MITSUBISHI CHEMICAL

Forged Molding Compound™

High Performance Chopped Carbon Fiber Composites

Steven Wusterbarth
Mitsubishi Chemical America
Steven_Wusterbarth@m-chem.com

Koichi Akiyama
Gemini Composites LLC | A subsidiary of
Mitsubishi Chemical Carbon Fiber and Composites
Koichi.Akiyama@mccfc.com

Agenda

- Traditional Carbon Fiber SMC
- Forged Molding Compound™ (FMC™) Technology
- FMC™ Material
- FMC™ Process
- FMC™ Design
- Conclusion

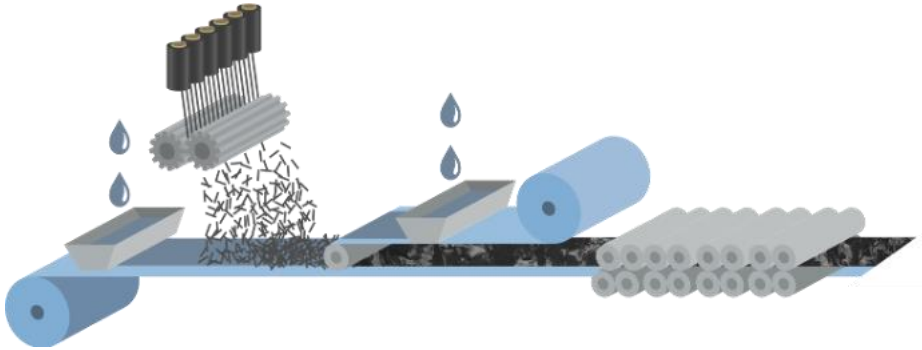
Mitsubishi Chemical Carbon Fiber Applications

Carbon Fiber Sheet Molding Compound (CF SMC)

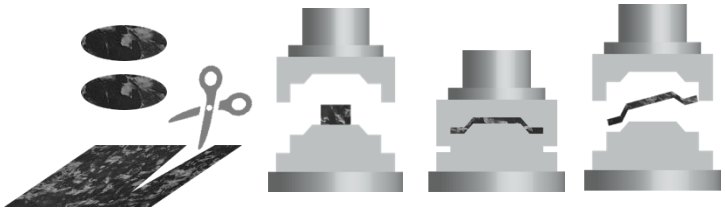
MITSUBISHI CHEMICAL

- CF SMC is a chopped fiber molding compound
  - Relatively large tow size of carbon fiber is commonly used
  - Small tow carbon fiber is too expensive for industrial applications
  - Vinyl ester resin is typical matrix resin system
- CF SMC is usually molded by traditional compression molding
  - Cure time is relatively short; suitable for high cycle molding
  - SMC is normally squeezed to flow and fill complex geometry

SMC Production



Compression Molding



Example of Carbon Fiber SMC applications

MITSUBISHI CHEMICAL

2017 Toyota Prius

Prime Rear hatch inner panel

2018 Lexus LC500

Door inner panel

2018 KTM

Skid plate

2018 Lexus LC500

Decklid inner panel

Suitable application for CF SMC and limitation

MITSUBISHI CHEMICAL

- Suitable for secondary structural or aesthetical applications
  - Most of those applications are designed for stiffness
  - Complex geometry can be molded
  - Snap cure material enables high cycle molding for high volume applications
- Limitations for use in primary structural applications
  - Material can’t keep isotropic fiber orientation and mechanical properties during traditional compression molding process
  - Mechanical properties of common CF SMC are insufficient
  - Large variation of mechanical properties
  - Sophisticated FEM analysis and design technique were unavailable

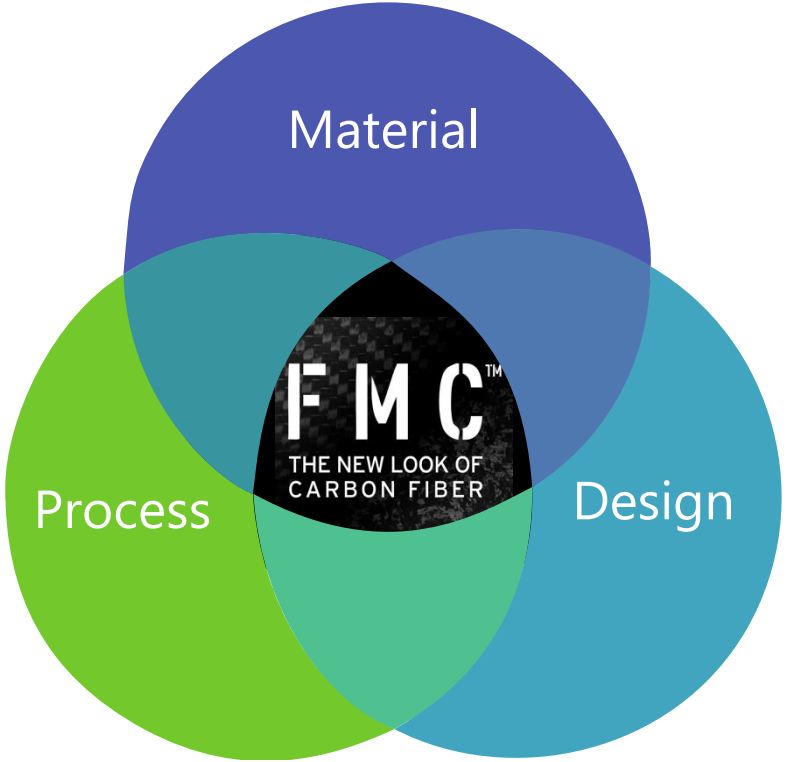
Forged Molding Compound™ (FMC™) technology

GEMINI
A Group Company of MITSUBISHI CHEMICAL

- Forged Molding Compound™ (FMC™) is the integrated technology of chopped carbon fiber composites

- FMC™ technology consists of three factors.
  - Advanced material
  - Optimized molding process
  - Dedicated design

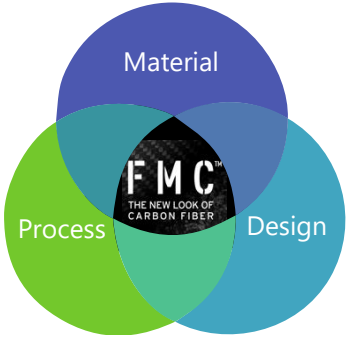
- The ideal combination of the three factors of FMC™ enables metal replacement with carbon fiber composites, achieving significant weight reduction of structural applications.



Advanced Chopped Carbon Fiber Composites

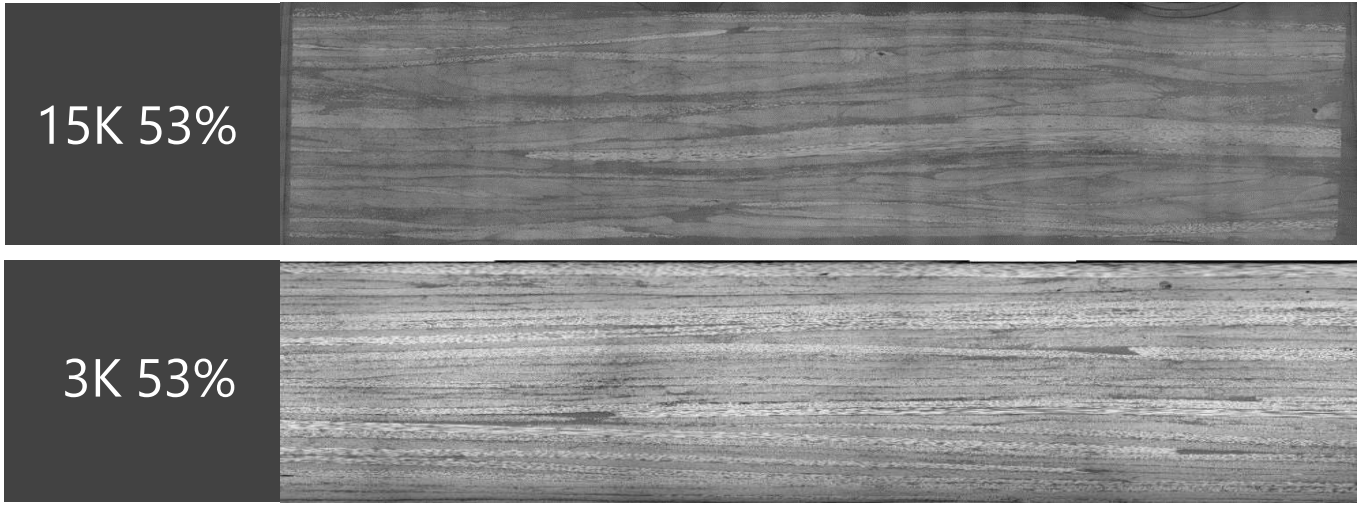
GEMINI
A Group Company of MITSUBISHI CHEMICAL

- FMC™ technology was developed for primary structural applications
  - FMC™ material is high performance sheet molding compound made with advanced chopped carbon fiber, which provides higher strength and specific modulus than light-weight metal
  - Snap cure material enable high cycle molding for high volume applications
  - Properties of advanced materials can be fully utilized in the molded part by optimizing the molding process
  - Dedicated FMC™ design replaces metal design
  - FEM analysis technique specialized for FMC™ is available



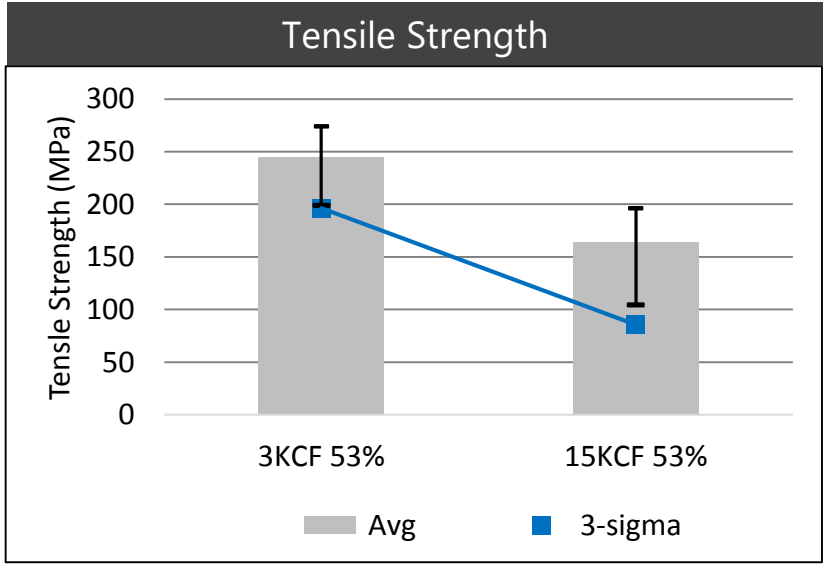
Smaller CF tow provides ideal structure

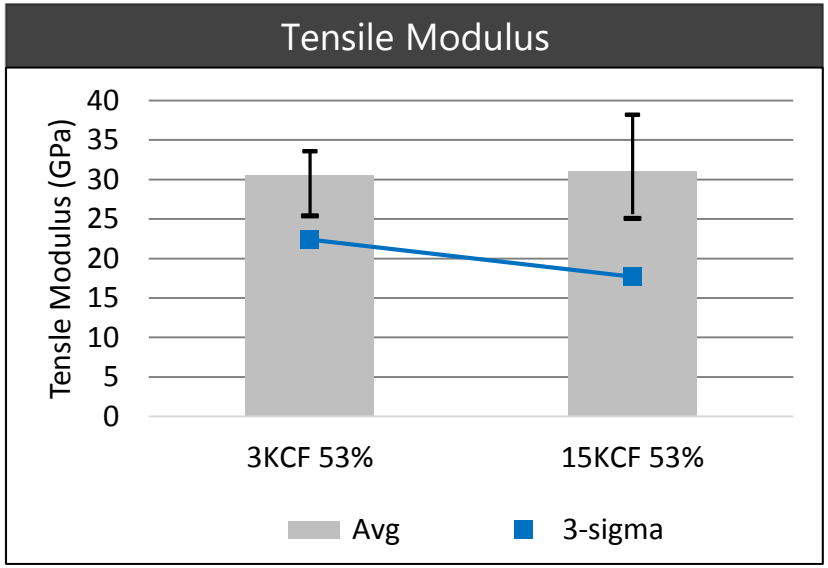
- Homogeneous structure provide excellent mechanical properties and dimensional stability
  - More fiber layers exist in the same thickness of 3K material than larger tow
  - Less resin-rich area is observed in 3K material



Effect of Carbon Fiber Tow Size on Mechanical Property

- Fiber bundle size has strong influence on mechanical properties
  - The smaller and thinner bundles gives the higher and more homogeneous mechanical properties
  - Property variation significantly lowers the value used for parts design

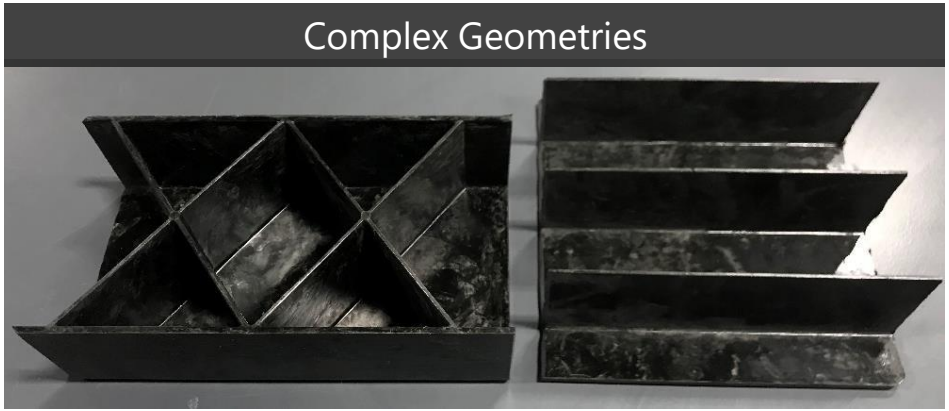




Small Tow CF SMC Provides Excellent Properties; However…

MITSUBISHI CHEMICAL

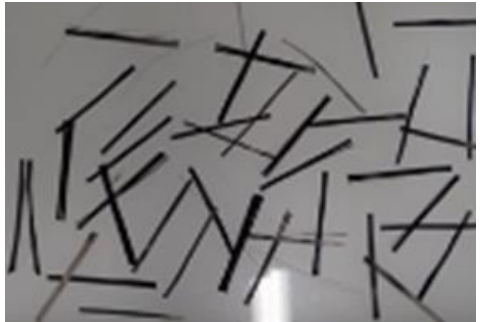
- Small tow CF SMC is good for certain applications, but there are limitations for use in industrial applications
  - The SMC cost is high due to the high expense of smaller tow carbon fiber
  - Limited moldability of complex geometries

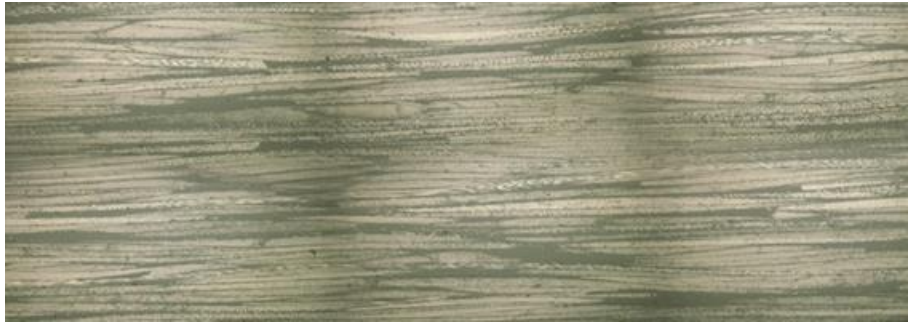


FMC™ Material | Advanced Chopped Carbon Fiber Composites

MITSUBISHI CHEMICAL

- FMC™ material is high performance sheet molding compound made with advanced chopped carbon fiber to provide an economic solution with excellent properties
  - The chopped fiber has tow size distribution providing excellent mechanical performance and good moldability
  - Split tow-based advanced chopped fiber provides an affordable solution
- FMC™ material contains many thin layers of carbon fiber tow
  - Homogeneous structure without the resin-rich portion also provides excellent properties





FMC™ Material | Product Line

MITSUBISHI CHEMICAL

- A variety of FMC™ products are available
  - Fiber contents and length can be chosen depending on application requirements
  - Both vinyl ester and epoxy matrix resin systems are available
  - Flame retardant and high Tg grades are under development and will be available soon

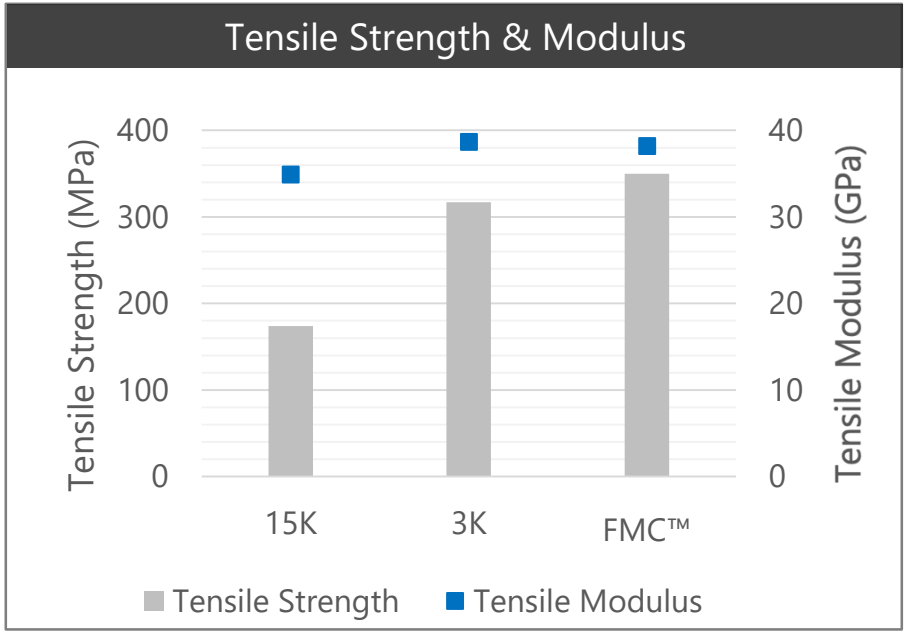
	Regular Carbon Fiber		Advanced Carbon Fiber	
	15K / Vinyl Ester	3K / Vinyl Ester	Vinyl Ester	Epoxy
Advantage	Lower Cost	Excellent Mechanical Property	Excellent Mechanical Property	Excellent Mechanical Property
	Easy to mold	Good Aesthetics	Cost Effective	Low VOC
			Good Moldability	No odor
				Low Shrinkage
Carbo Fiber Tow	15K	3K	Adjustable distribution	Adjustable distribution
Carbon Fiber Length	1/2", 1", 2"	1/2", 1", 2"	1", 2"	1", 2"
Fiber Content	45 - 60%	45 - 60%	45 - 60%	45 - 60%
Suitable Application	Secondary structure	Aesthetic parts	Primary Structure	Primary Structural
				Inner Application

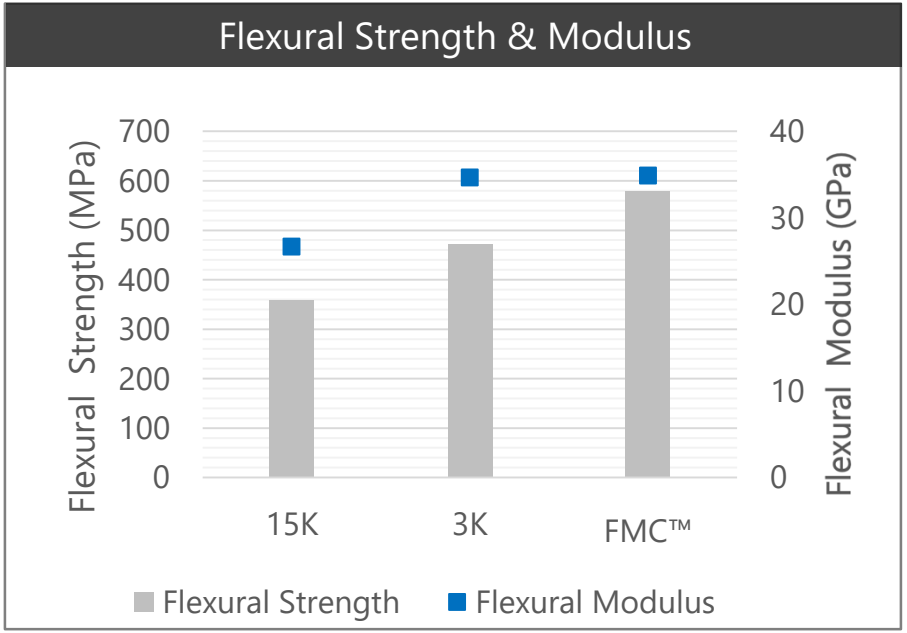
FMC™ Material | Excellent Mechanical Properties

MITSUBISHI CHEMICAL

- FMC™ made with advanced carbon fiber provides higher strength than 3K CF SMC with the same fiber content

Mechanical Properties of 60% fiber content vinyl ester material



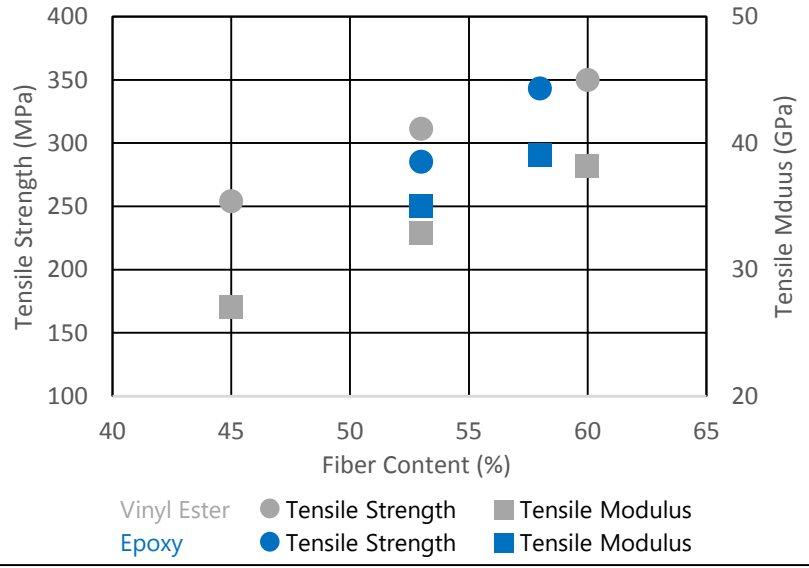


FMC™ Material | Carbon Fiber Content

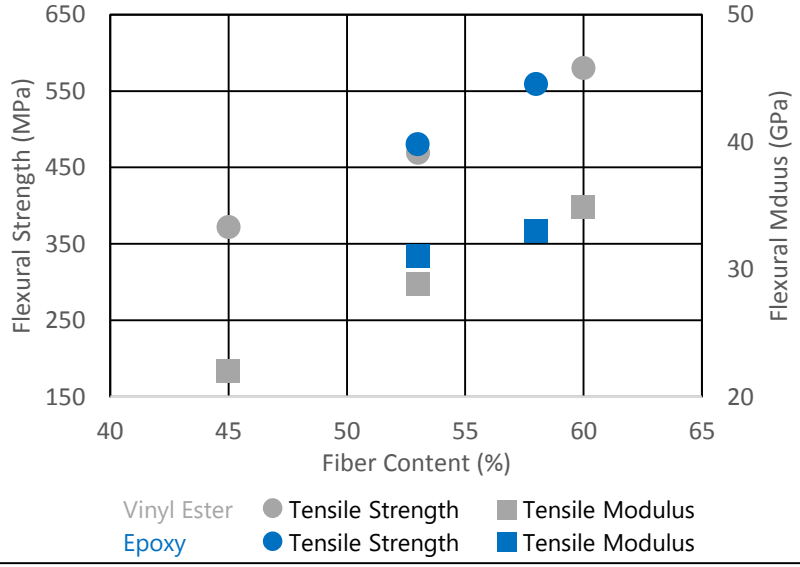
MITSUBISHI CHEMICAL

- FMC™ can be made with any fiber content from 40% to 65%
  - The resin system and fiber content can be specified depending on desired mechanical properties or other application requirements

Tensile Strength & Modulus



Flexural Strength & Modulus



FMC™ Moldability | Spiral flow

MITSUBISHI CHEMICAL

- FMC™ made with advanced carbon fiber flows better than 3K CF SMC
  - FMC™ flows well even though tow size is small to provide higher property than 3K CF
  - Low flow molding is essential for FMC™, however good moldability is still quite important to mold complex geometry.

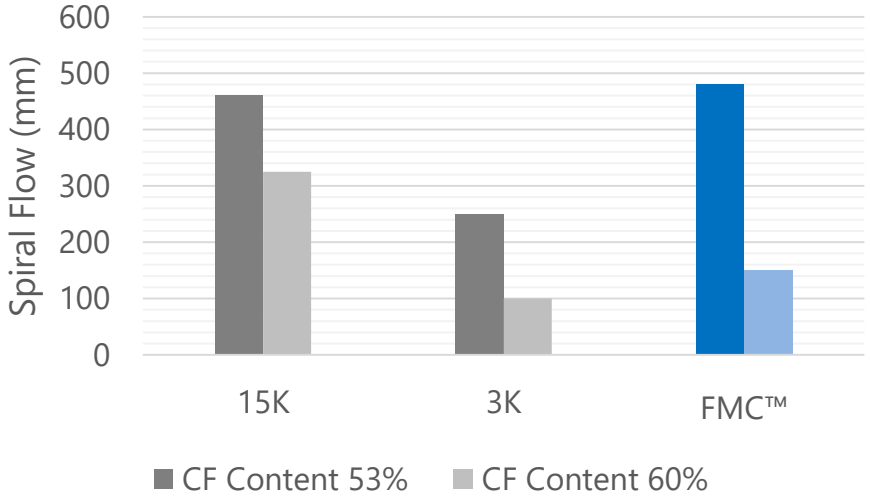
Spiral Flow

53% 3K

53% FMC

MCC Standard Test Method
Width of channel: 5cm, Thickness of Channel: 2mm
Plunger pressure: 10Mpa, Mold Temp: 140 °C

Spiral Flow of Vinyl Ester Material

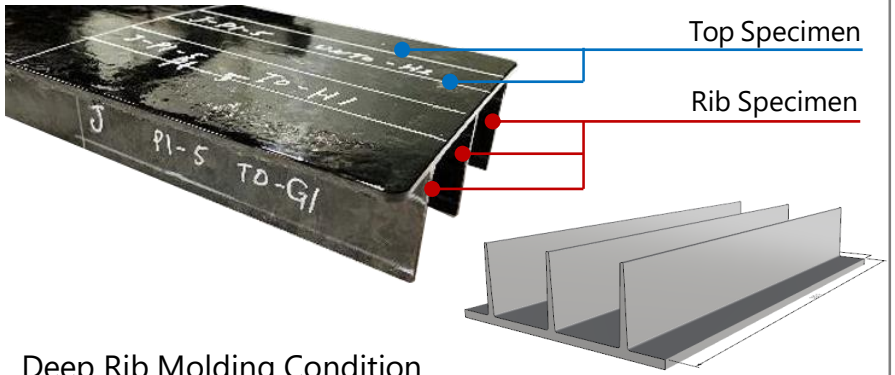


FMC™ Moldability | Deep Rib Part Molding

MITSUBISHI CHEMICAL

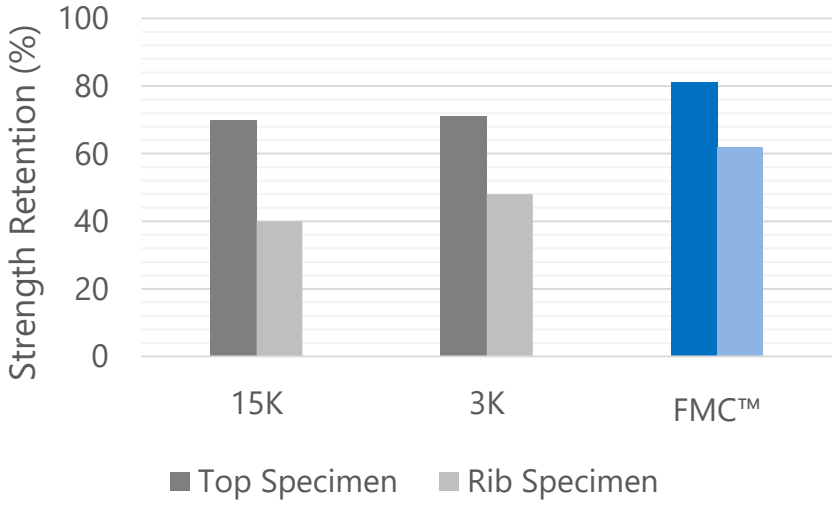
- FMC carries carbon fiber better into complex geometry such as ribs.
  - Advanced CF keeps isotropic fiber orientation better than regular CF during molding
  - Advanced CF retains 85% and 66% of nominal tensile strength in top and rib specimens respectively

Deep Rib Molding



<u>Deep Rib Molding Condition</u>
Mold Coverage: 95% charge only on top, no insert in rib
Part Thickness: Top 2.0 mm, Rib root 3.0mm, Rib top 2.0mm
Rib Height: 43mm, Rib Draft angle: 1 degree
Molding pressure: 10Mpa, Mold Temp: 140 °C

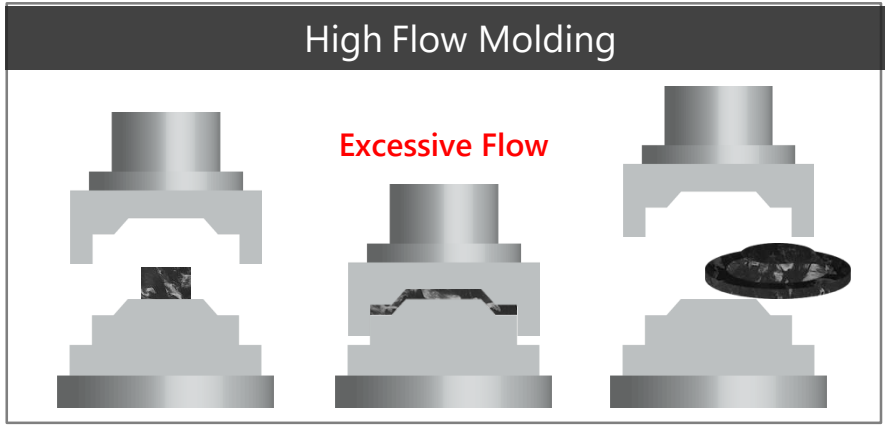
Tensile Strength Retention of Top & Rib Specimens

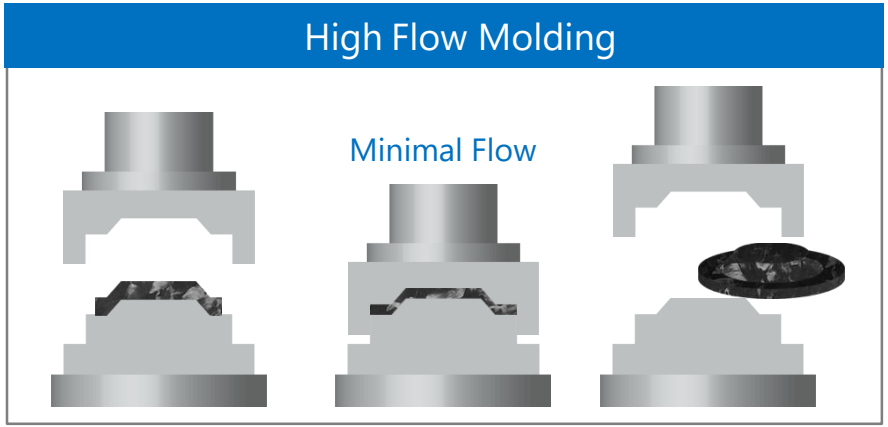


FMC™ Process | Low Flow Molding

GEMINI
A Group Company of MITSUBISHI CHEMICAL

- Minimizing material flow during molding process
  - Minimal material flow prevents sacrificing mechanical properties
  - Optimizing the change pattern by shape and weight distribution is the key
  - Utilizing a preformed charge pattern is recommended
  - Low flow molding-friendly part design makes a large impact on properties





Material Flow During Compression Molding

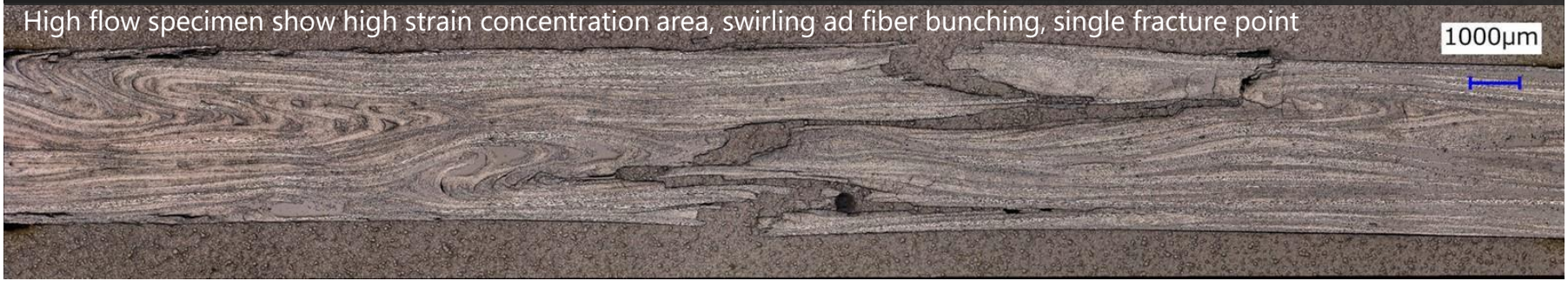
GEMINI
A Group Company of MITSUBISHI CHEMICAL

FMC ™ Low Flow Molding

Low flow specimen shows more uniform strain distribution and parallel tow/fiber breakage

Traditional High Flow Molding

High flow specimen show high strain concentration area, swirling ad fiber bunching, single fracture point

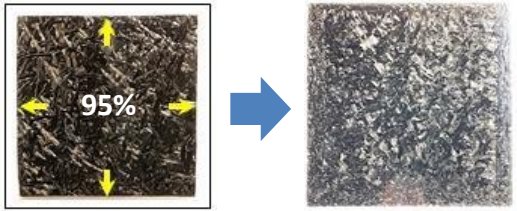


Fiber orientation after material flow during molding

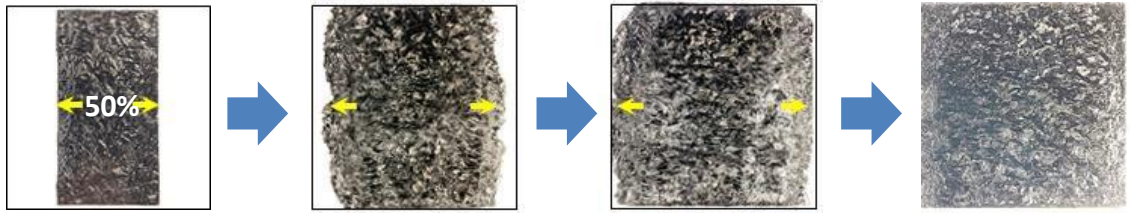
GEMINI
A Group Company of MITSUBISHI CHEMICAL

- Material flow orientates carbon fiber and makes a swirl of fiber
  - Fiber aligns along to direction of material flow
  - At the flow front of material, a swirl of fiber occurs and creates defects

Low Flow Molding | 95% coverage



High Flow Molding | 50% coverage



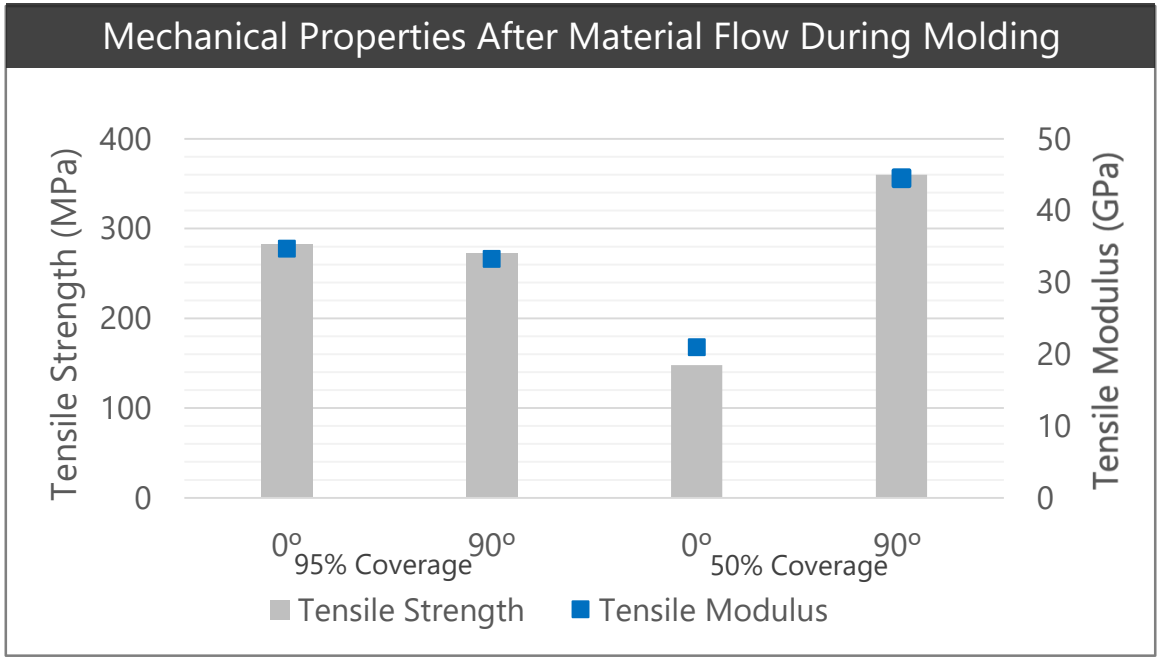
300x300mm flat panel

Material:	CF SMC PTO130N127 Vinyl ester matrix resin 1" 53% 3K CF
Panel Thickness:	3.2–3.4mm
Molding Temperature:	140 °C
Molding Pressure:	10 MPa
Cure time:	3 minutes
Charge pattern:	95% coverage 50% coverage

Mechanical Properties | After Material Flow During Molding

GEMINI
A Group Company of MITSUBISHI CHEMICAL

- Material flow significantly changes mechanical properties
- Fiber orientation creates anisotropic and inhomogeneous properties



300x300mm flat panel

Material:	CF SMC PTO130N127 Vinyl ester matrix resin 1" 53% 3K CF
Panel Thickness:	3.2–3.4mm
Molding Temperature:	140 °C
Molding Pressure:	10 MPa
Cure time:	3 minutes
Charge pattern:	95% coverage 50% coverage

FMC™ Design

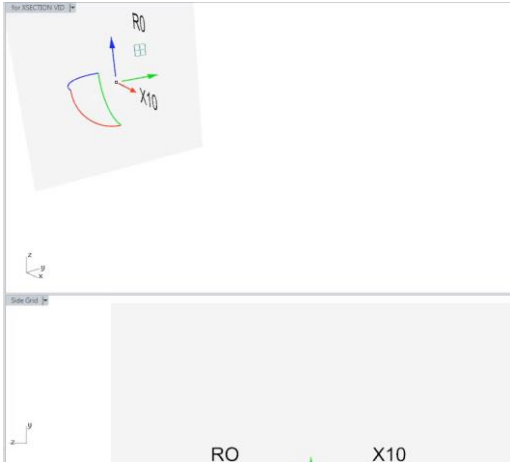
Design philosophy of FMC™ technology is completely different from that for either metal or continuous carbon fiber composites.

- FMC™ parts design is dedicated to chopped fiber material.
- Parts should be designed as material flow can be minimized during compression molding. So the parts can keep isotropic fiber orientation and mechanical property.
- FEM analysis and simulation optimized for FMC™ material should be used.
- Holes, thickness change, molded-in inserts can be used, which is difficult in the case of traditional continuous carbon fiber composites.

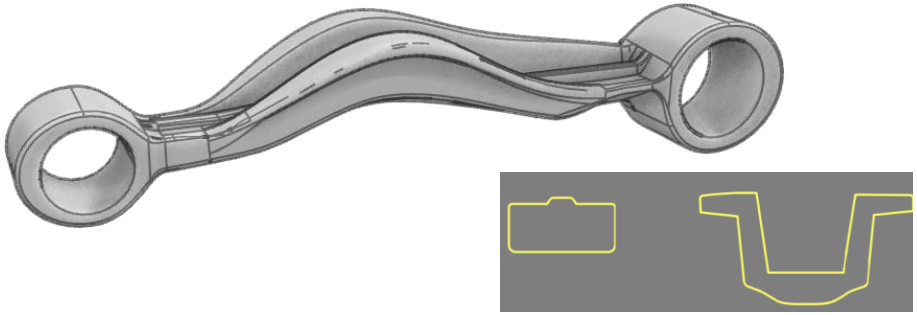
FMC™ Design Example | Suspension Prototype

GEMINI
A Group Company of MITSUBISHI CHEMICAL

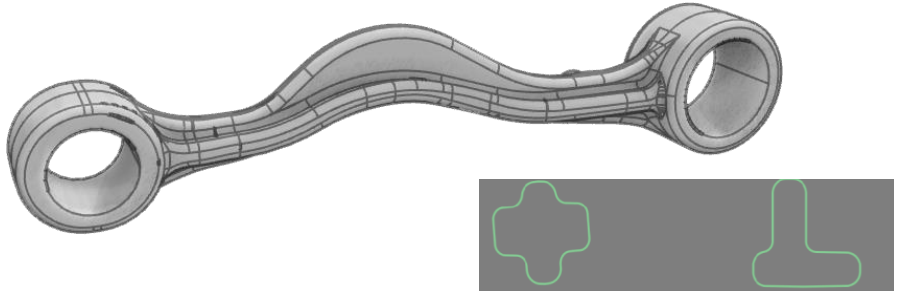
- FMC™ design was developed for suspension prototype part.
  - Size; 362(L)x63(W)x70(H)mm
  - Thickness; 3–13 mm
  - Prototype parts were manufactured and its property was evaluated



FMC™ Design



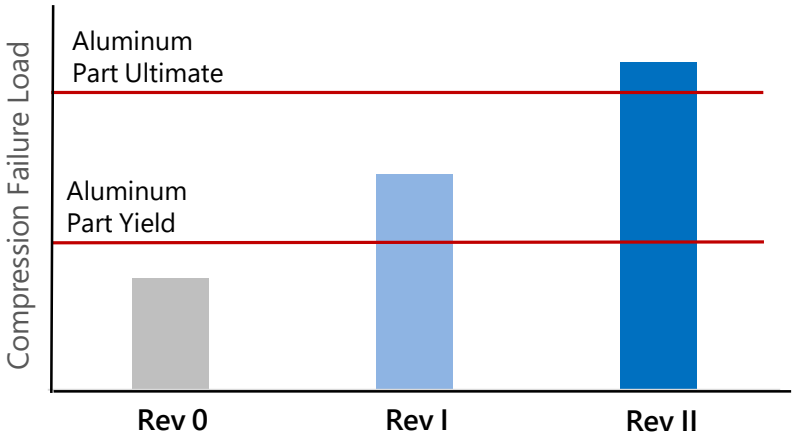
Metal Design



FMC™ Design Improvements

GEMINI
A Group Company of MITSUBISHI CHEMICAL

- FMC™ design can make composite part stronger than metal part
  - Example: Automotive suspension part
- Compression property
  - Rev II: FMC™ design with the right material and process achieved higher load than ultimate failure of aluminum part.
- More than 40% weight reduction



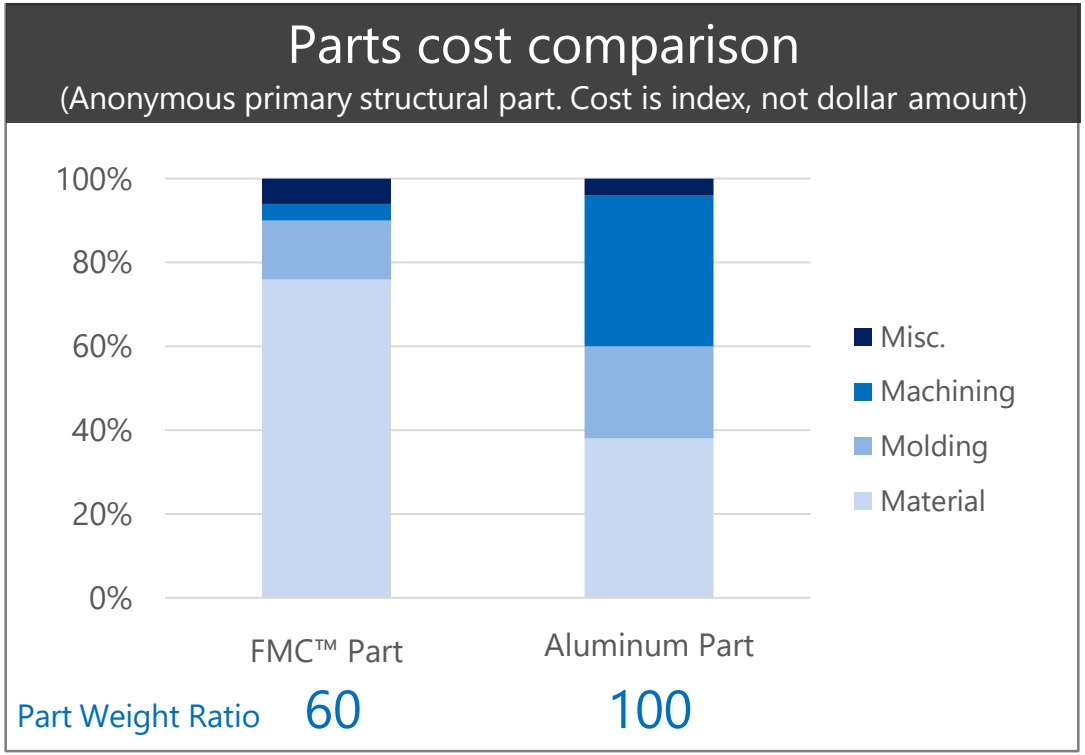
- Rev 0: Typical material substitution
- Rev I: Material and Process are good, but design is metal design.

	Rev 0	Rev I	Rev II
Design	Aluminum part design	Aluminum part Design	FMC™ Design
Material	15K CF SMC	FMC™	FMC™
Molding Process	Traditional High Flow	FMC™ Low Flow	FMC™ Low Flow
Weight Reduction from Aluminum Part	**47%**	**47%**	**41%**

FMC™ Cost Competitiveness to Aluminum

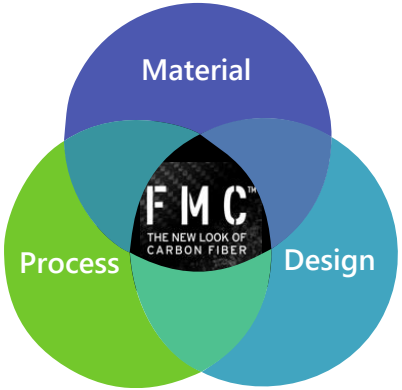
MITSUBISHI CHEMICAL

- Cost of compression molding is normally lower than metal forging
  - FMC™ material is more expensive than aluminum.
    - However mass of FMC™ part is 60% of aluminum part.
    - 40% of impact can be deducted.
  - Molding cycle of FMC™ is short.
  - FMC™ can mold complex geometry, so most of machining can be eliminated.
  - Total process cost is lower than metal forging



In Conclusion…

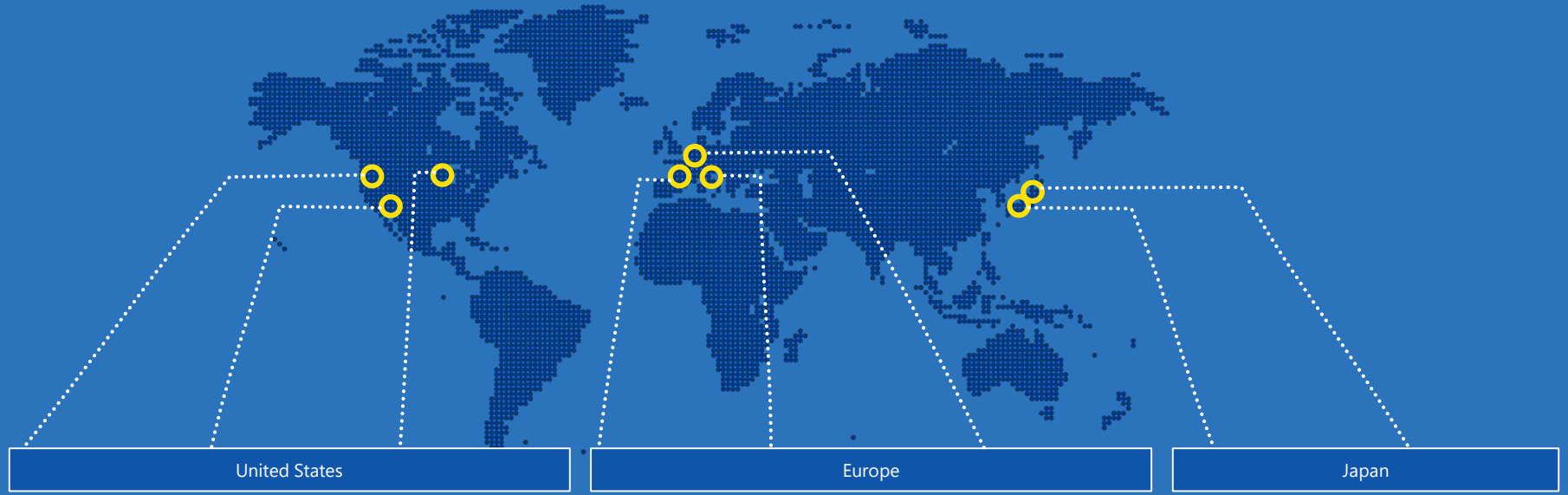
- FMC™ technology has been developed as the lightweight solution for primary structural applications with high production volumes.
- The advanced chopped carbon fiber is the key technology of FMC™ material, which provides high mechanical performance and excellent moldability at an affordable cost.
- FMC™ technology consists of not only advanced material, but also optimized molding process and dedicated design. The combination of those three factors enables utilization of chopped carbon fiber composite to primary structural applications that require high mechanical performance.
- FMC™ technology can be utilized in a variety of structural applications such as large body structure, suspension, power train, crash box, EV battery enclosure and more.



MCC Global FMC™ Network | The Customized Solution Provider

MITSUBISHI CHEMICAL

Contact us! We can design the parts, supply the advanced material and build optimized process depends upon your needs.



United States

Gemini Composites Seattle WA
- Engineering

MCAM, Phoenix AZ
- R&D

MCAM/R3 Composites Alliance Grabill IN
- Parts manufacturing

Europe

CPC
- Parts manufacturing

Wethje, Pleinting DE
- Parts manufacturing

MCAM, Modena IT Chemnitz DE
- SMC manufacturing
- Engineering

Japan

Mitsubishi Chemical Tokyo, Toyohashi JP
- R&D
- SMC manufacturing

Challenge Co. Ltd. Iruma, JP
- Molding, Prototyping

MITSUBISHI CHEMICAL

Thank you.