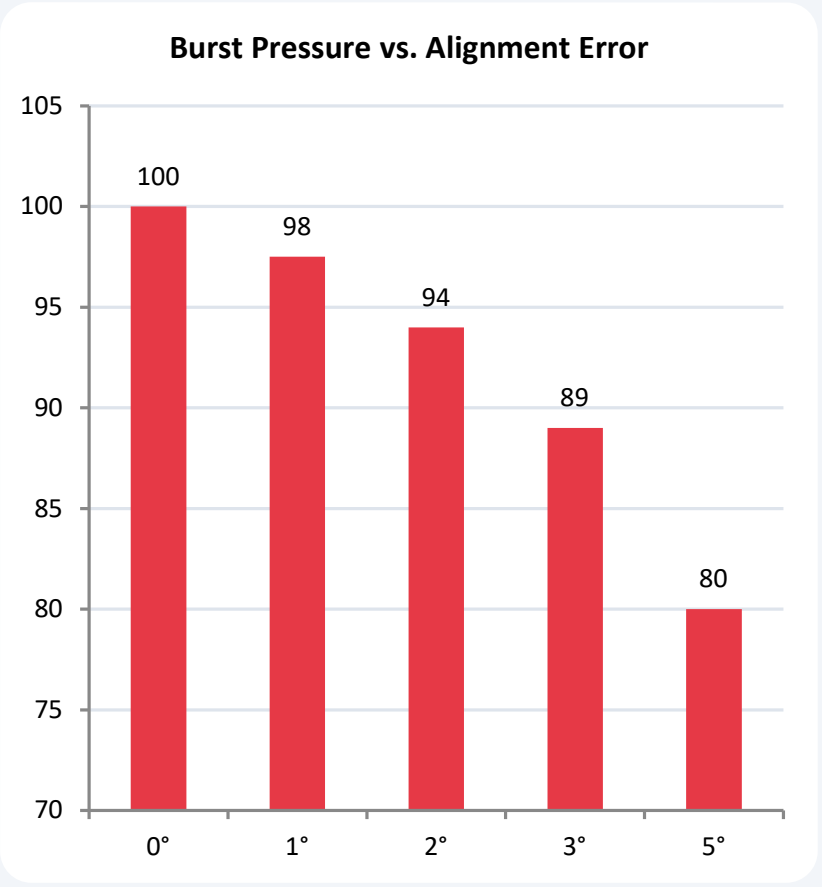
In a COPV, a filament misalignment of only 1–2° can change burst pressure by several percent or more.

Process Stages at Risk of Alignment Loss

Tow Spreading	Resin Coating	Impregnation Roll Compaction	Cooling	Winding
⚠ Fiber crossover	⚠ Uneven tension	⚠ Filament buckling	⚠ Uneven shrinkage	⚠ Cumulative tension variation

Performance Loss from Poor Alignment

Tensile Strength	Compressive Strength	Burst Pressure	Fatigue Life
↓2–5%	↓5–15%	↓3–10%	↓10–30%



Ranking the Five Core Technologies for Hydrogen COPVs

Priorities for 700-bar pressure cycling | Toray, Mitsubishi and Teijin technology review

1st	01	Resin Formulation Design	Toughened epoxy, Tg and cure: core competitiveness	★★★★★+
2nd	05	Maintaining Filament Alignment	Direct impact: burst pressure 3–10%, fatigue life 10–30%	★★★★★+
3rd	02	Uniform Resin Impregnation	Minimize voids through resin-viscosity optimization	★★★★★
4th	03	Resin Content / Tow Shape	RC ±1%, width ±0.2 mm and winding quality	★★★★☆
5th	04	Low Tack / Processability	AFP / FW productivity and balanced tack	★★★★☆

Top Tiers' Common Direction Low viscosity → good impregnation → fast cure → high Tg → high toughness → long fatigue life