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Development of Resin Impregnation Simulation on Compression-Resin Transfer Molding for Mass Production of CFRP
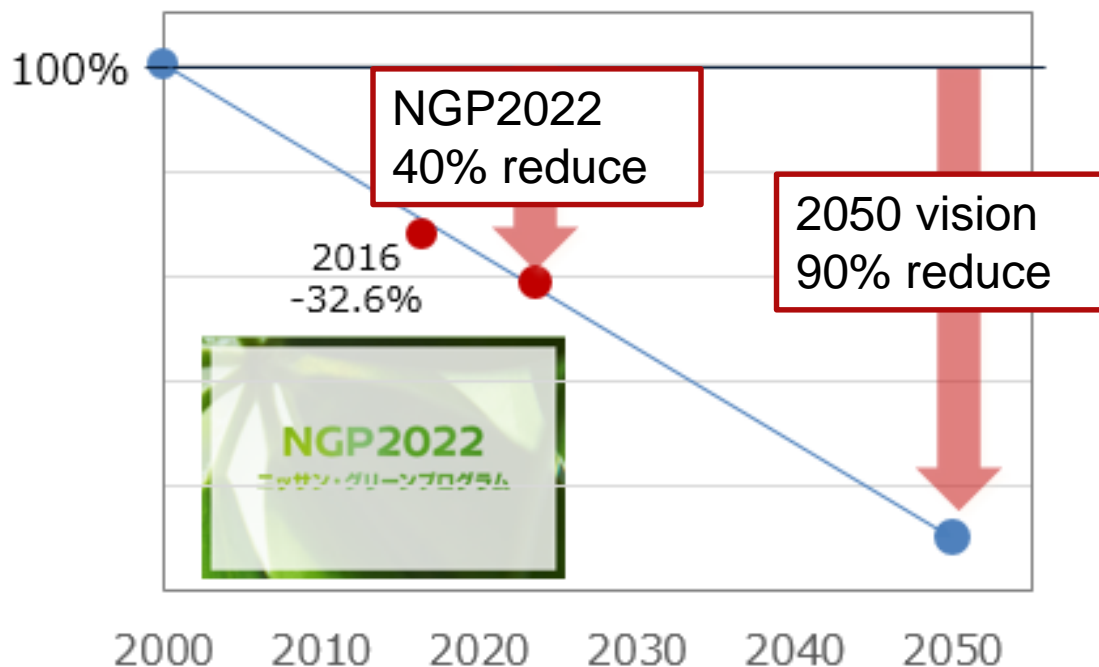
Atsushi Mizutani
Expert Leader
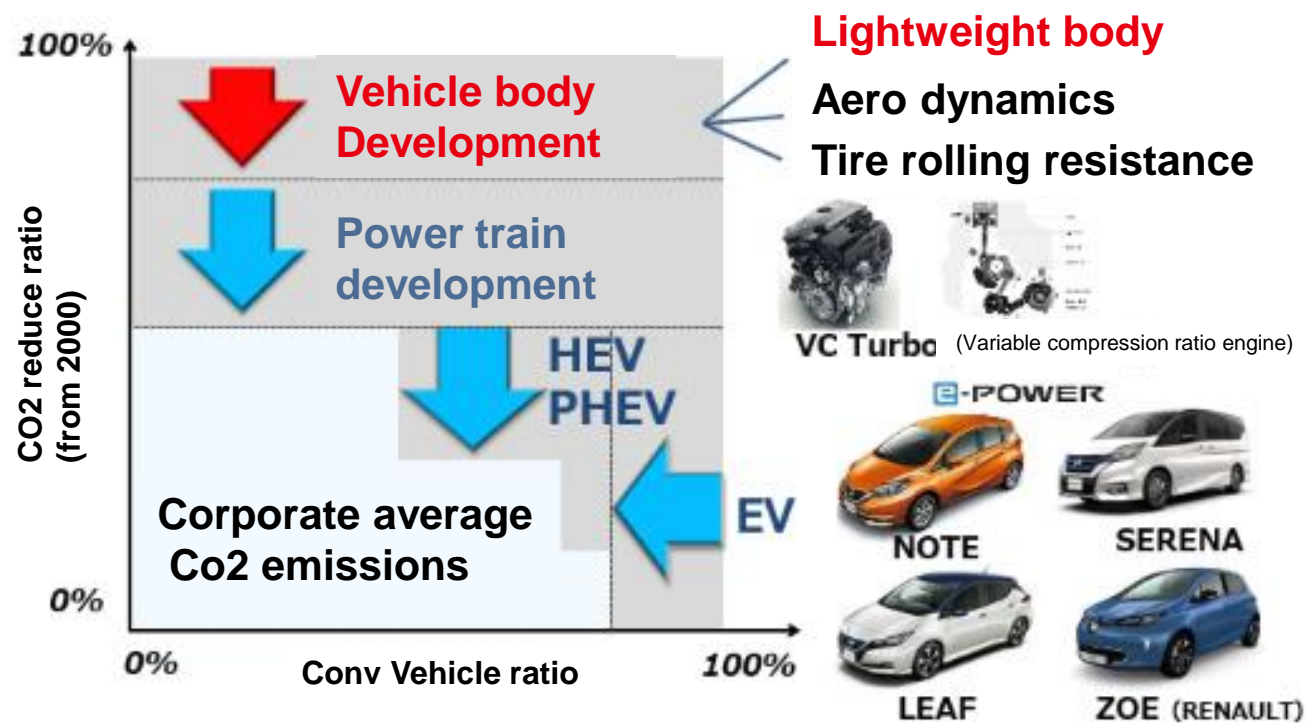Production Engineering R&D Center
September 3, 2020

Background

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Background

- NISSAN GREEN PROGRAM aims to reduce CO_2 by 40% until 2022 and 90% until 2050 compared with 2000
- Promotion of electrification and vehicle weight reduction to meet strict environmental regulations
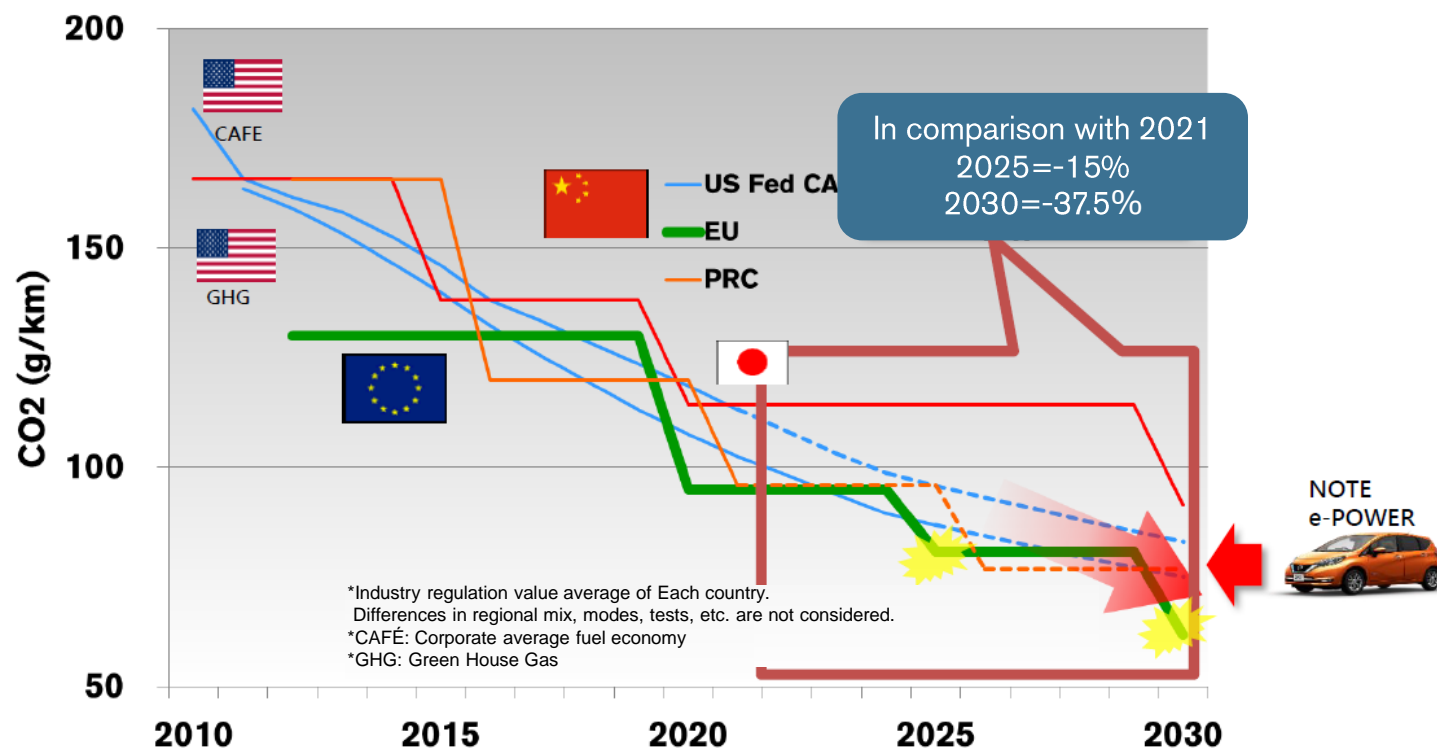

100%

NGP2022
40% reduce

2050 vision
90% reduce

2016
-32.6%

NGP2022
ニッサン・グリーンプログラム

2000 2010 2020 2030 2040 2050

Calculated independently based on the survey results of the IPCC Fourth Assessment Report

Lightweight body

Vehicle body Development

Aero dynamics
Tire rolling resistance

Power train development

VC Turbo (Variable compression ratio engine)

CO2 reduce ratio (from 2000)

HEV
PHEV

EV

Corporate average Co2 emissions

0%

0%   Conv Vehicle ratio   100%

e-POWER

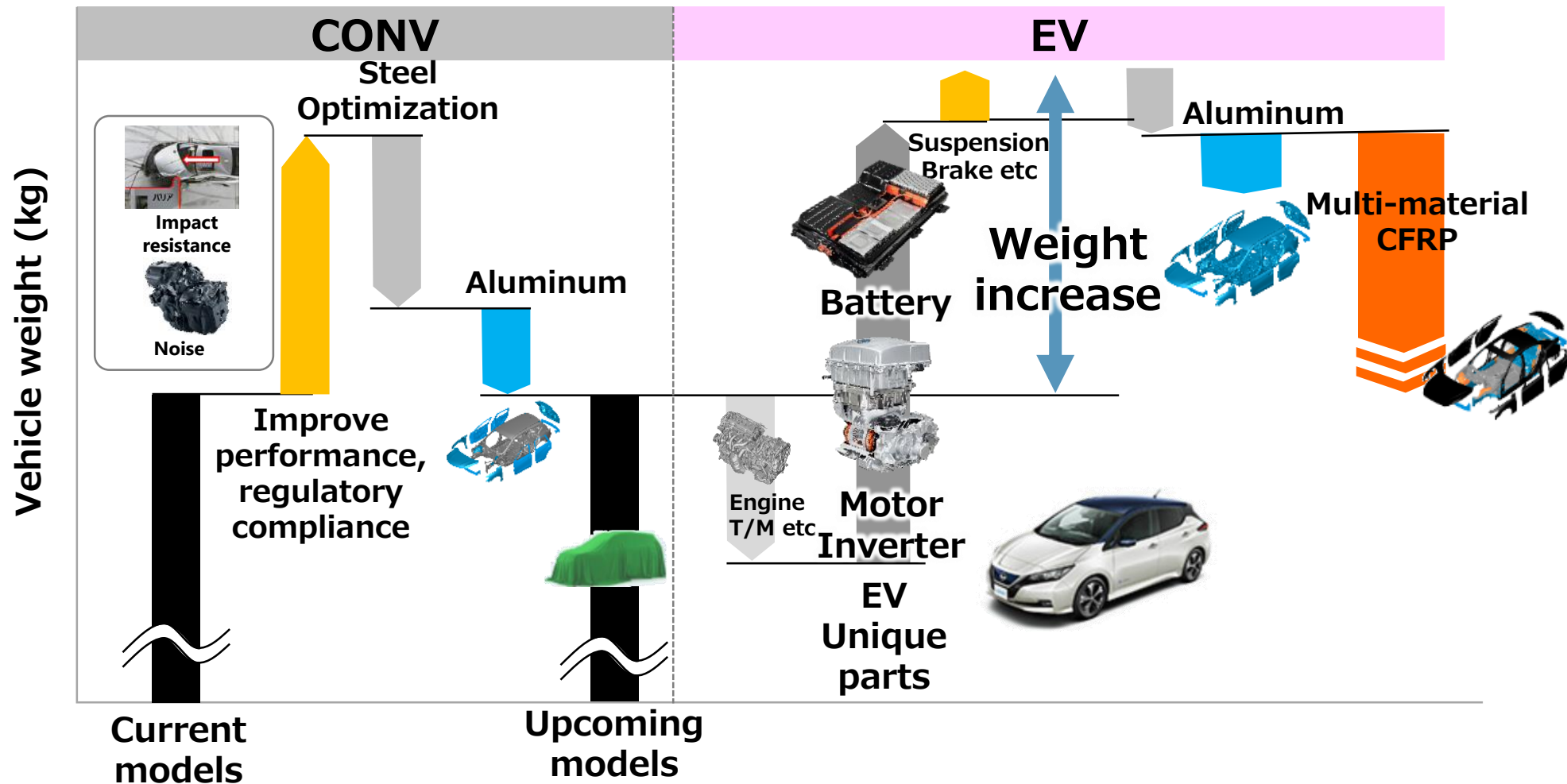NOTE   SERENA

LEAF   ZOE (RENAULT)

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CO2 regulation by country and region

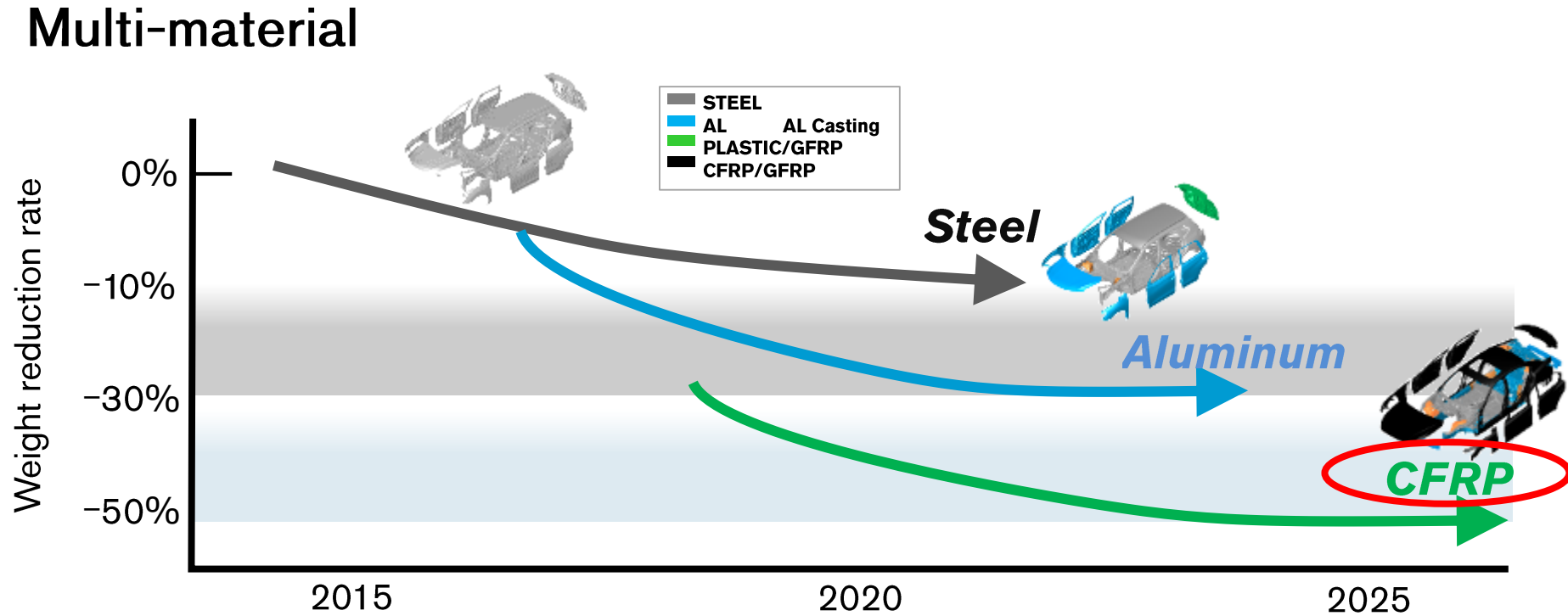- After 2022, regulations become stricter, and EU has the strictest regulations after 2025

In comparison with 2021
2025=-15%
2030=-37.5%

*Industry regulation value average of Each country.
 Differences in regional mix, modes, tests, etc. are not considered.
*CAFÉ: Corporate average fuel economy
*GHG: Green House Gas

NOTE
e-POWER

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EV and vehicle weight

■ Vehicle weight will increase due to battery and motor inverter for EV

Vehicle weight (kg)

CONV

EV

Steel Optimization

Impact resistance

Noise

Aluminum

Improve performance, regulatory compliance

Battery

Suspension Brake etc

Weight increase

Aluminum

Multi-material CFRP

Engine T/M etc

Motor Inverter

EV Unique parts

Current models

Upcoming models

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Multi-material use for future vehicle body

- Realizing further weight reduction by multi-material application for future vehicle body benefitting of each material characteristics

Multi-material

Legend:
- STEEL
- AL / AL Casting
- PLASTIC/GFRP
- CFRP/GFRP

Steel

Aluminum

CFRP

Y-axis: Weight reduction rate (0%, −10%, −30%, −50%)

X-axis: 2015, 2020, 2025

CFRP Technical challenges

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CFRP lightweight and strong material

※CFRP : Carbon Fiber Reinforced Plastic

- Carbon fiber is thinner than hair, has excellent strength and rigidity, and is 50% lighter than steel
- CFRP is carbon fiber solidified with resin

<Carbon fiber>

Diameter 5-7μm
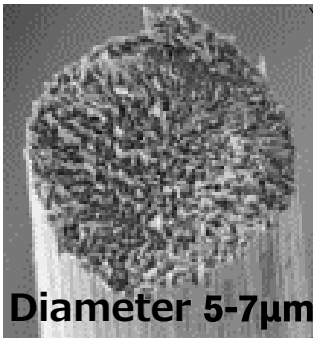
Section of Carbon fiber

Carbon fiber roll

Source : JCMA Home page

<Carbon fiber reinforced plastic >

Carbon fiber sheet

+
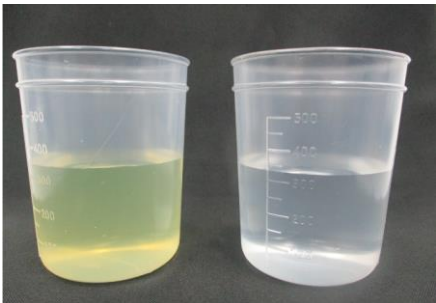
Resin   **Hardened**
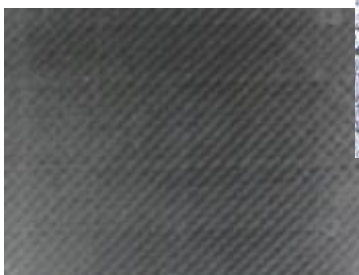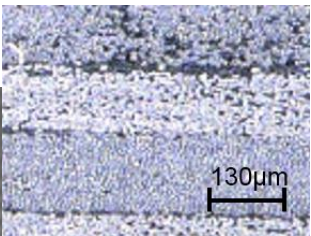
Macro photograph Section

CFRP

Material	Specific gravity	Strength (MPa)	Specific strength (10^4m)	Elastic modulus (GPa)	Specific rigidity (10^6m)
Steel	7.8	780	1.0	210	2.7
Aluminum	2.7	370	1.4	72	2.7
CFRP	1.5	600-1,600	4.0-10.7	60-120	4.0-8.0

130μm

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CFRP body part adoption in Nissan vehicles

■ Currently used exclusively in the GT-R NISMO

ROOF

SPOILER

TRUNK LID

HOOD

REAR BUMPER

SILL COVER
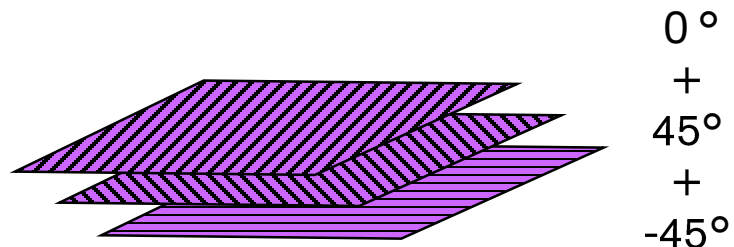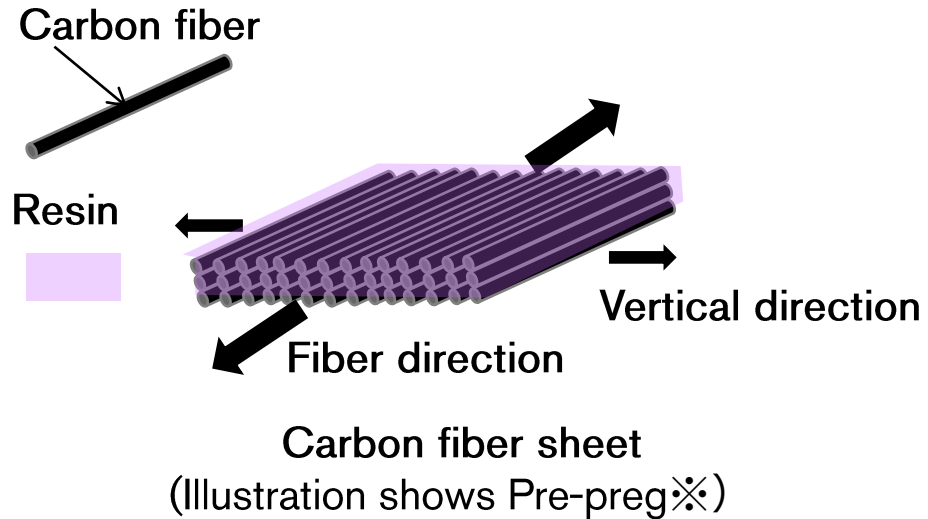
FENDER

FRONT BUMPER

GT-R NISMO 2020 model

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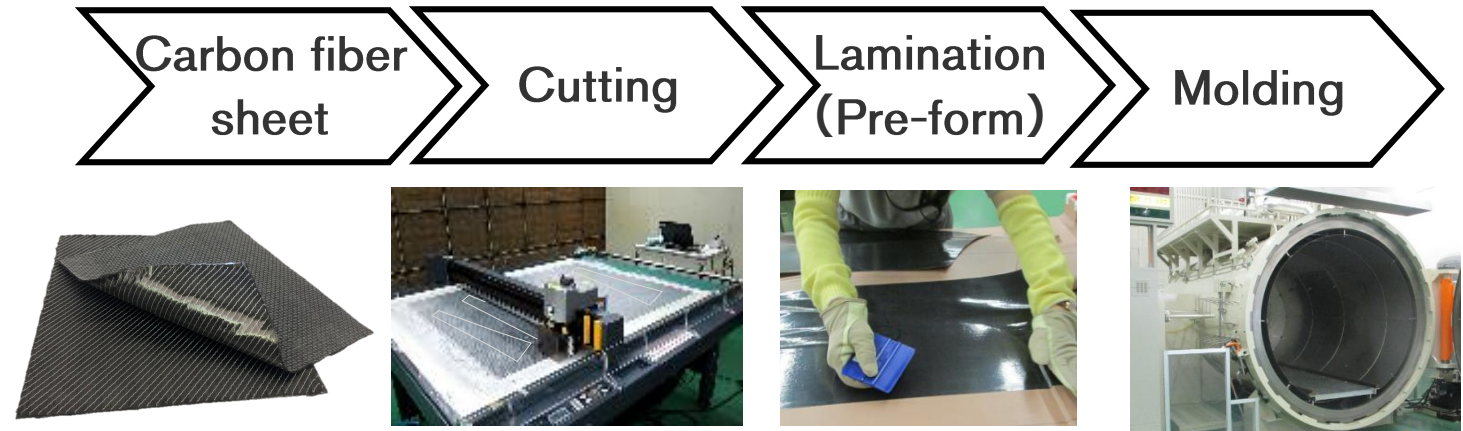# Challenges of CFRP application for automotive parts

- Challenges are cost and productivity; the cost is about 10 times higher than steel parts
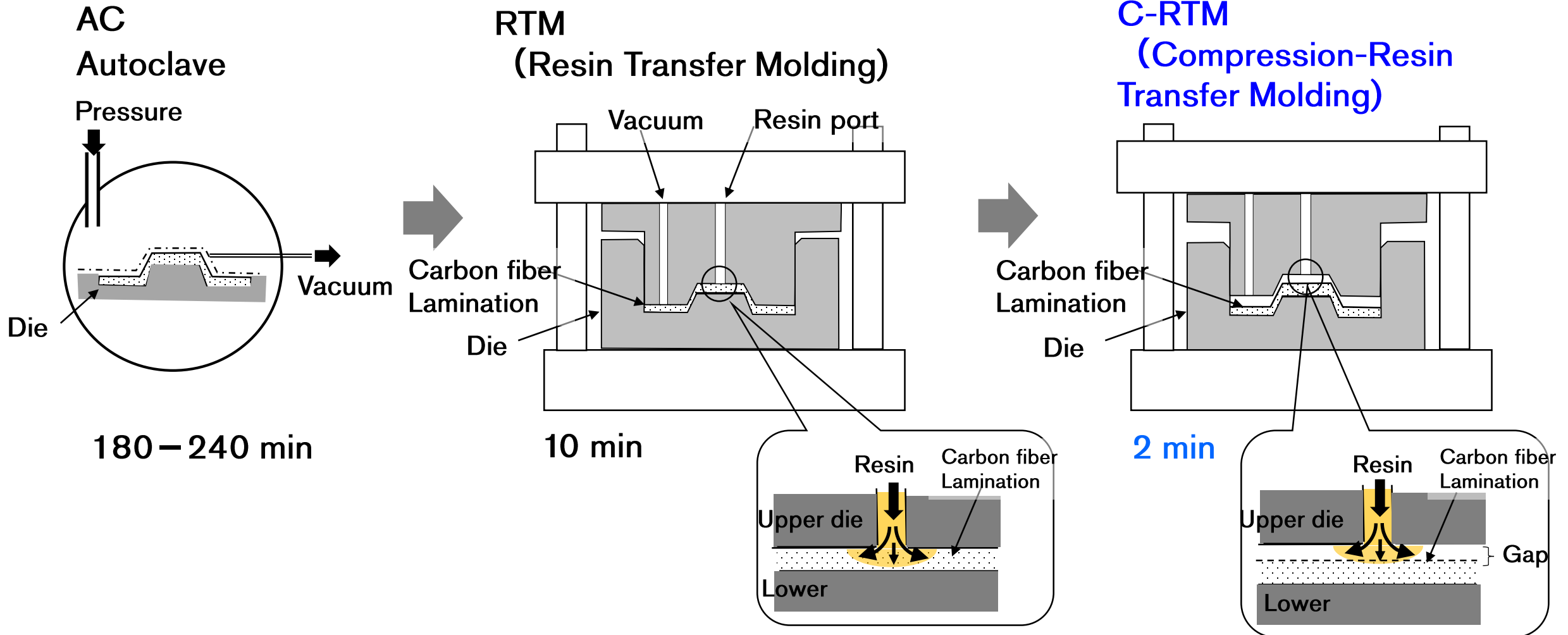- Manufacturing process is complicated, and molding time is long

＜Characteristic of carbon fibers＞

Carbon fiber

Resin

Vertical direction

Fiber direction

Carbon fiber sheet
(Illustration shows Pre-preg※)

0°
+
45°
+
-45°

Lamination design

＜Production process＞

| Carbon fiber sheet | Cutting | Lamination (Pre-form) | Molding |

※Pre-preg : The sheet of carbon fiber impregnated with resin beforehand

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Innovation of production speed in molding

- The production speed has significantly improved in the last 10 years
- Further innovation of molding method will improve speed

AC
Autoclave

Pressure

Vacuum

Die

180－240 min

RTM
（Resin Transfer Molding）

Vacuum   Resin port

Carbon fiber
Lamination

Die

10 min

Resin   Carbon fiber
Lamination

Upper die

Lower

C-RTM
（Compression-Resin
Transfer Molding）

Carbon fiber
Lamination

Die

2 min

Resin   Carbon fiber
Lamination

Upper die

Gap

Lower

Technical issues in molding

- Wrinkles and deformation occur when carbon fiber sheet is pressed
- Necessary to impregnate the resin before it hardens

Flat carbon fiber sheet transforms into three-dimensional shaped parts

Press

Carbon fiber sheet

Test part
(Center Pillar)
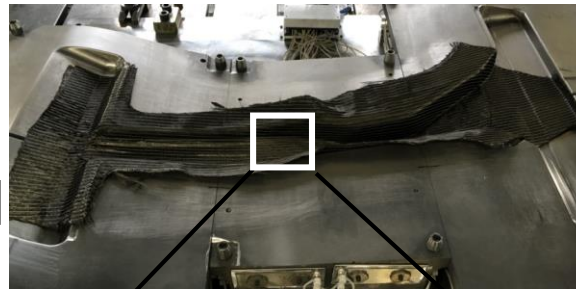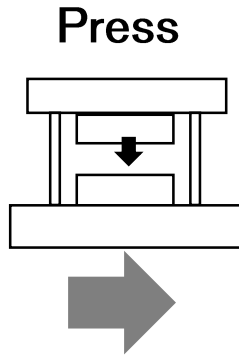
Wrinkle is generated

Resin stiffens while flowing in carbon fiber sheet

Solid

Liquid

Hardness Resin (Viscosity)

Time

Upper side
(resin injected side)

Lower side
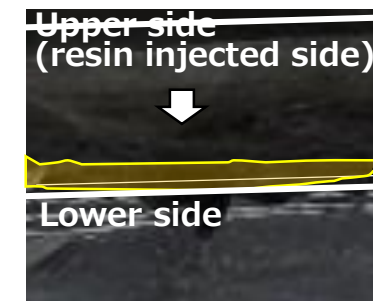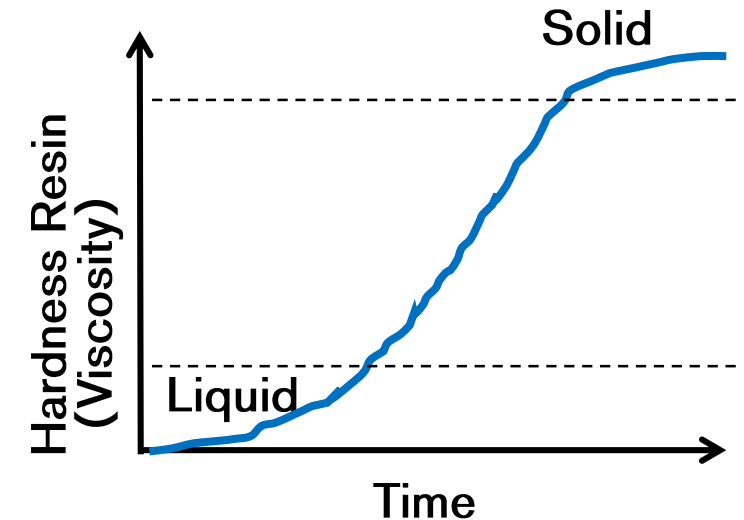
Solidification started before the resin reached the bottom of the preform

Cross-section of CFRP

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Video of C-RTM
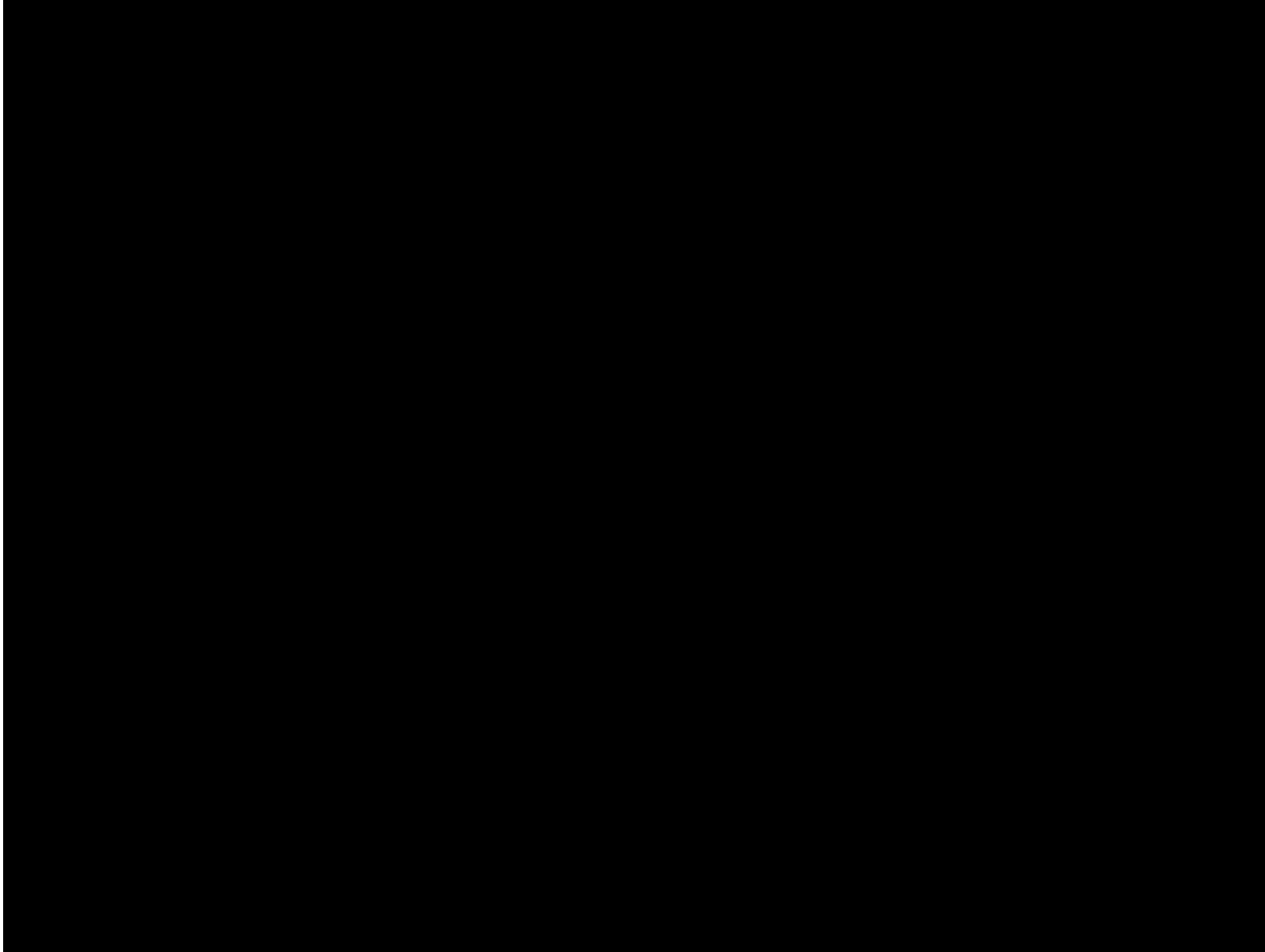
Carbon fiber
Lamination
(Pre-forming)
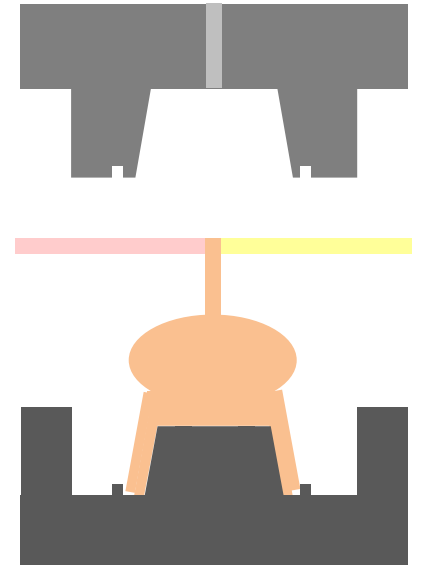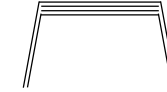
Scheme of molding method

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Development of Nissan original simulation on C-RTM

Technical challenges of C-RTM

- A long development period and significant amount of cost is necessary for trial and error to manufacture parts and dies that meet design requirements, material types and production goals
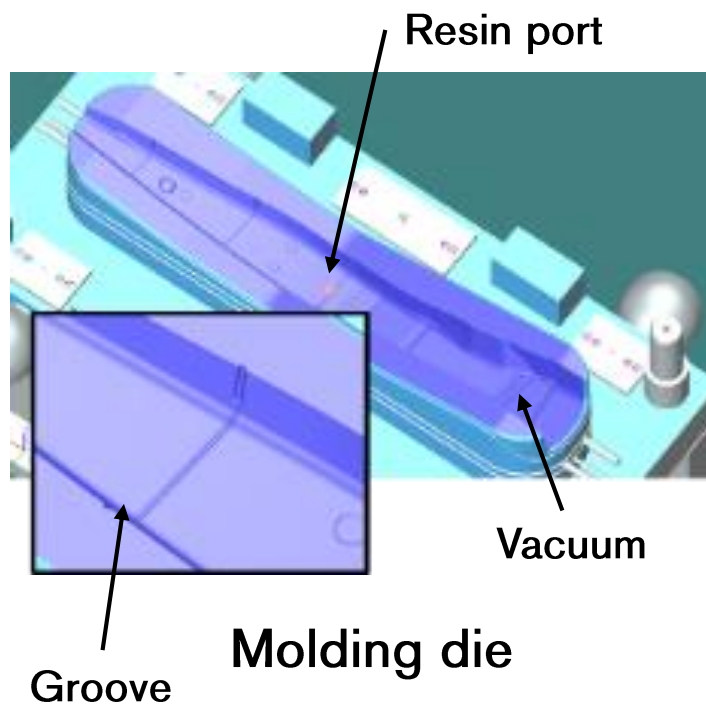
<Design of parts and die>

Design
- CF layer
- Shape
- Thickness

Material
- Type of CF and Resin

Production
- Cycle time
- Quality

Groove

Molding die

Resin port

Vacuum

<Shorter development period>

Current

| Die Design | Die Prod. | Trial #1 | Modify #1 | Trial #2 | Modify #2 | Trial #2 | Modify #3 | Trial #4 | Evaluate |

After development

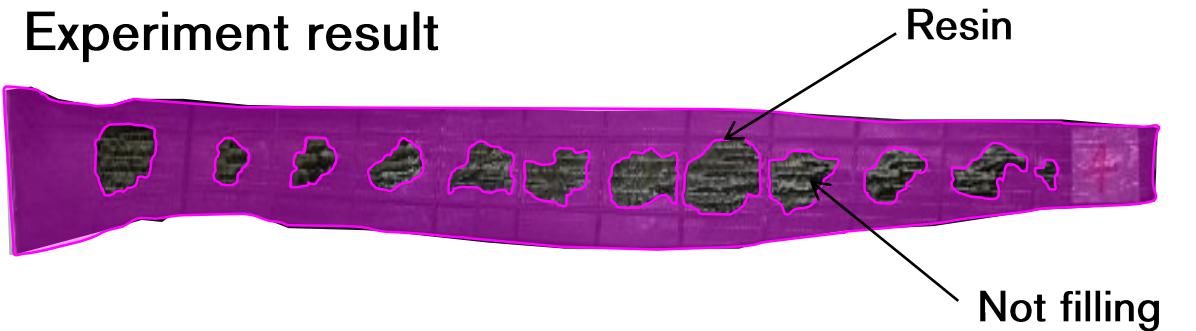| Die Design | CAE | Die Prod. | Trial #1 | Evaluate |

-50%

※CF : Carbon fiber

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Technical challenges of C-RTM simulation development

- The final impregnation results differ between simulation and actual experiment
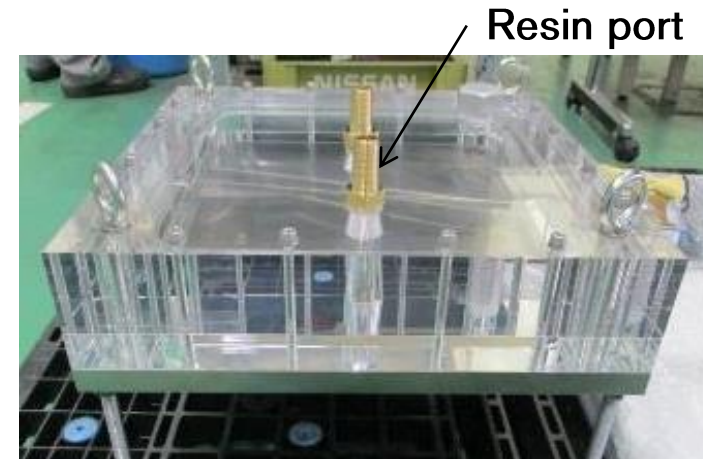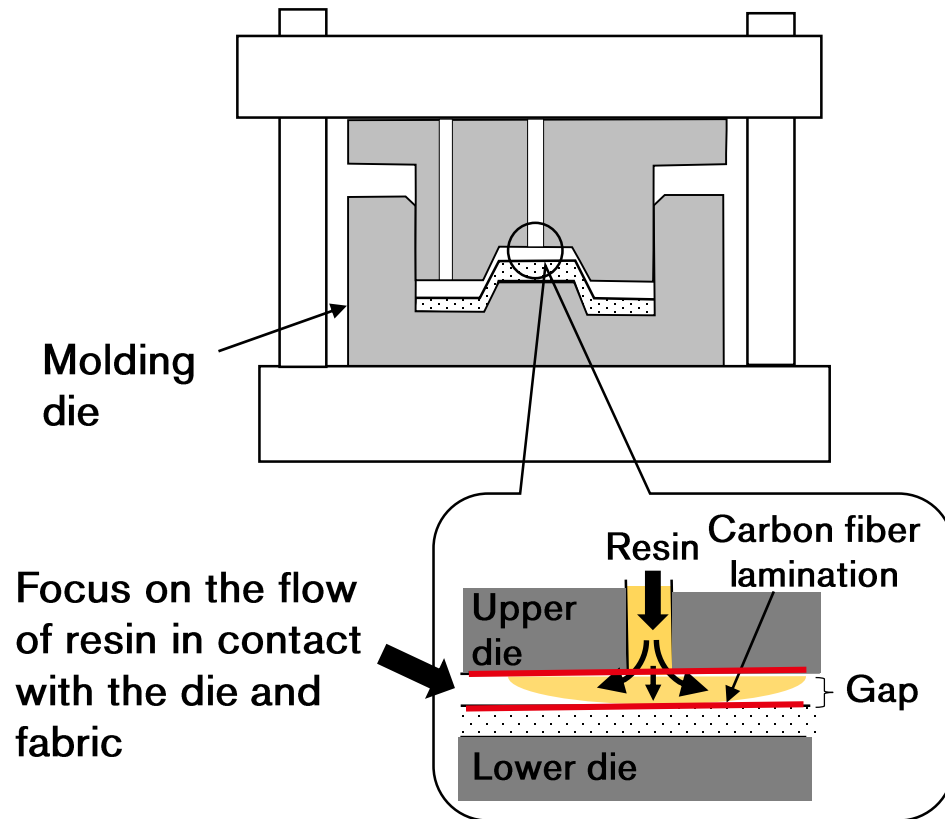- Difficulty in predicting resin flow and transfer

Resin port

Molding die

Carbon fiber lamination
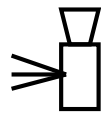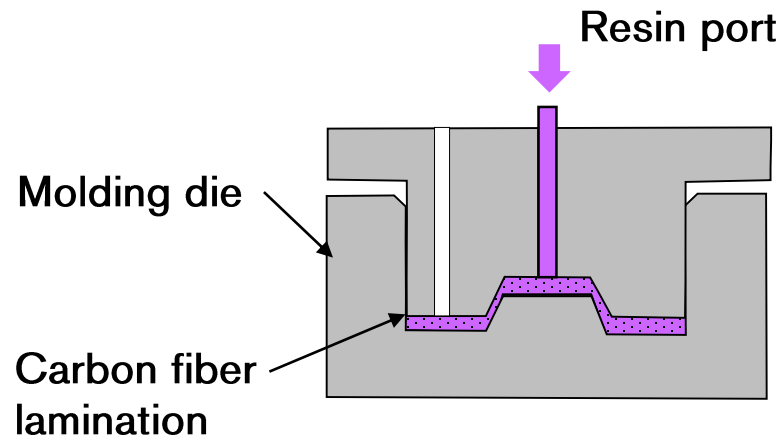
State of the flow of the resin from the backside of the product

Experiment result

Resin

Not filling

Simulation result

Resin

Not completely filled

Not completely filled

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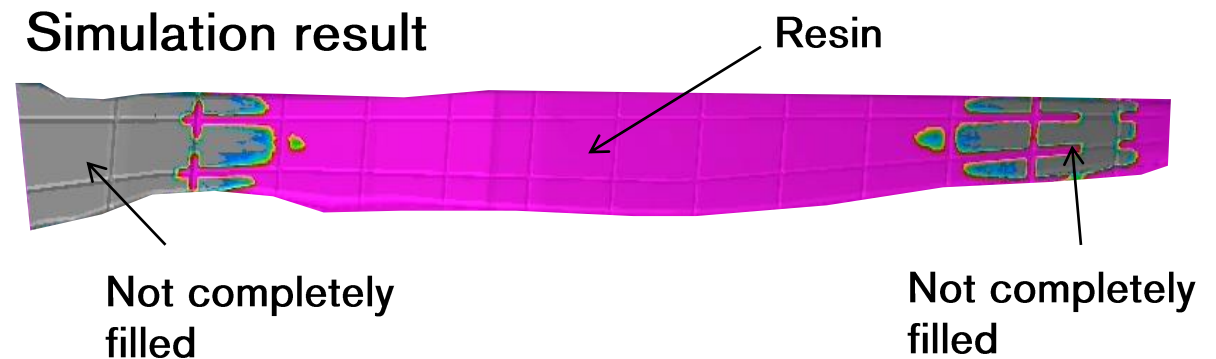
C-RTM simulation development/Flow friction resistance

- Frictional resistance of the resin flowing over a carbon fiber is considered as a calculation parameter
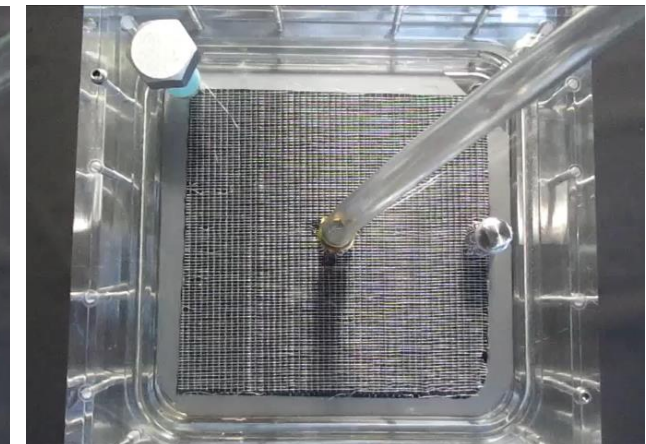- Identify the relationship between carbon fiber and the flow of the resin using a transparent die
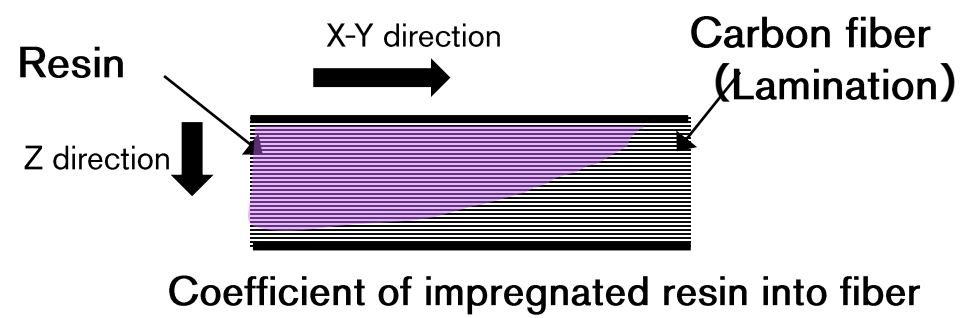

Molding die

Focus on the flow of resin in contact with the die and fabric

Resin

Carbon fiber lamination

Upper die

Gap

Lower die

Resin port

Transparent die

※From the top
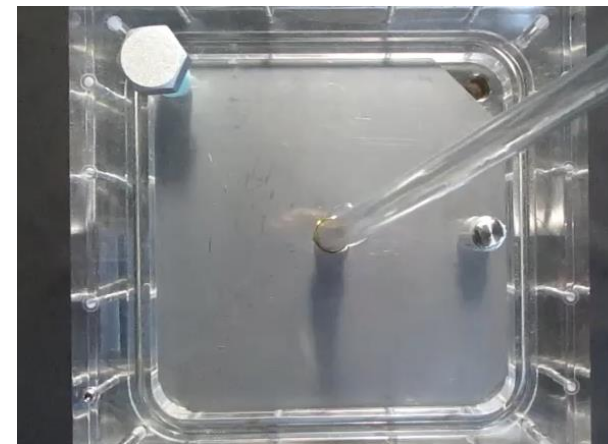
Flow on steel

Flow on carbon fiber sheet

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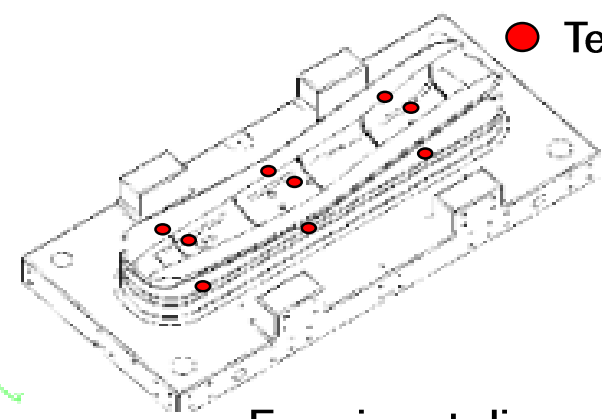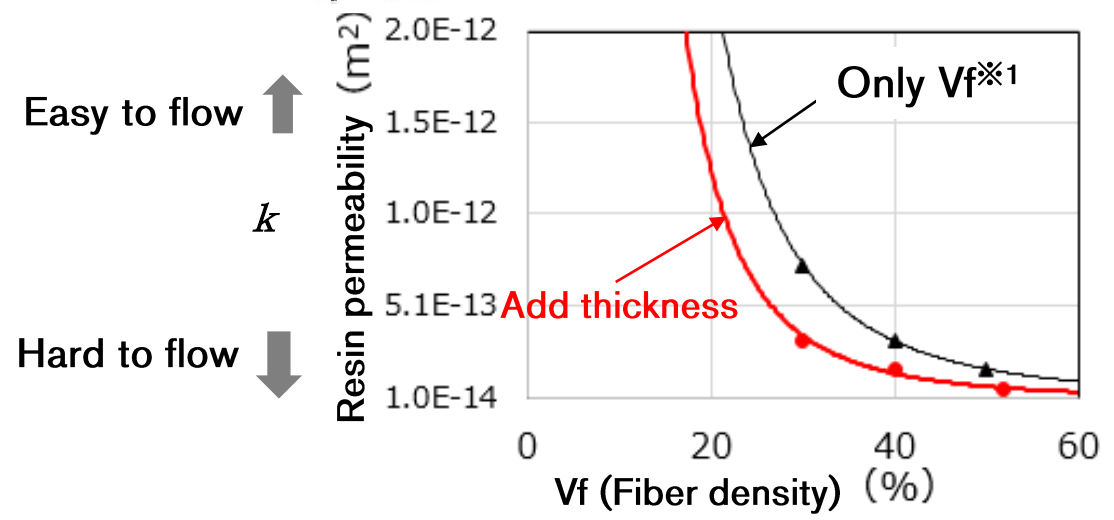# C-RTM simulation development/Temperature of the resin

- Visualize the internal die resin flow by detecting temperature change due to resin introduction
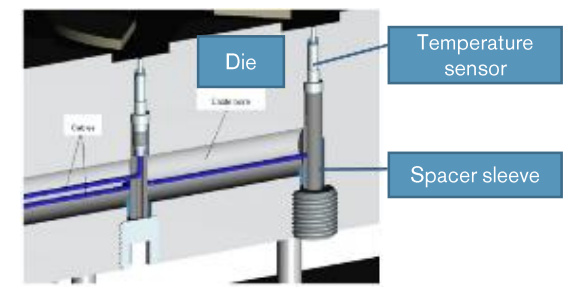- Calculate the impregnation fiber coefficient logic according to the thickness of the fiber sheets

Resin X-Y direction Carbon fiber (Lamination)

Z direction

● Temperature sensor positions

Coefficient of impregnated resin into fiber

Experiment die

Temperature sensor

Resin permeability

$$Q = -\frac{Ak}{\eta}\frac{dP}{dz}$$

Q : 体積流量率　　P : 圧力　　k : 厚み方向 Permeabili

Z : 厚み　　η : 粘度　　A : 断面積

Easy to flow

k

Hard to flow

Only Vf[1]

Add thickness

Resin permeability (m²)

Vf (Fiber density) (%)

Evaluate resin flow speed by temperature changes
Die temperature　120℃
Resin temperature 80℃

Die temperature（℃）

Flow time（sec）

※1　Vf：Volume fiber content

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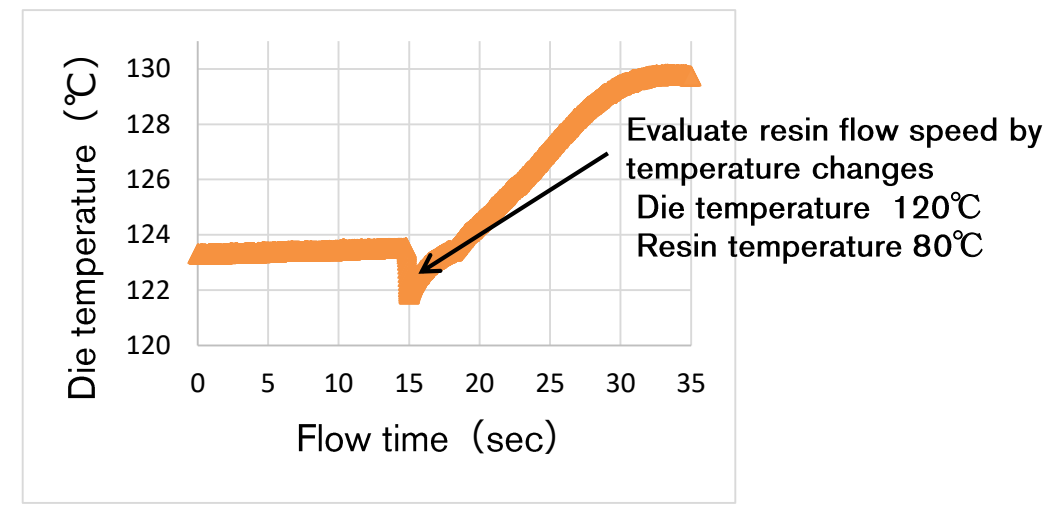
Results of new resin impregnation simulation

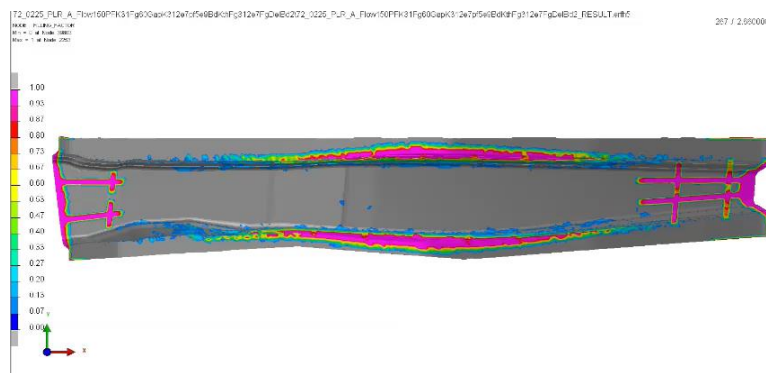- Improved simulation result accuracy
- Reconsidered gate and groove shape, developed CFRP parts to satisfy performance and quality tolerances

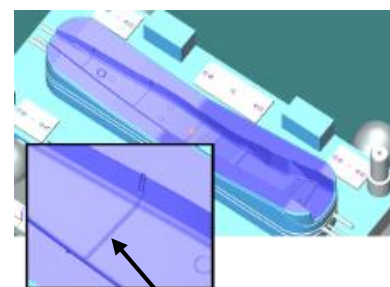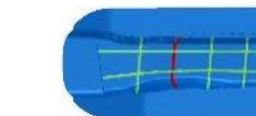<Experiment and simulation results>

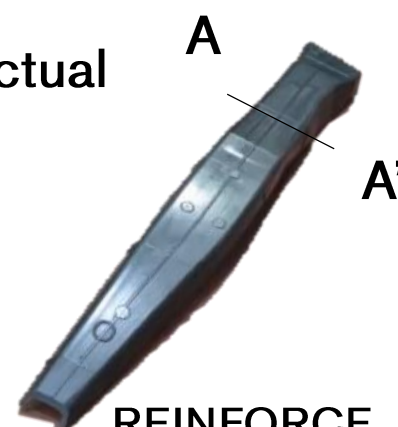<Development by new simulation>
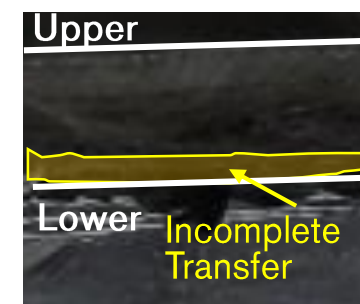
Actual

Simulation

Groove

Change groove shape

Change corner R shape

Actual

A

A'

REINFORCE CENTER PILLAR

Upper

Lower   Incomplete Transfer

Before

After

Cross-sec. A-A'

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Thank you