# EXOTHERMIC COMPOSITE LAMINATE PANEL MANUFACTURING TECHNOLOGY FOR RAILWAY VEHICLES USING RESIN INFUSION METHOD

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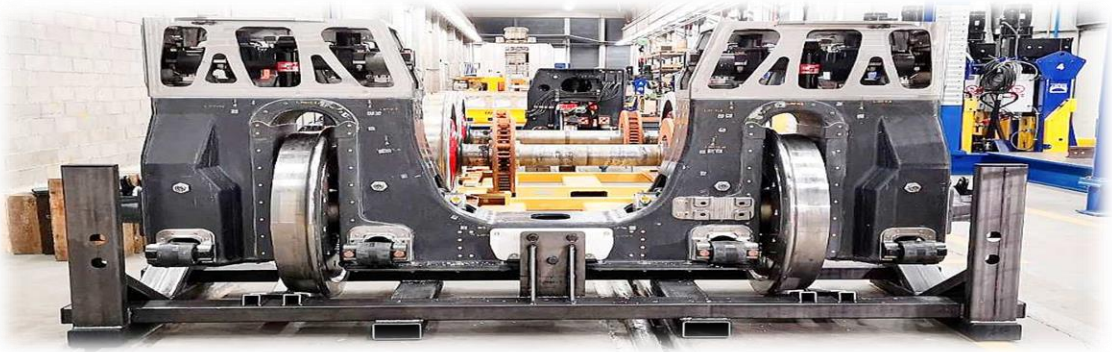
# Background

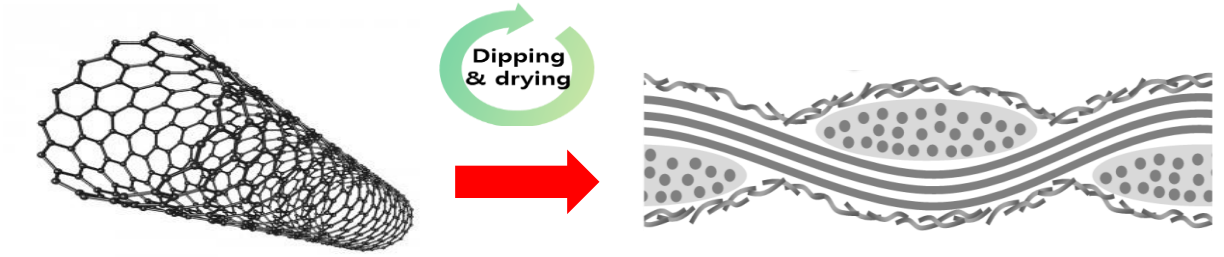
✓ **Expansion of composite application area and multi-functionalization**

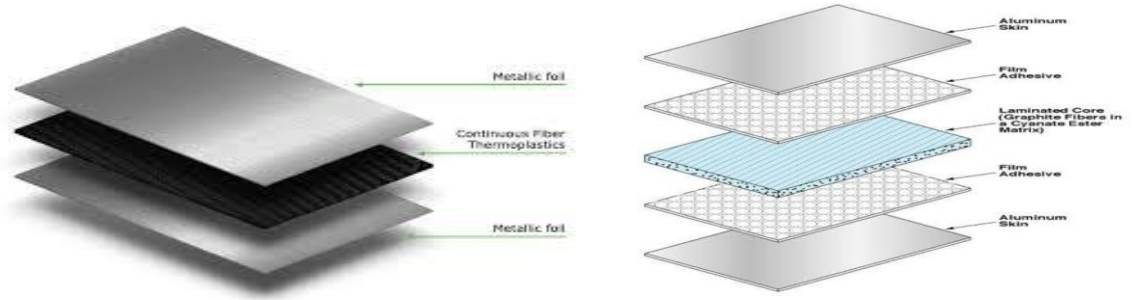
- Application in the railroad field : Improvement in manufacturability & various research and development
  - train nose, roof, interior materials, car body, bogie frame, etc.
- Multi-functionalization research : Insertion of advanced materials (CNT, Graphene, etc.)

→ Composite limitations: High production cost (50% of total) / Price competitiveness ↓



Application of railway vehicle



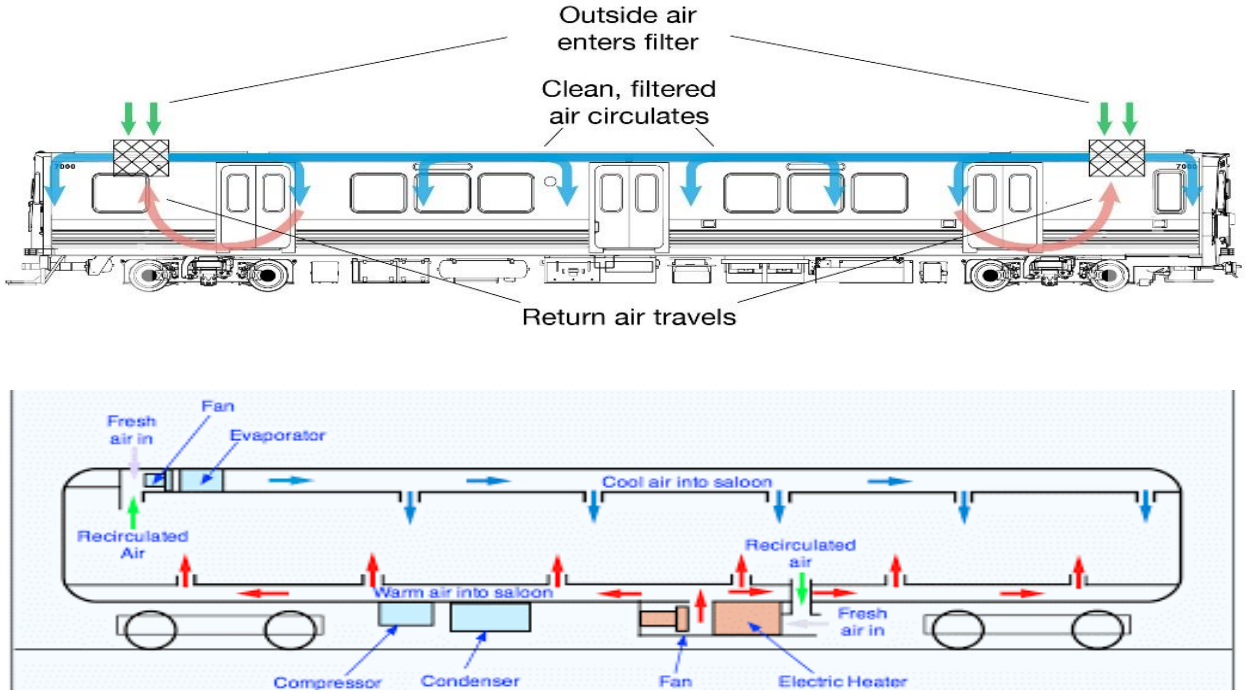

Multi-functionalization of composite

# Background

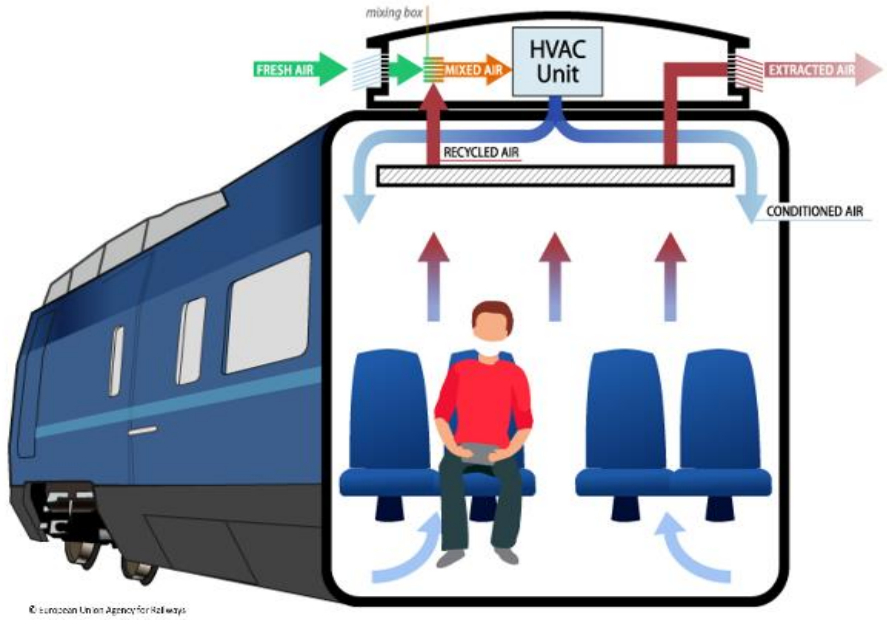
## ✓ Public transport (railway) heating system problems

- Public transportation heating system : Hot air convection heating (using heater and fan)
- Problem : 1. Temperature difference by seat position, dry & hot air
  2. Main cause of virus propagation in the room or space

→ Need to improve the existing heating system (convection method)




Railway vehicle air circulation

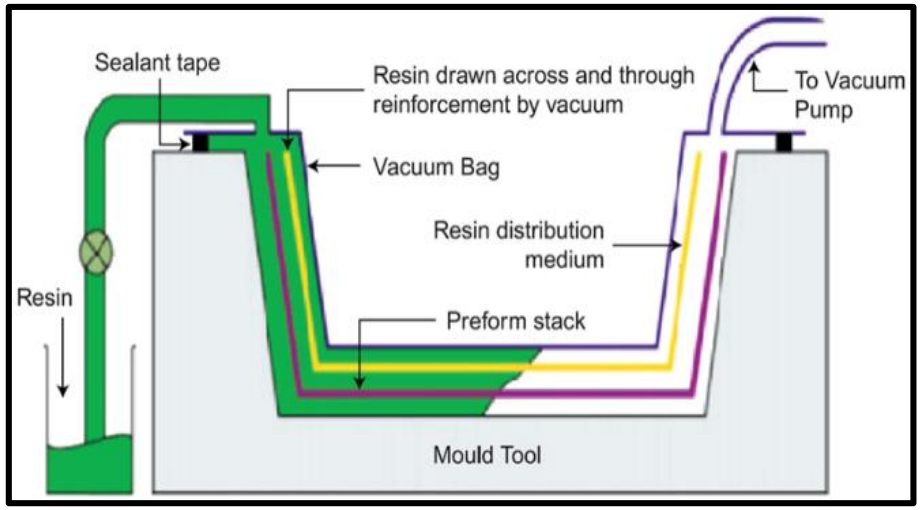



Air conditioning system for railway vehicles

# Background

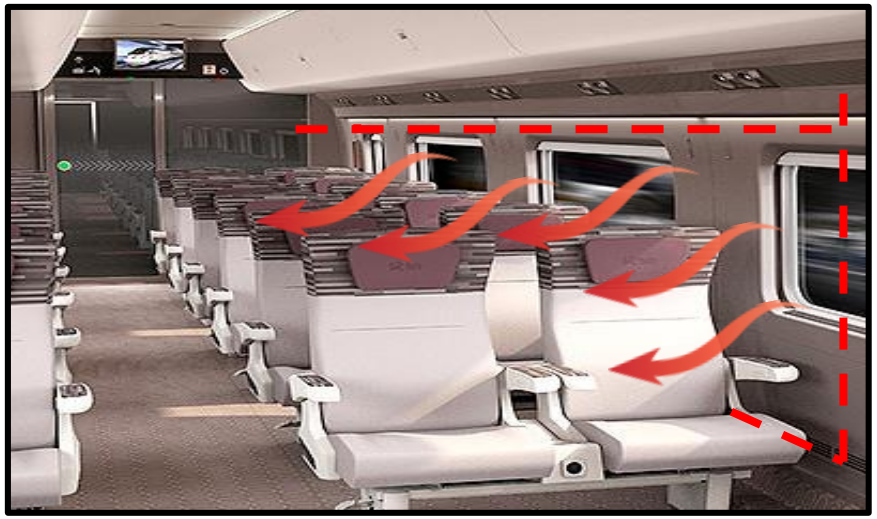
- ✓ **Problem : Constraints on commercialization due to high production cost**
  - Solution : Application of efficient molding method that can improve price competitiveness
- ✓ **Problem : Existing heating system (convection method) needs improvement**
  - Solution : Development of self-heat composite by inserting a heating element (radiation method)

➡ Development of self-heating composite for railway vehicles by cost-saving method




Cost effective molding method

+



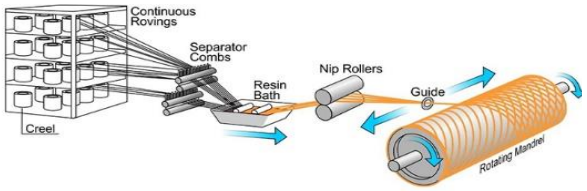
Heat function

# Reducing composite manufacturing cost

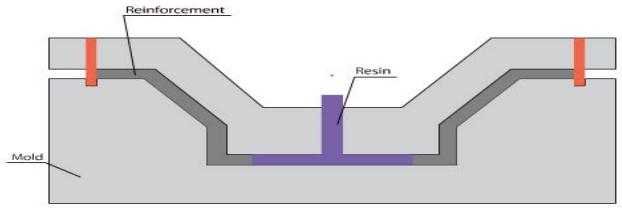
## ✓ Application of manufacturing method with excellent price competitiveness

- Current: Vacuum thermoforming (High material cost & facility cost )
- Improvement: Resin infusion (Prepreg& Thermal chamber& Clean Room ×)

➡ About 30% of the manufacturing cost of composite can be reduced [1]

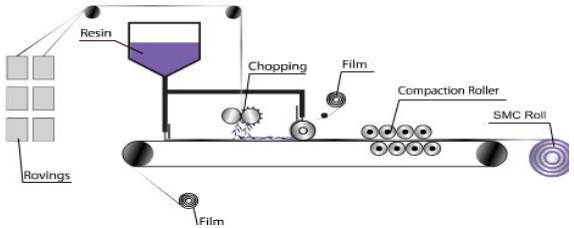



Filament winding




RTM
(Resin Transfer Molding)

Vacuum Bag Molding




SMC
(Sheet Molding Compound)

Composite manufacturing method

Vacuum thermoforming

Resin infusion

Manufacturing method of composite for railway vehicles

[1] Journal of the Korean society for urban railway vol.9 no.1, pp.781 – 789 (2021)

# Composite panel heating functionalization

## ✓ Selection of heating elements

- Heating element: Paper type carbon fiber(CF) heating element
  - According to Joule's heating principle, heat generated by resistance
  - Advantages: Possible surface heating and excellent durability, Thin thickness (t = 0.04㎜)

(a) Pulper agitation

(b) Water agitation

(c) Carbon pulp

(d) Hot drying

(e) Roll drying

(f) Winding

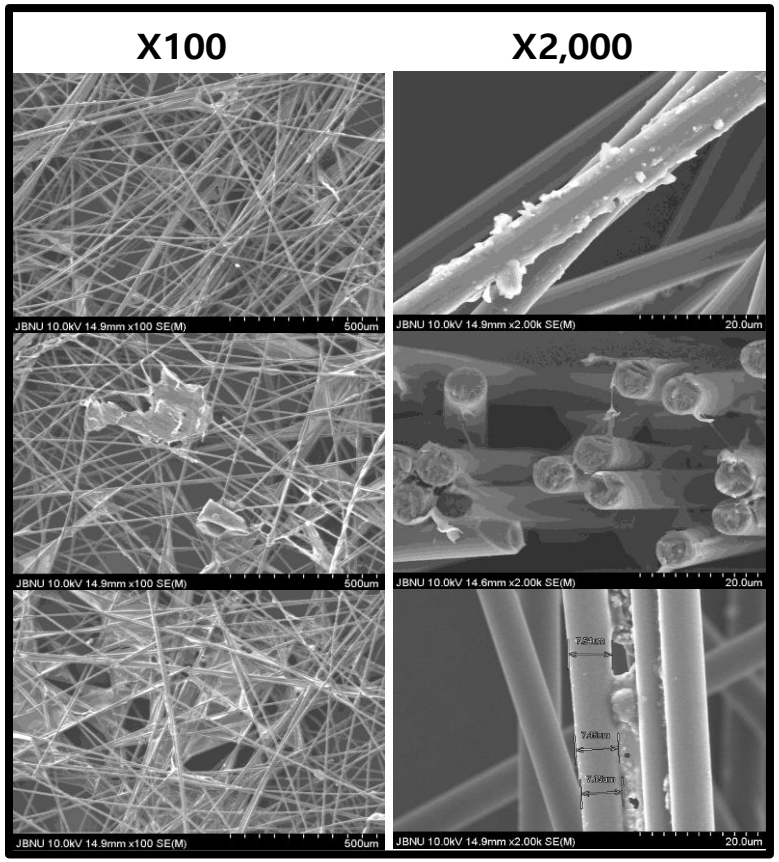
Carbon fiber paper manufacturing process

Carbon fiber(CF) heating element image

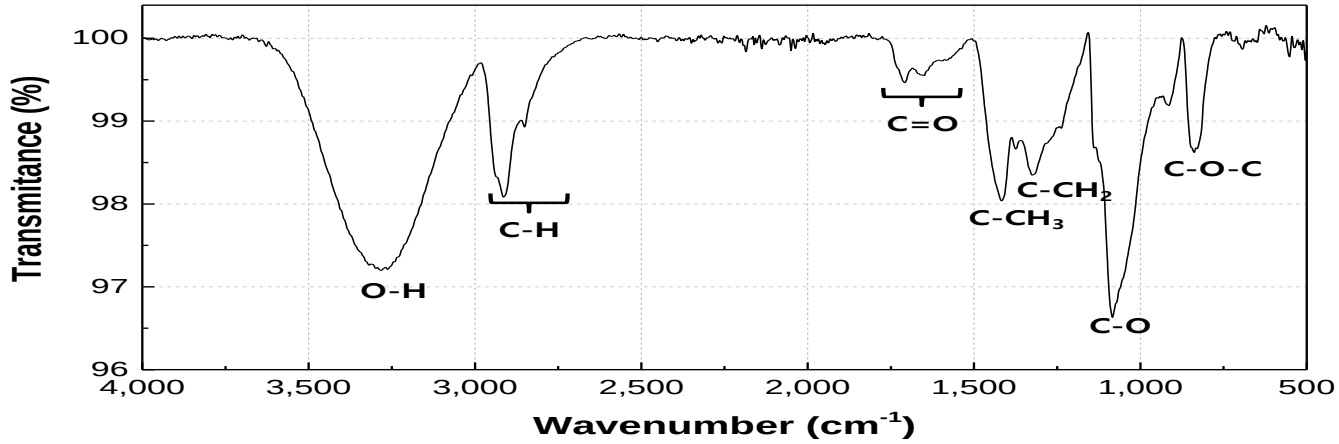
# Carbon fiber heating element applicability analysis

## ✓ Carbon fiber heating element functional group component analysis

- Analysis method : FE-SEM, FT-IR, EDS
  - Carbon fiber stem interconnect structure / weight by material ( C - 91.69% , O - 4.17 %, Na - 1.01%, Cl - 3.13%)




FE-SEM analysis




FT – IR analysis

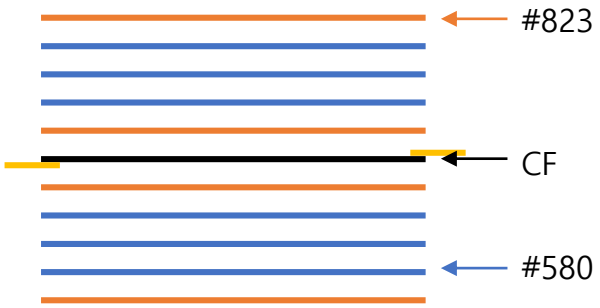
| Element | Weight (&) | Atomic (%) | Net Int. | Error (%) | ratio | Z | A | F |
|---|---|---|---|---|---|---|---|---|
| C | 91.69 | 95.11 | 4853.4 | 2.38 | 0.7115 | 0.7506 | 1.0338 | 1.0000 |
| O | 4.17 | 3.25 | 187.95 | 9.28 | 0.0197 | 0.7186 | 0.6559 | 1.0000 |
| Na | 1.01 | 0.55 | 58.88 | 8.21 | 0.0063 | 0.6574 | 0.9549 | 1.0019 |
| Cl | 3.13 | 1.10 | 107.87 | 7.49 | 0.0203 | 0.6319 | 1.0111 | 1.0155 |

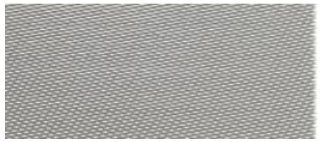
EDS analysis

# Self-heating composite specimen molding

## ✓ Composite specimen with carbon fiber heating element inserted

- Fiber lamination – 1. Same as manufacturing method of composite materials for railway vehicles
  2. Insert of mid-point of carbon fiber heating element with electrode
- Forming process – Fiber lamination → Vacuum pressure → Resin infusion → Curing and demolding



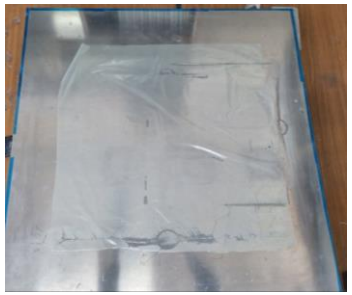



#823(Yan cloth)

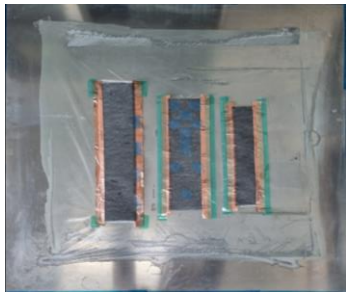
#580(Roving cloth)

CF(Carbon Fiber)

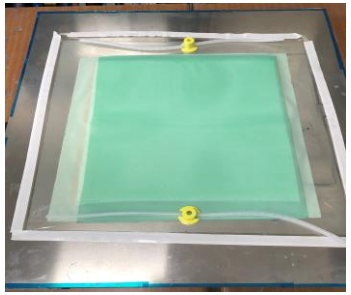
Composite fiber lamination



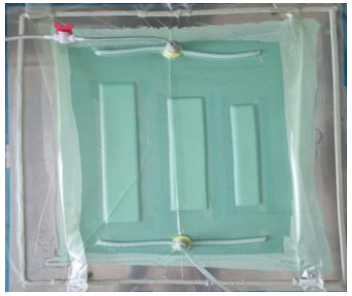
(a) Release film lay up



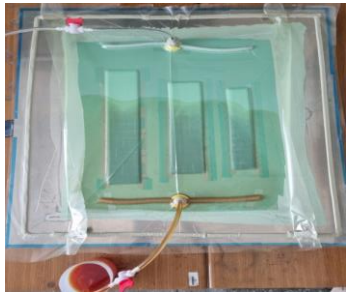
(b) Fiber lay up



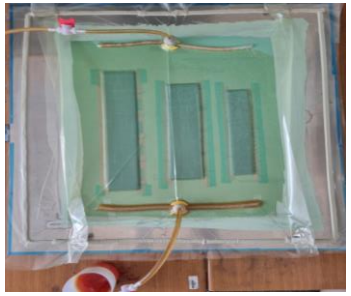
(c) Resin gate installation



(d) Vacuum bagging

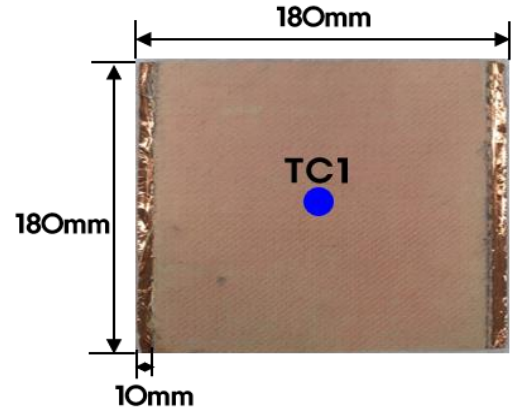


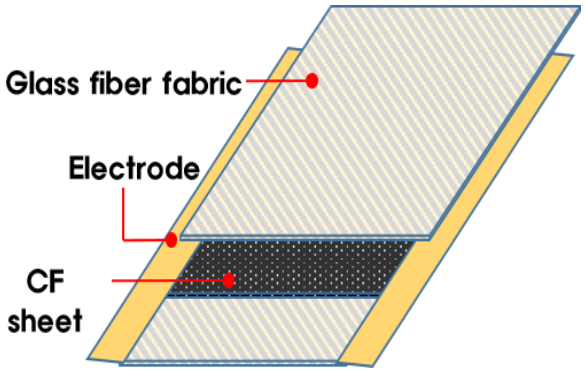
(e) Resin infusion



(e) Curing and demolding

Resin infusion method manufacturing process



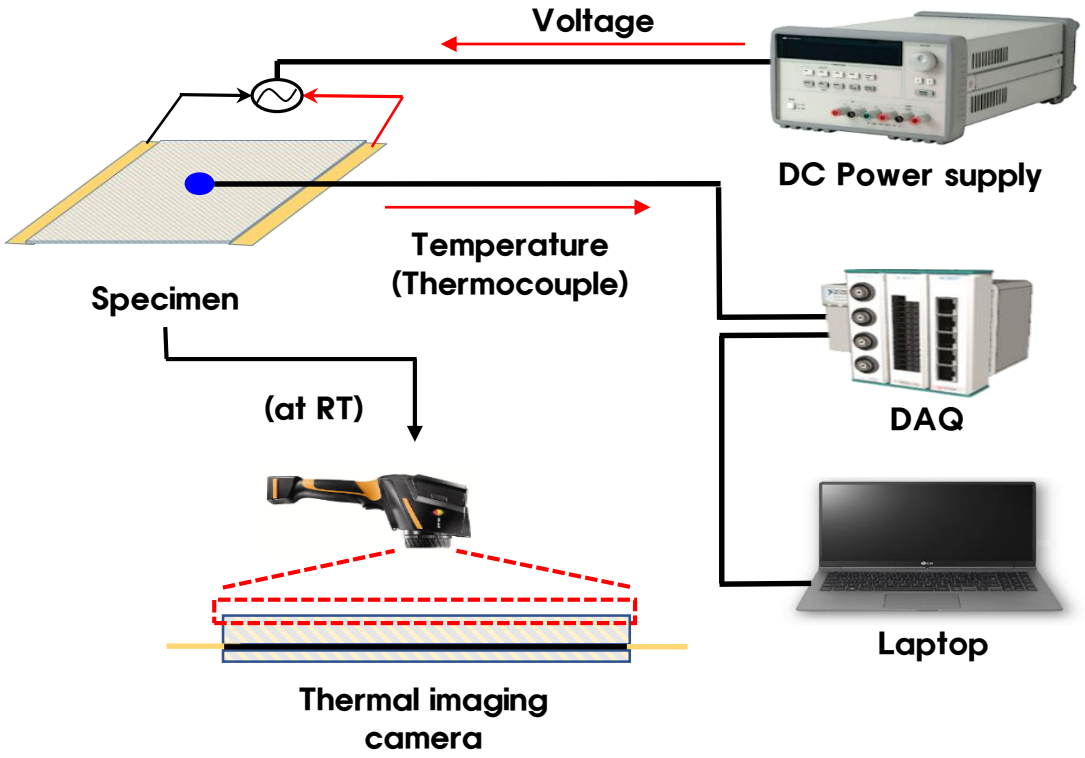




Composite specimen

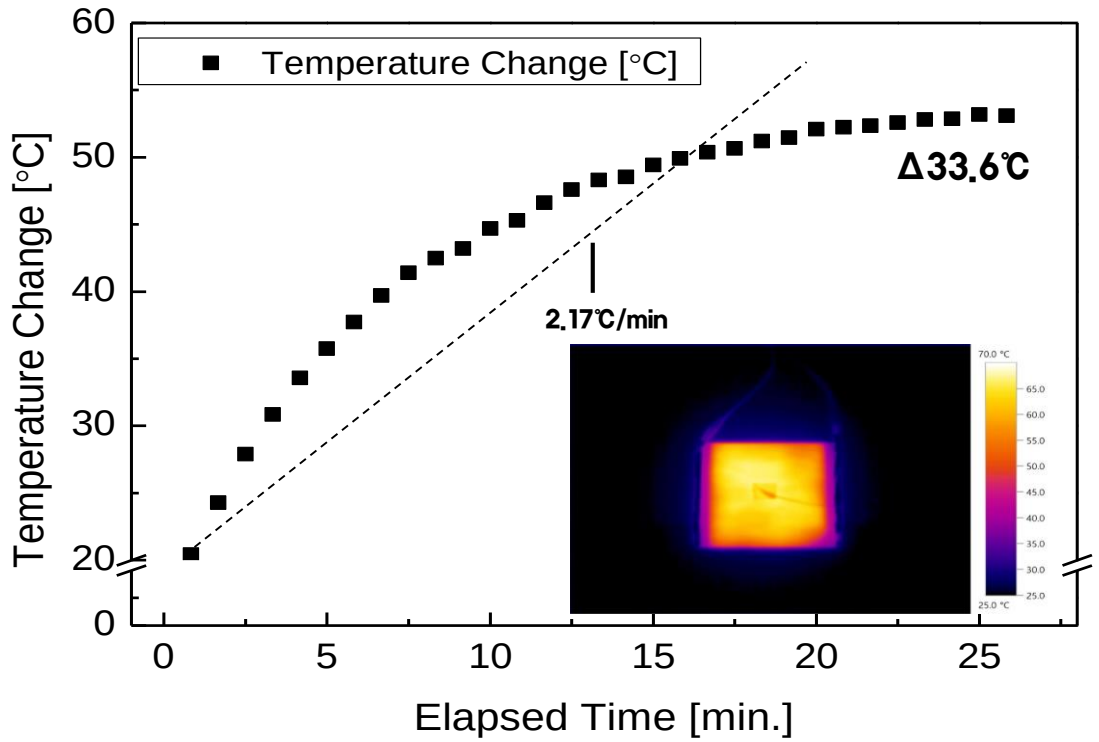
# Evaluation of heating performance of composite

## ✓ Composite heating performance evaluation test configuration and result

- Condition : DC 12V, room temperature 20℃
- Temperature measurement : 1. center of specimen (K-type, 1EA) / 2. Infrared thermal image (Testo 882)
- Evaluation : exothermic performance, Infrared thermal image capture and analysis
- Experiment result : **Confirmation of excellent heating performance and uniformity**




Experiment composition and progress

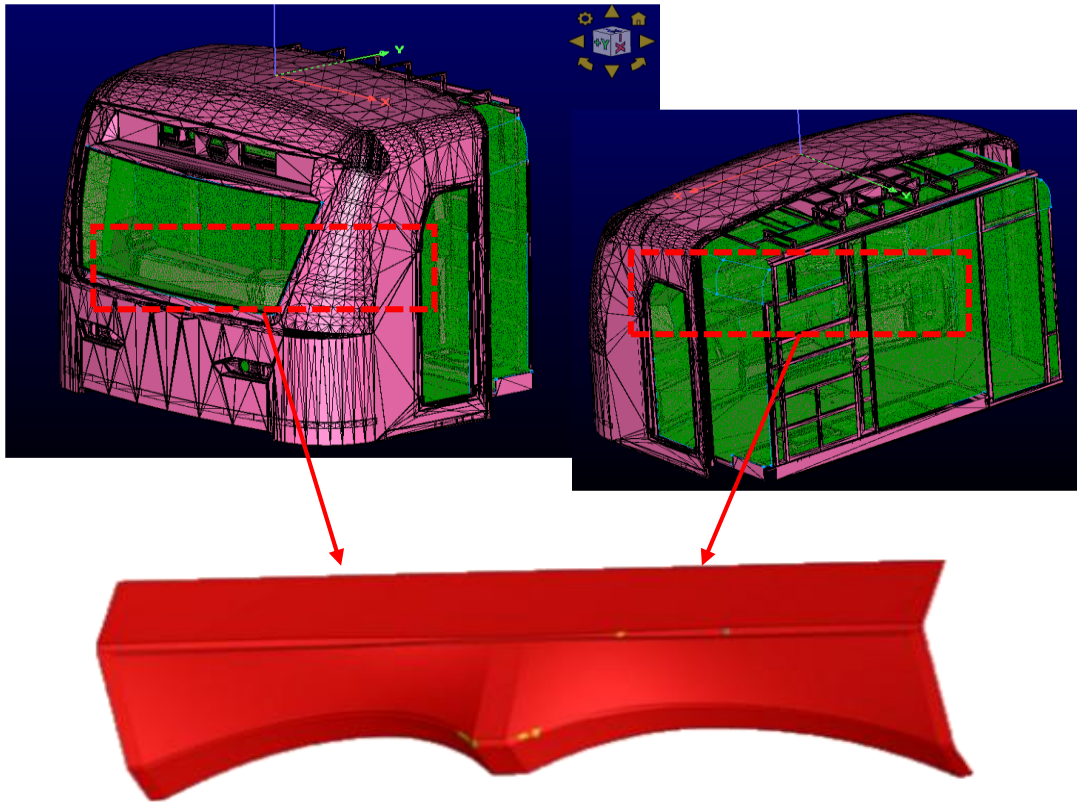



Thermal performance test results

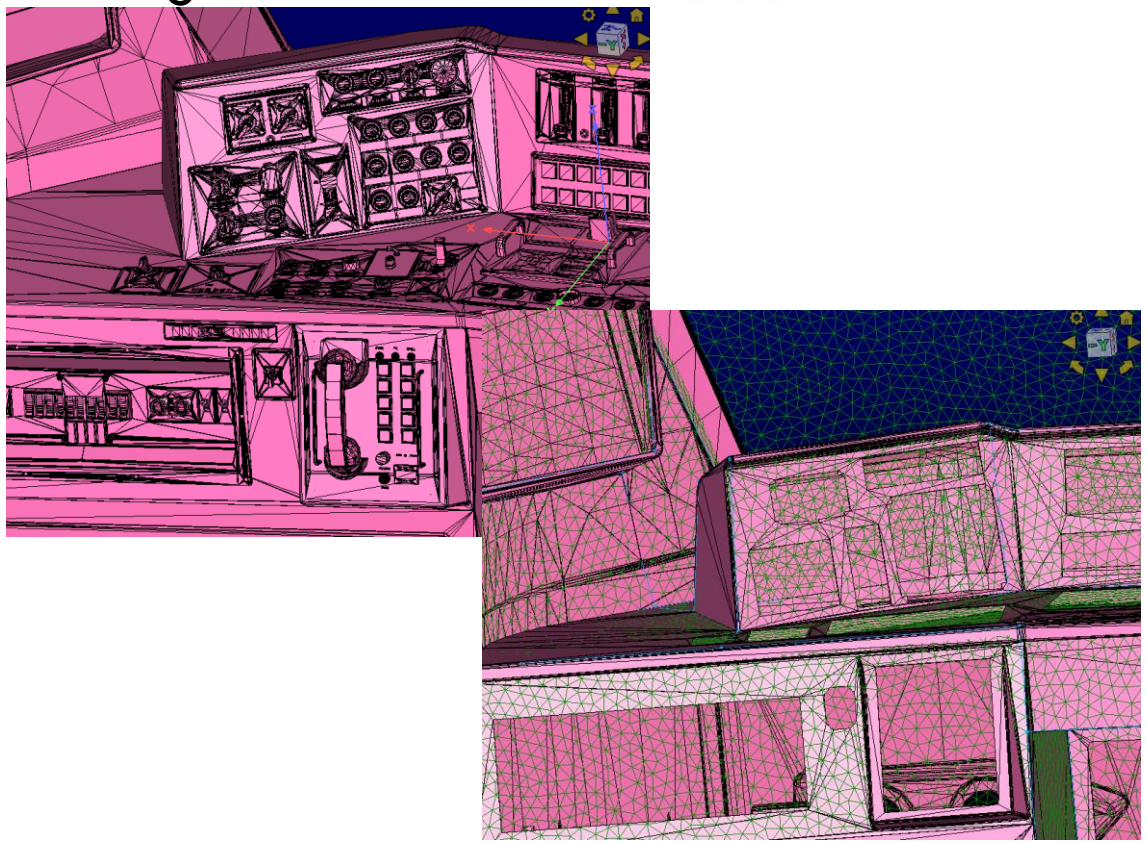
# Applicability of self-heating composite to actual railway vehicles

## ✓ 1:1 real scale (railway vehicle part) interior panel application

- Actual railway vehicle interior material (Cab front Interior panel)
- Heat flow analysis progress: Check applicability and appropriate exothermic temperature
  - Heat flow analysis progress through the formation of the grid structure inside the cab



Cab front Interior Panel



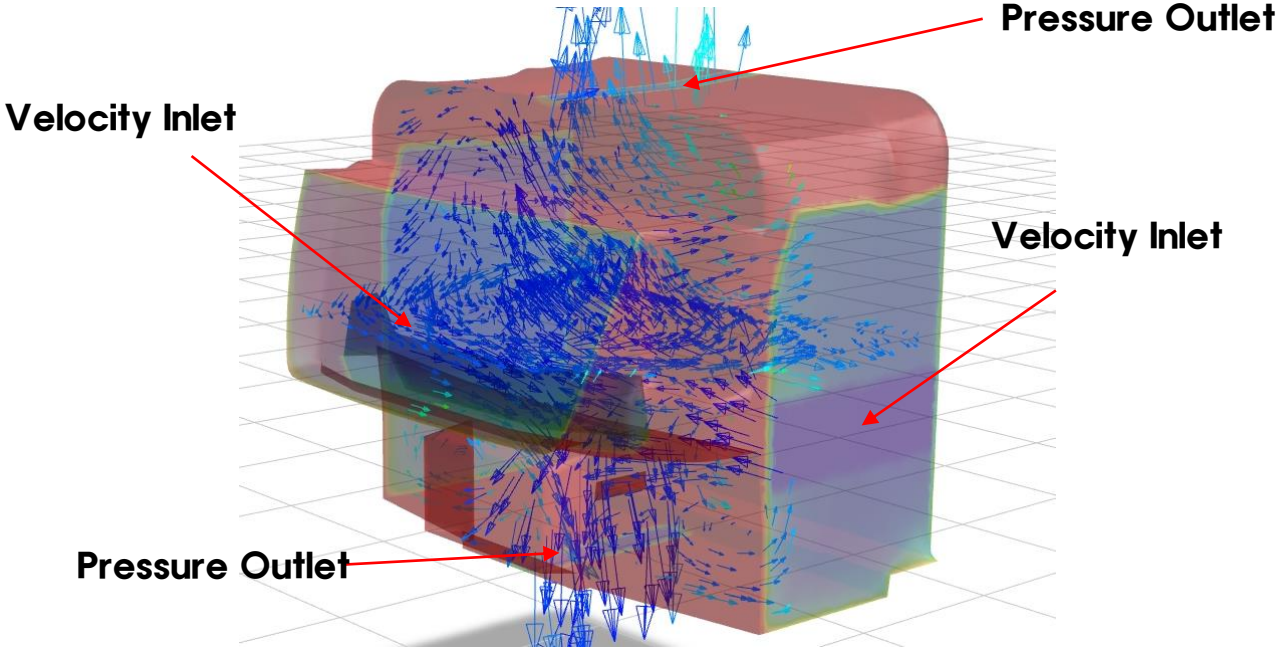
Simplify the internal structure

# Heating flow analysis

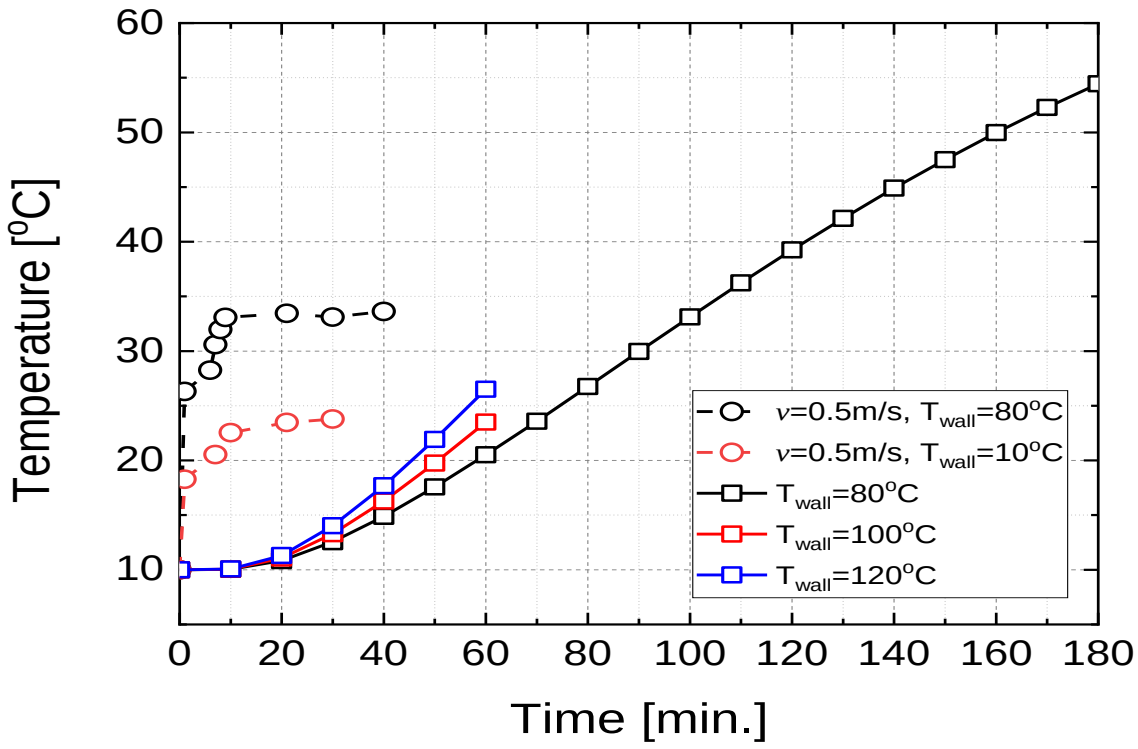
✓ **Quantitative analysis of heating effect according to heat level**

- Condition : Incompressible, Turbulent, Unsteady state, Air velocity 0.5 m/s, 101,411 grids
- S/W : OpenFOAM 8.0, Solver : icoFoam (with Heat Equation)
- Interior material panel 80℃ heat + inlet air 10℃ → Internal temperature reached 23℃ (after 10 minutes)

➡ **Heating function can be performed when the temperature exceeds 80℃**




Example of air flow inside the cab



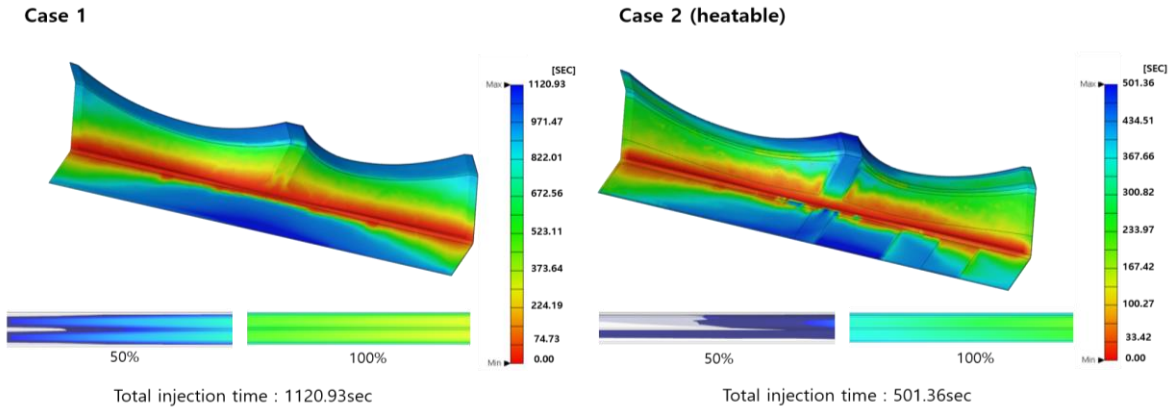

Flow analysis result

# Deriving the optimal molding method

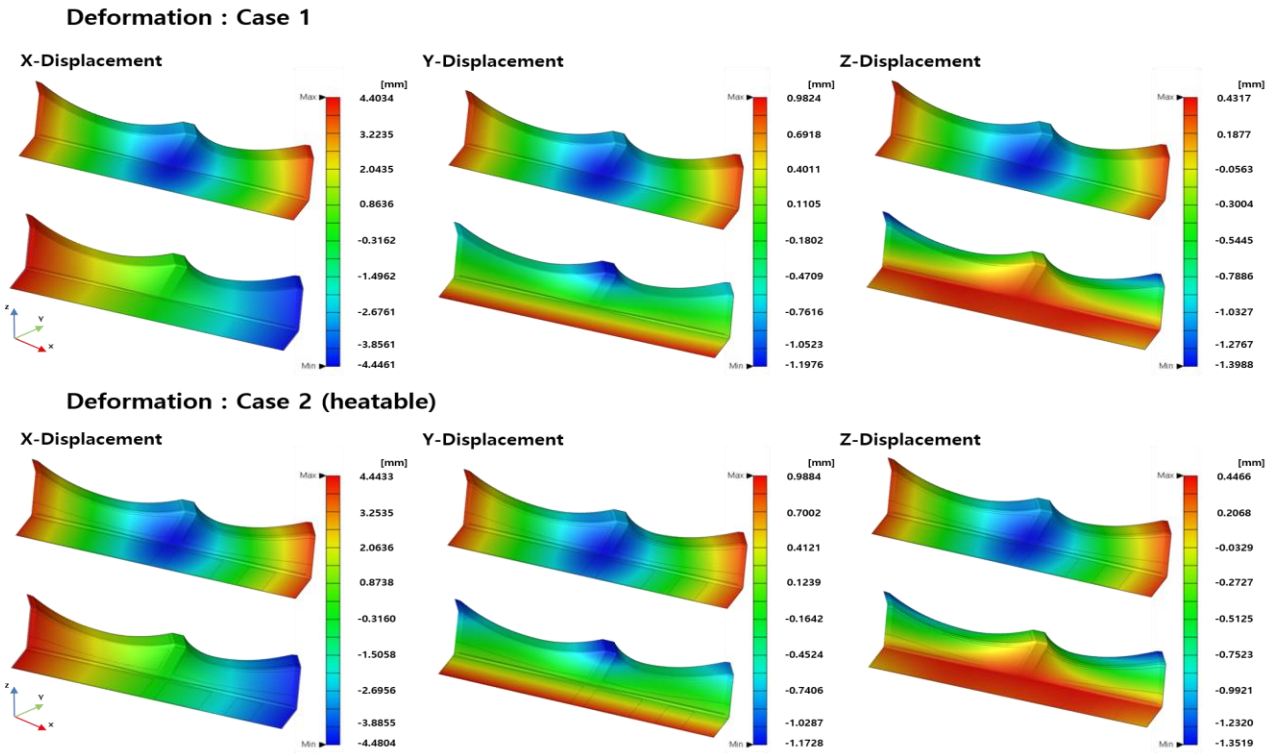
✓ **Resin-infusion process flow analysis for 1:1 scale products of railway vehicles**

- Target: Case 1 (without heating element) / Case 2 (with heating element)
- Conditions: Viscosity 100g/cm·sec, 0.1㎫, 25℃, Vent 6㎜, curing temperature (70℃),
- Evaluation : Melt Front Time, Pressure Density, Air Trap, Weld Line, Velocity, Deformation

➡ **Optimization of molding process** by checking the characteristics of various factors




Melt Front Time & Air Trap

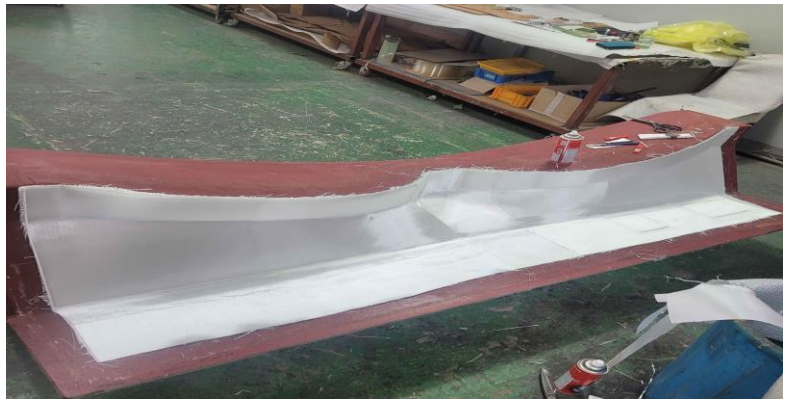



Deformation

# 1:1 real-scale exothermic composite specimen fabrication

## ✓ Application of molding optimization method

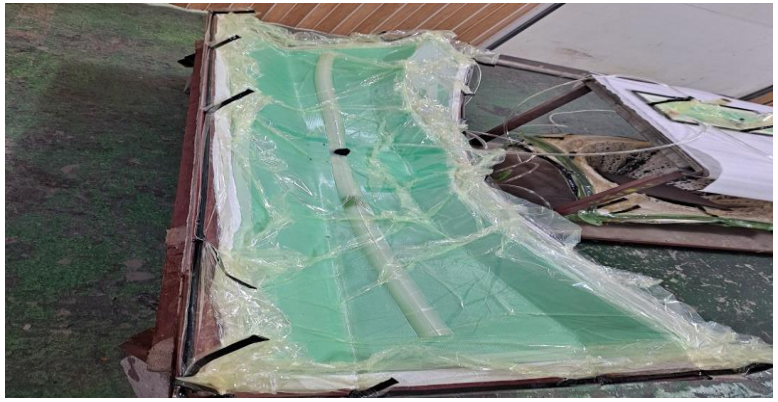
- Specimen production: Heating element insertion (7 pieces) & application of resin infusion method
- Heating element (Left panel) : #1 (20×100cm) / #2 (18×100cm) / #3 (8×100cm)
- Heating element (Right panel) : #4 (20×35cm) / #5 (20×20cm) / #6 (18×100cm) / #7 (8×100cm)



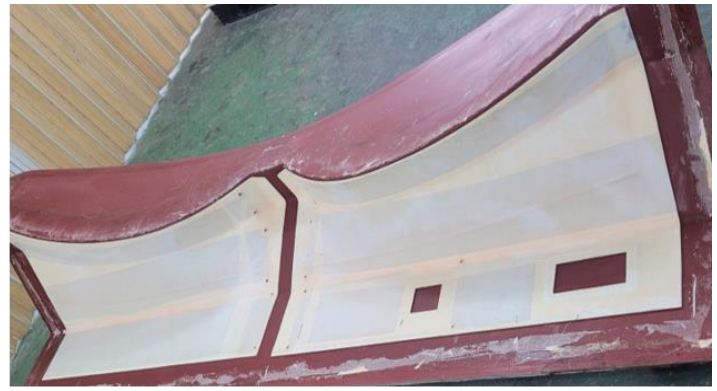
(a) Fiber lay up



(b) Carbon Fiber lay up



(c) Vacuum pressure and injecting resin

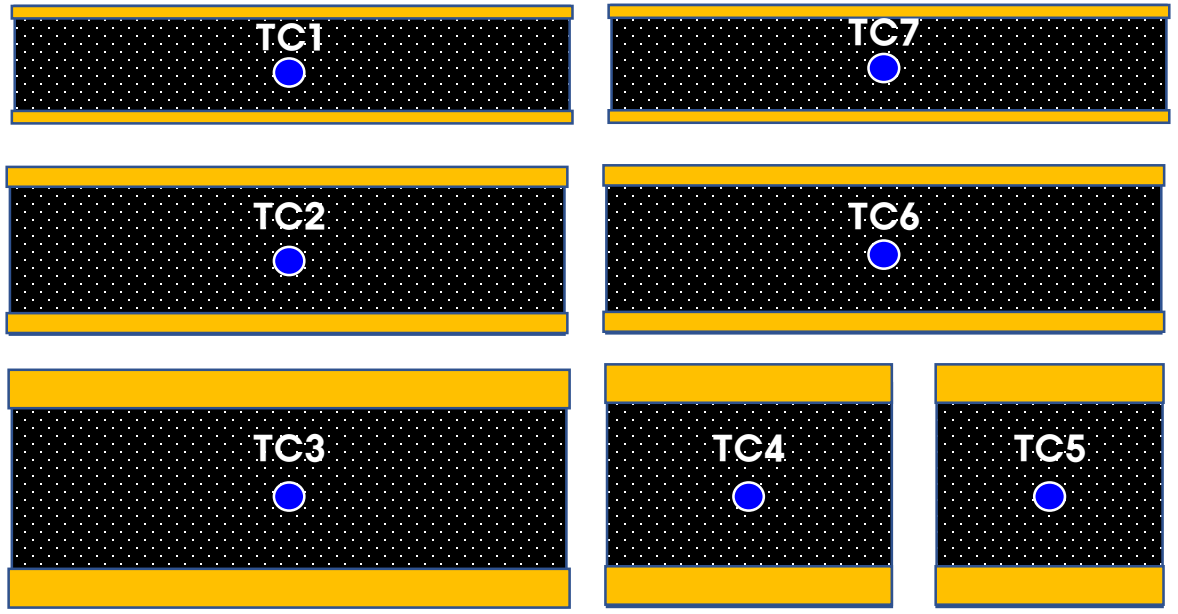


(d) 1:1 scale heating panel specimen production completed

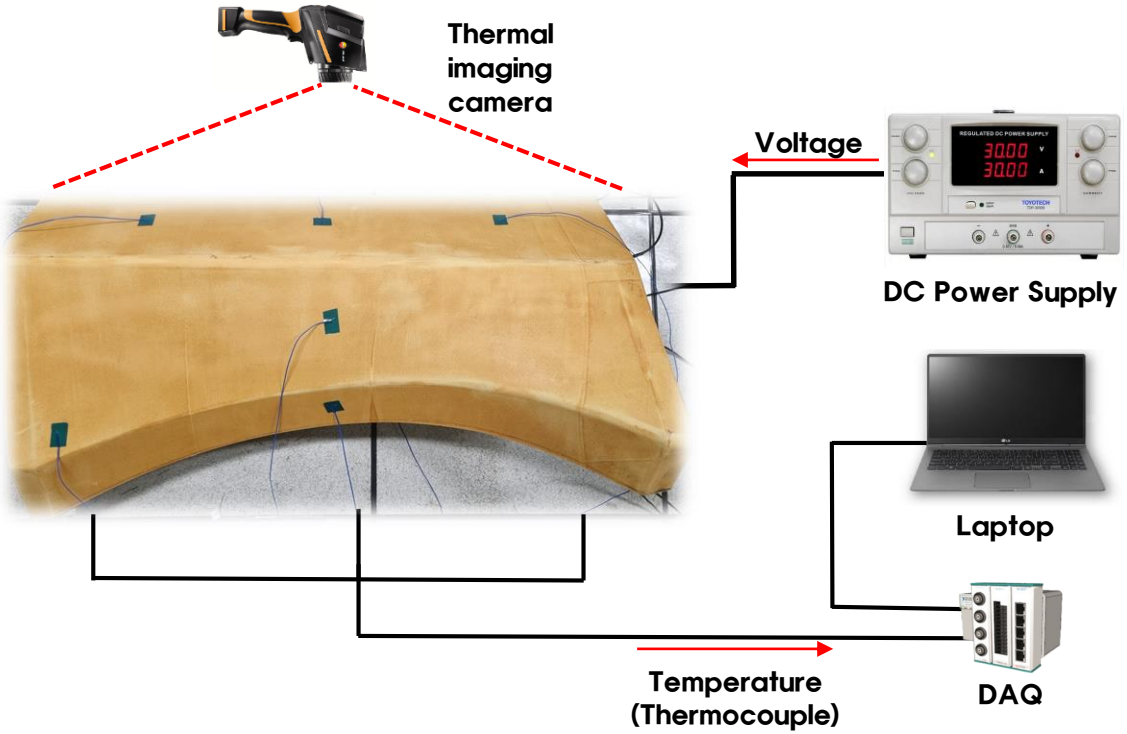
# 1:1 real-scale specimen exothermic performance evaluation

## ✓ Configuration of experiment

- Conditions: DC 24V, room temperature 20℃
- Temperature measurement: 1. Central of the heating element application area (K-type, 7EA)
  2. Infrared thermal image (Testo 882)
- Evaluation : exothermic performance, infrared thermal image capture and analysis




Application of heating element and thermocouple



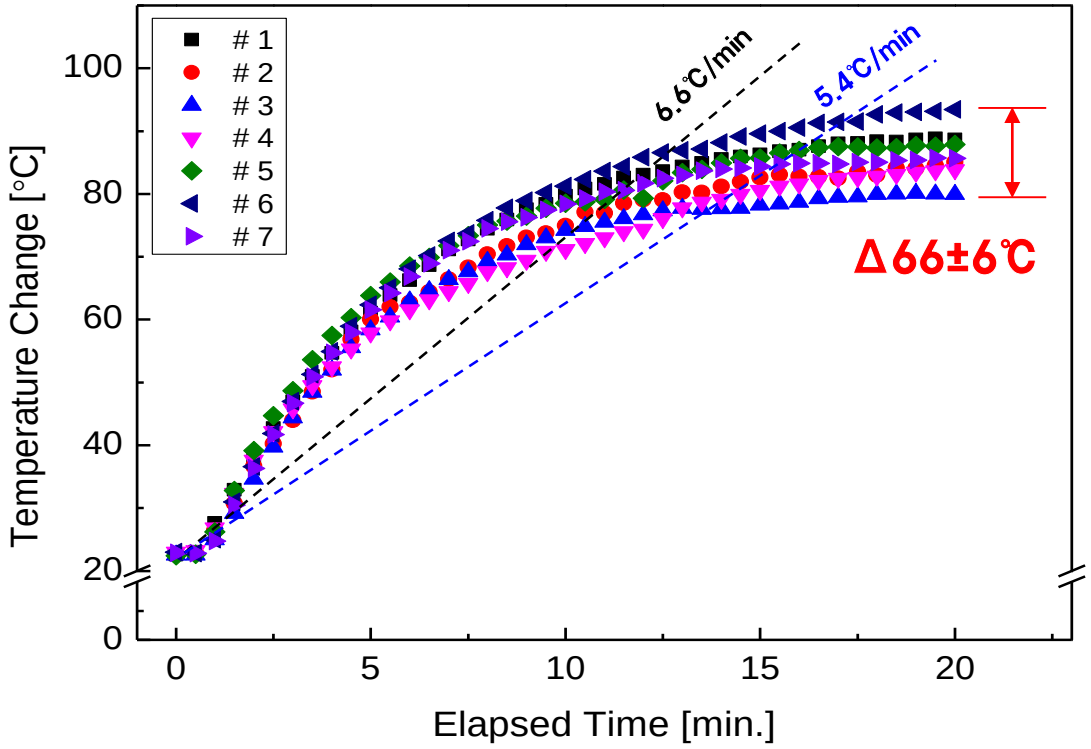

Configuration of experiment

# 1:1 real scale composite panel performance evaluation result

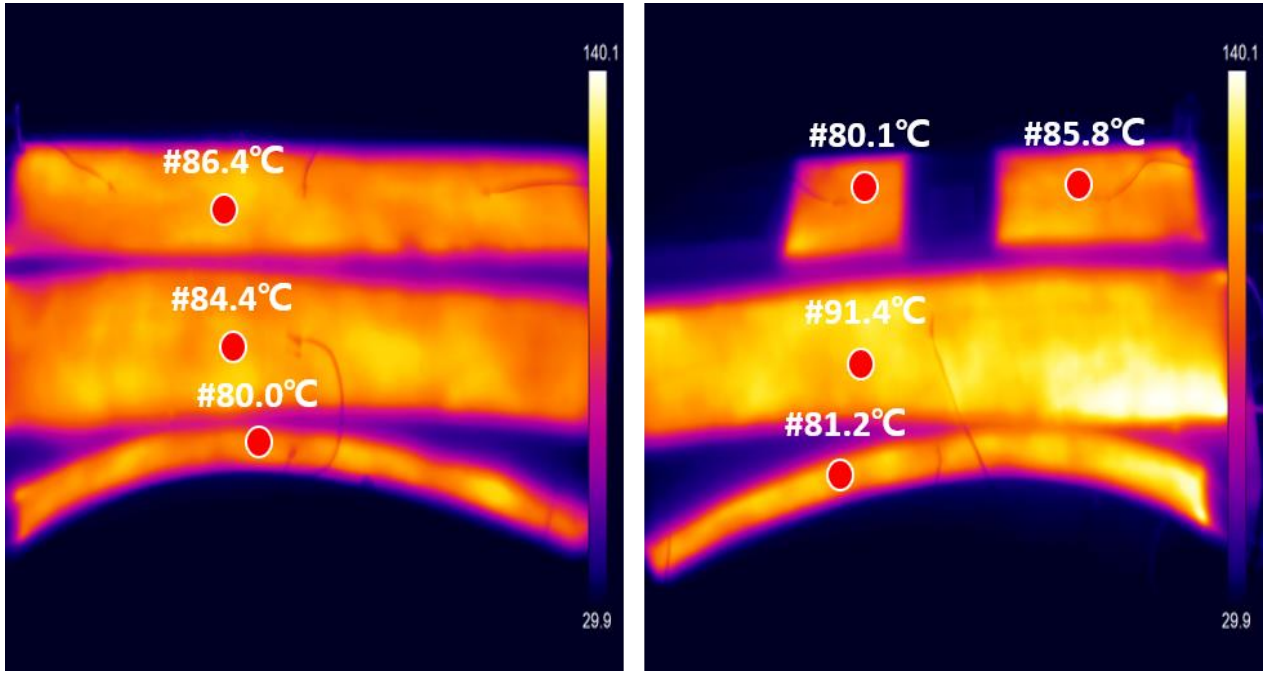
## ✓ Panel temperature change amount and thermal image

- Excellent heating performance of over 80℃ reached (in 20 minutes) in all heating elements
  - Within 10% (△66±6℃) of temperature deviation for each heating element
- Confirmation of uniform heat generation in the heating element insertion area (thermal image)

➡ Demonstration of excellent heating performance of self-heating composite panel




Heating performance evaluation result




Infrared thermal image of self-heating composite panel

# Exothermic uniformity analysis

## ✓ Analysis of temperature data through infrared thermal image

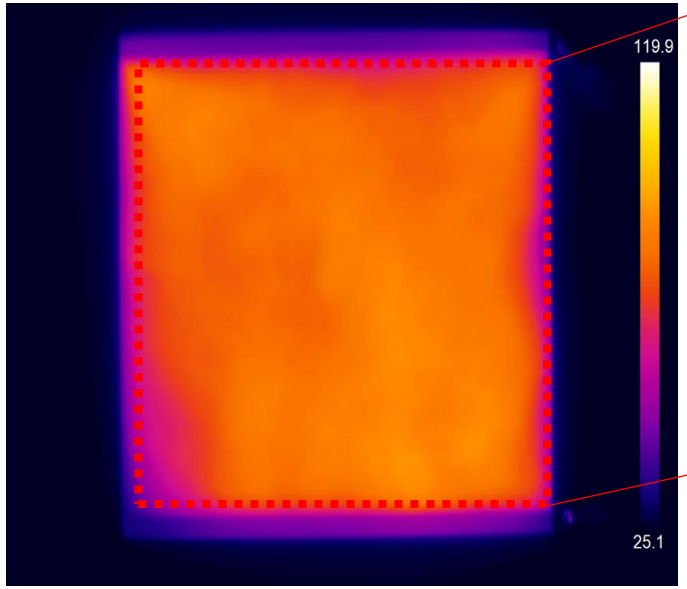
· Using statistical techniques for quantitative analysis, extracting temperature data in pixel units (350×350)

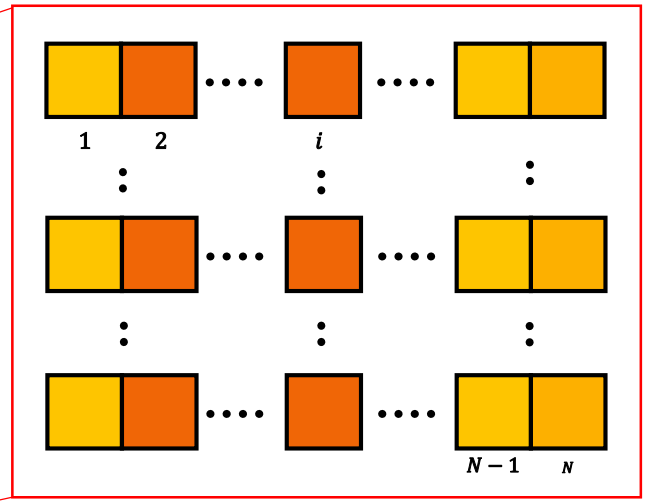
- Skewness (SK) : Indicates the degree of bias in the distribution relative to the median of the data

→ $\mathrm{Sk} = \frac{1}{N}\sum_{i=1}^{N}(X_i - \bar{X})^3 \Big/ \left(\frac{1}{N}\sqrt{\sum_{i=1}^{N}(X_i - \bar{X})^2}\right)^3$

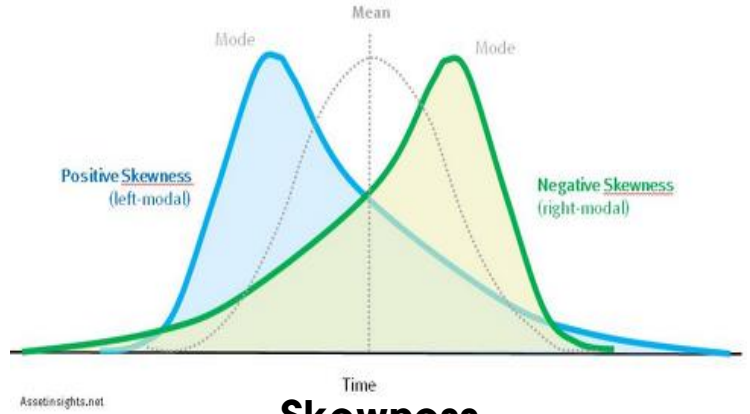
- Kurtosis (Ku) : Indicates the density of data

→ $\mathrm{Ku} = \frac{1}{N}\sum_{i=1}^{N}(X_i - \bar{X})^4 \Big/ \left(\frac{1}{N}\sum_{i=1}^{N}(X_i - \bar{X})^2\right)^2$

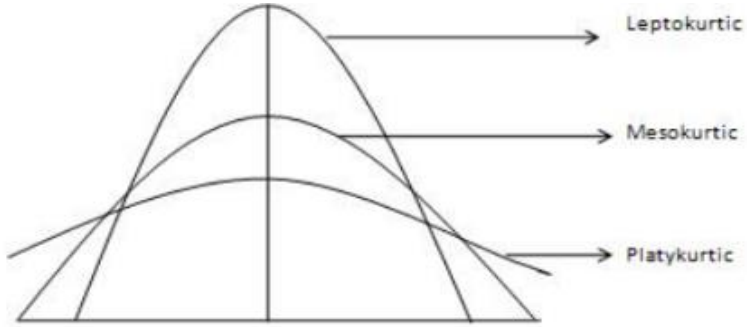



$X_i, \quad \bar{X}, \quad N$




Skewness

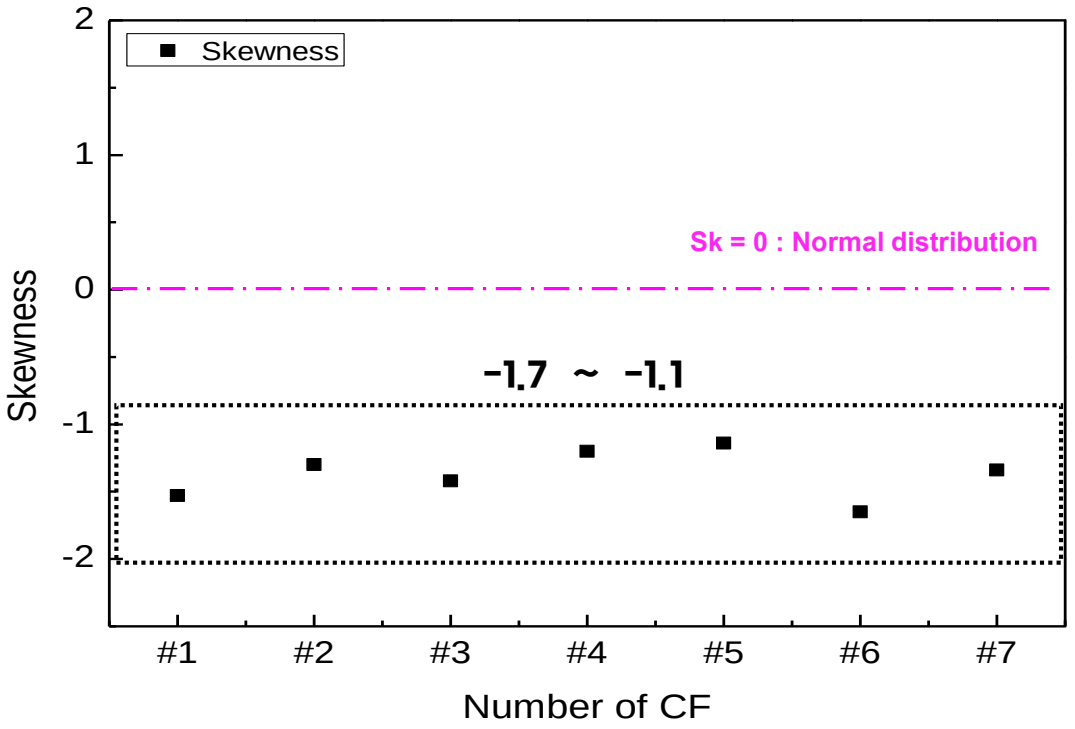



Kurtosis

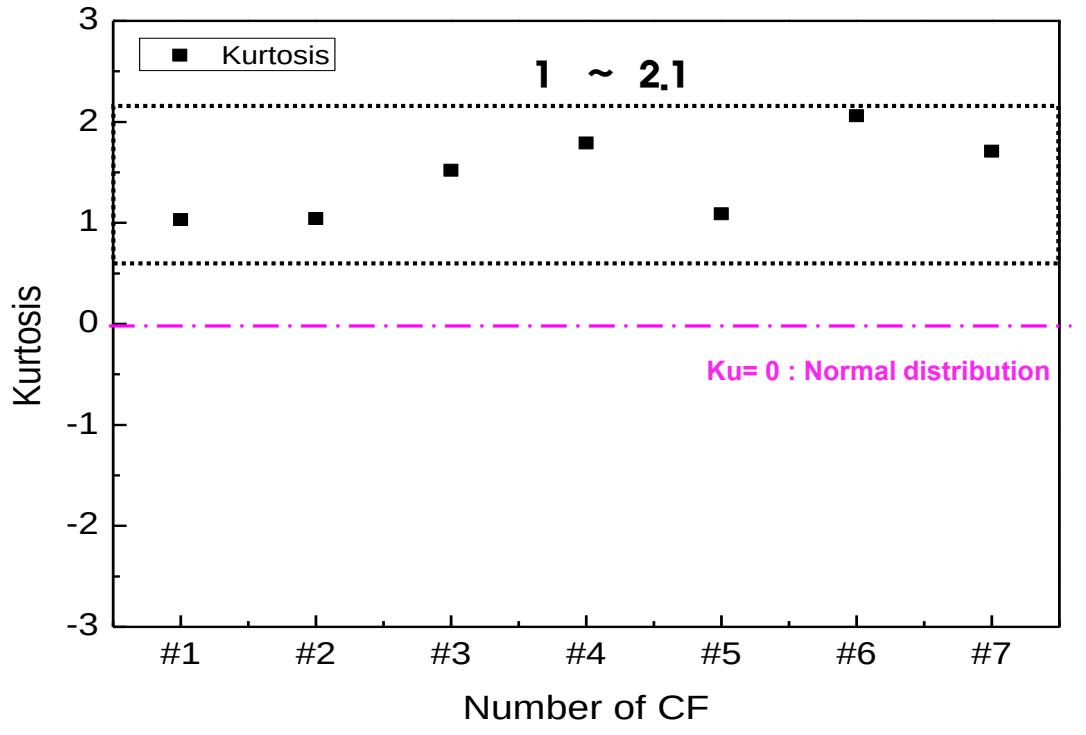
# Infrared thermal image statistical analysis results

- ✓ **Skewness** – If the average value is higher than the normal distribution, it is negative (–), if it is low, it is positive (+)
  - All values of each heating element are negative (-1.7 ~ -1.1) → high temperature heating
- ✓ **Kurtosis** – Appears as negative (–) when variance compared to normal distribution, positive (+) when crowded
  - All values of each heating element are positive (1 ~ 2.1) → temperature-dense properties

➡ **Confirmation of excellent heating uniformity (high temperature & dense)**




**Skewness**



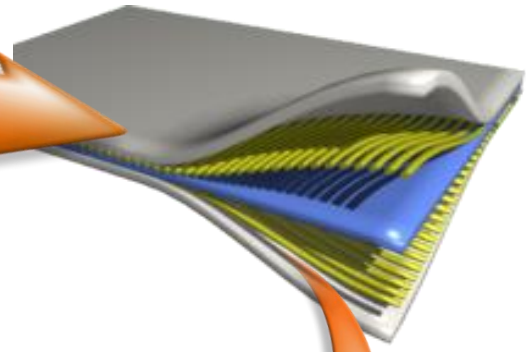

**Kurtosis**

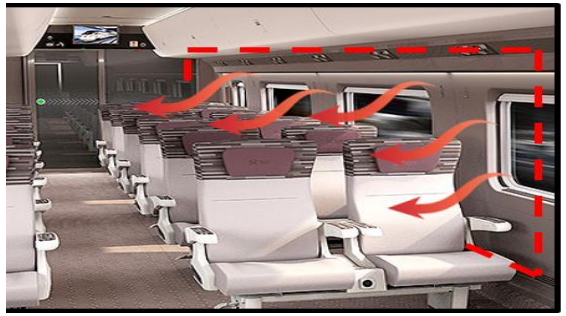
# Conclusion

✓ **Confirmation manufacturability and performance of self-heating composite for railway vehicles**

- Application of resin infusion method that can reduce cost by about 30%
- Development of self-heating composite and confirmation of exothermic performance
- Field applicability verification through real-scale specimen production and exothermic performance test

⟶ **Development of self-heating composite with reduced prices**





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