1206

SIMULATION OF FIBER ORIENTATION DURING COMPRESSION MOLDING PROCESS OF CFRTP-SMC

Graduate School of Engineering, Systems Innovation

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OUTLINE

- **Background**
  - ✓ Background of the topic
  - ✓ Purpose and Approach

- **Experimental Fabrication with different flow circumstances**

- **Mechanical test & Internal structure characterization**
  - ✓ Three-point bending test and result
  - ✓ Fiber orientation distribution analysis

- **Numerical simulation**
  - ✓ Method
  - ✓ Molding simulation and result

- **Correlation and tasks**

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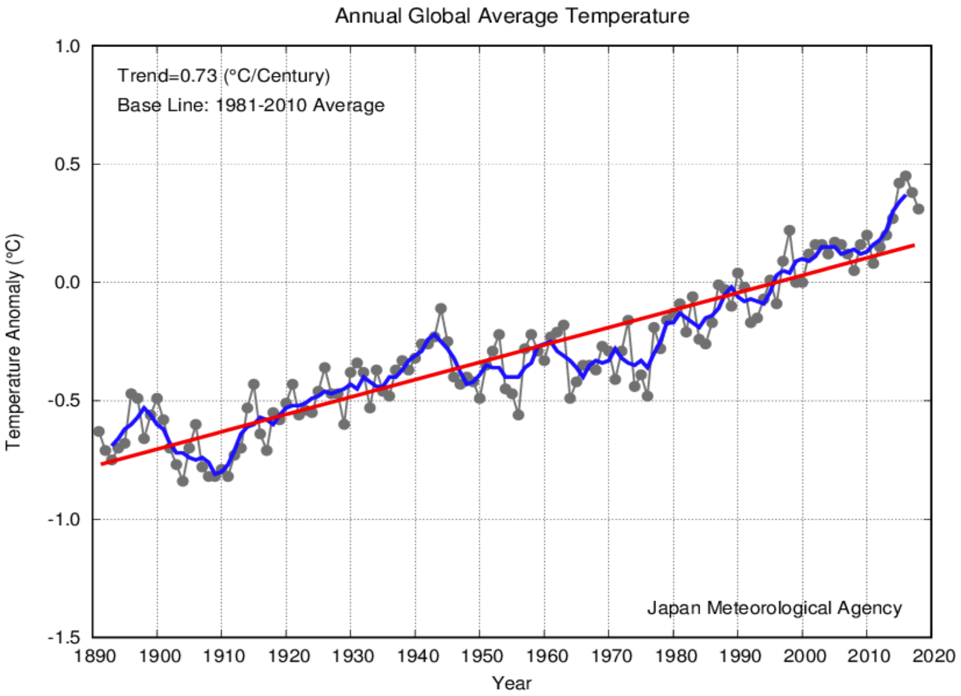
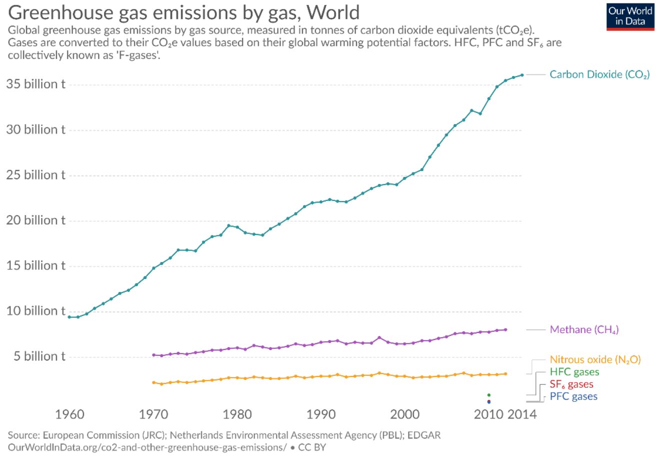
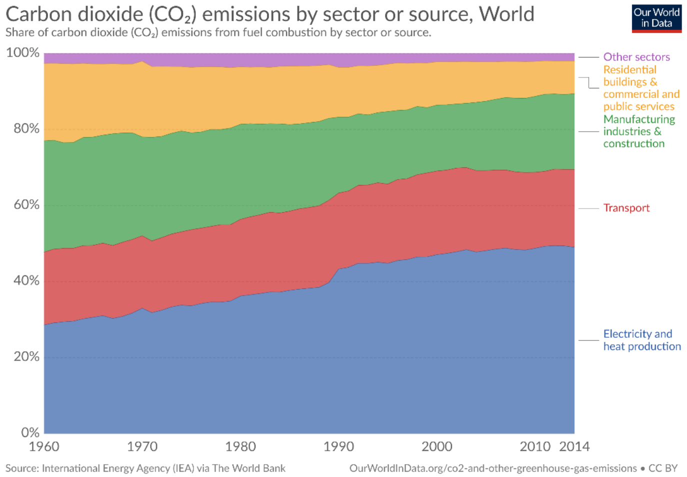
Background | Background of the topic

- **Environmental issues - Global Warming**

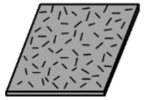
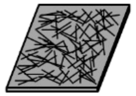
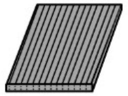


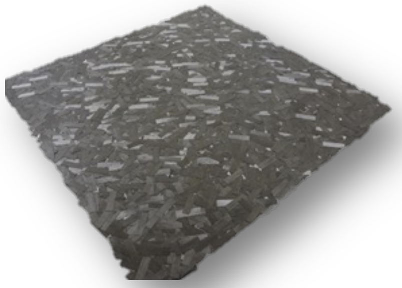
Anomalies are deviation from baseline (1981-2010 Average).
The black thin line indicates surface temperature anomaly of each year.
The blue line indicates their 5-year running mean.
The red line indicates the long-term linear trend.

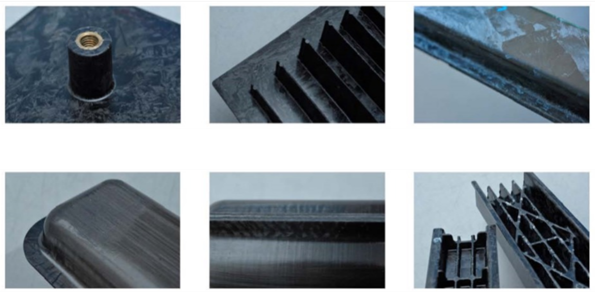


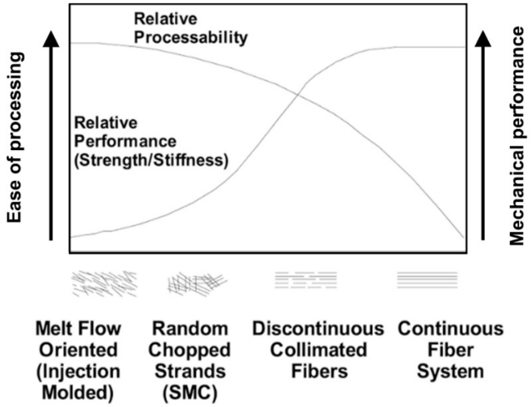


- **CFRP & CFRTP & Sheet Molding Compound (SMC) (CTT)**

Type of composite system	Injection molded 	Mat structure thermoplastics 	Chopped carbon fiber tape reinforced thermoplastics **(CTT)** Sheet Molding Compound 	Continuous Laminates 
Fiber volume fraction V_f	Relatively low	Middle (20-30%)	**High (>50%)**	High (>50%)
Aspect ratio L/D	Low (variation)	Middle (hundreds)	**High (hundreds-thousands)**	Highest
Formability	Superior	General	**Superior**	Directional dependent
In-plane isotropy	Process dependent	Feasible	**Feasible**	Designable





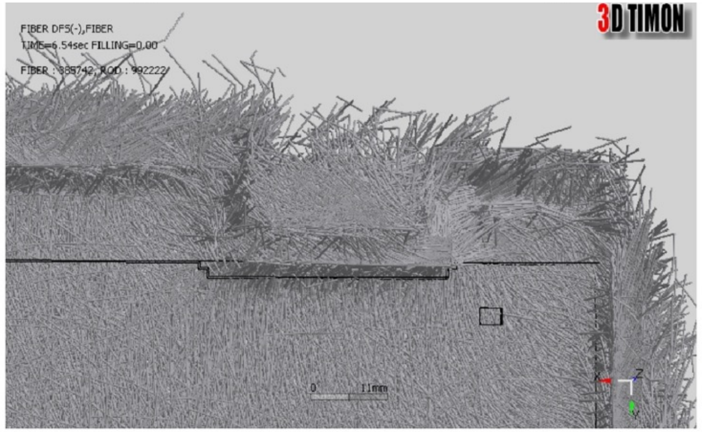


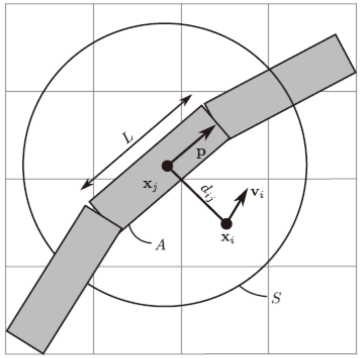
Propose and verify a reliable CFRTP-SMC compression molding simulation method

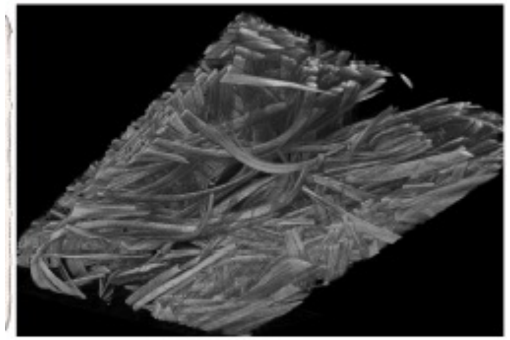
Simulate complex component forming process in industry

- **Process simulation on SMCs**

Direct Simulation Models at Microscale and Mesoscale	Abaqus	ABAQUS/EXPLICIT(SPH)
		ABAQUS/EXPLICIT (Coupled Lagrangian Eulerian (CEL) feature.)
	3D TIMON	3D TIMON CompositePRESS
Macroscopic Process Simulation	Moldflow	
	Moldex3D(+LS-Dyna)	







<u>Verification on:</u>

Fiber orientation; Compression force; Flow front curves; Modulus distribution; Warpage; Fiber length; thickness

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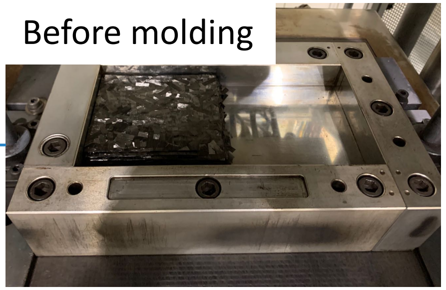
Fabrication | Molding process

Chopped CFRTP-SMC sheet with PA6

Before molding

Cut sheet in Mold



Molding condition

Temperatures/℃	270
Force/kN	156
Time/min	20

$$\text{Charge ratio} = \frac{\text{Area after molding}}{\text{Area before molding}}$$

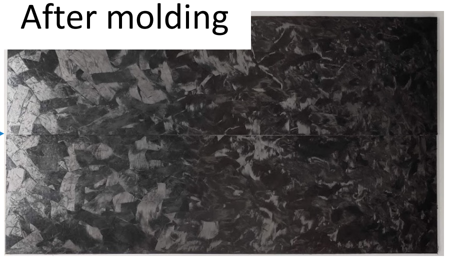
Area after molding is constant
Area before molding is used to control the charge ratio

Expected parameter of different charge ratio plate:

Size of sheet	Charge Ratio	Weight/g	Thickness/mm
125x250 (Size of the mold)	1	92	2
125x167	1.5	92	2
125x125	2	92	2
125x100	2.5	92	2

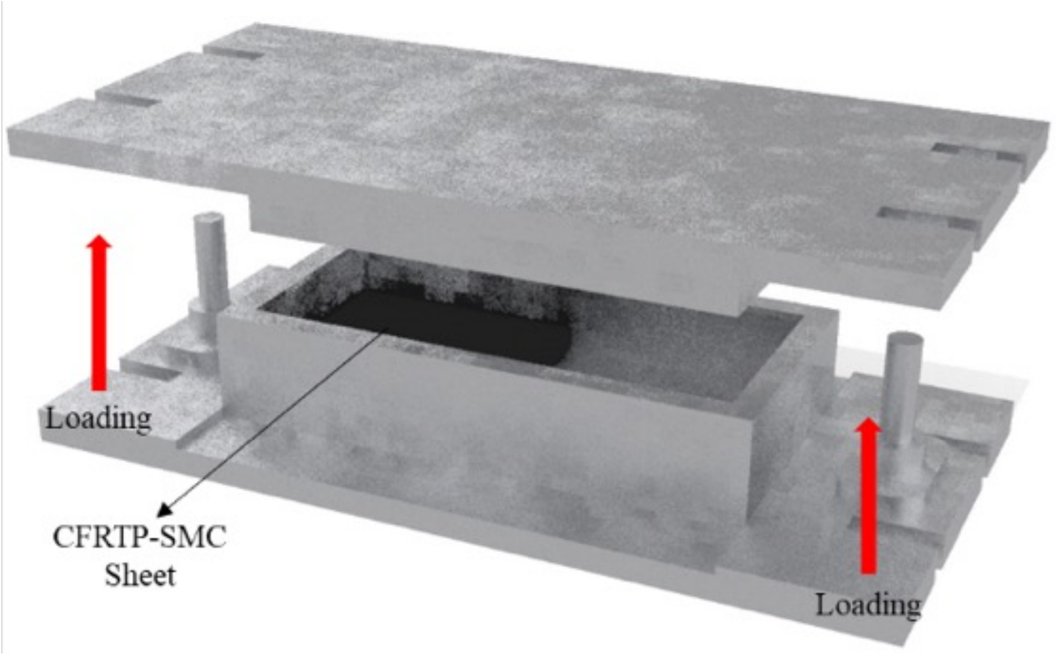
(2 plate for each size, totally 8 plates)

After molding

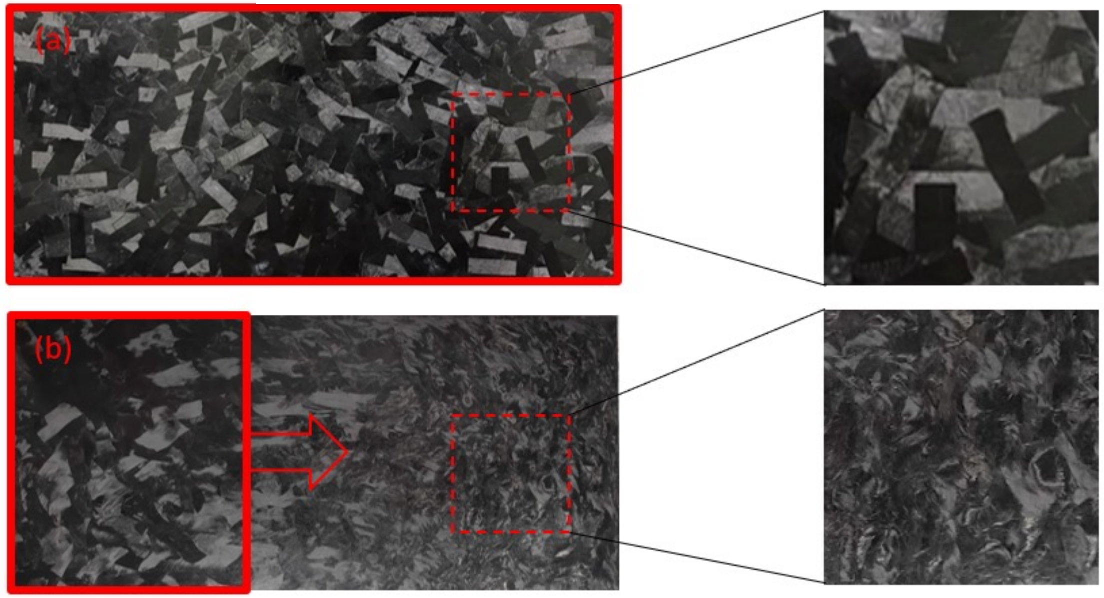


E.g. Molded plate of Charge ratio 1.5

Fabrication | Different charge ratio



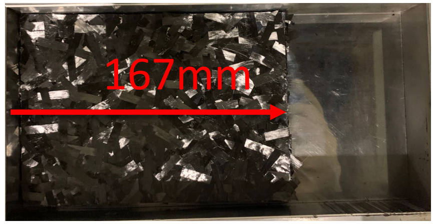
Charge Ratio: 1



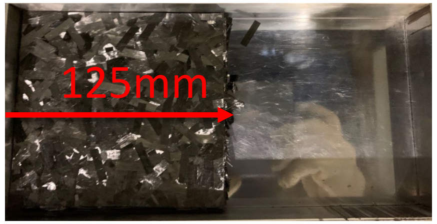
Charge Ratio: 2.5

- CFRTP-SMC sheets in the mold before molding of different charge ratio:

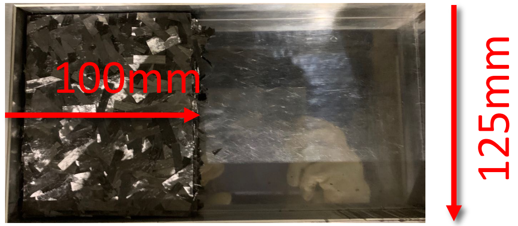
Charge Ratio: 1



Charge Ratio: 1.5



Charge Ratio: 2



Charge Ratio: 2.5

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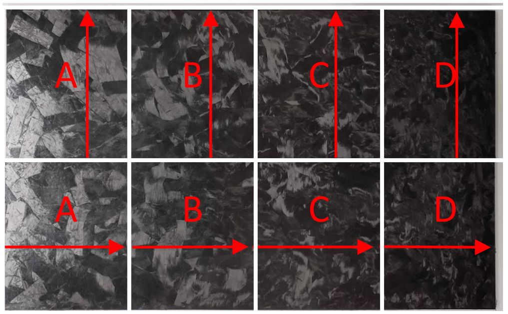
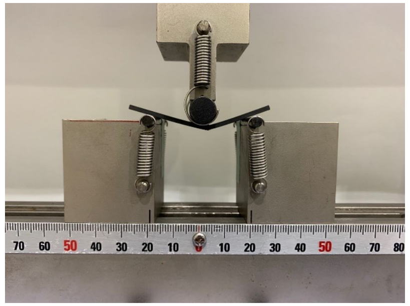
Specimen

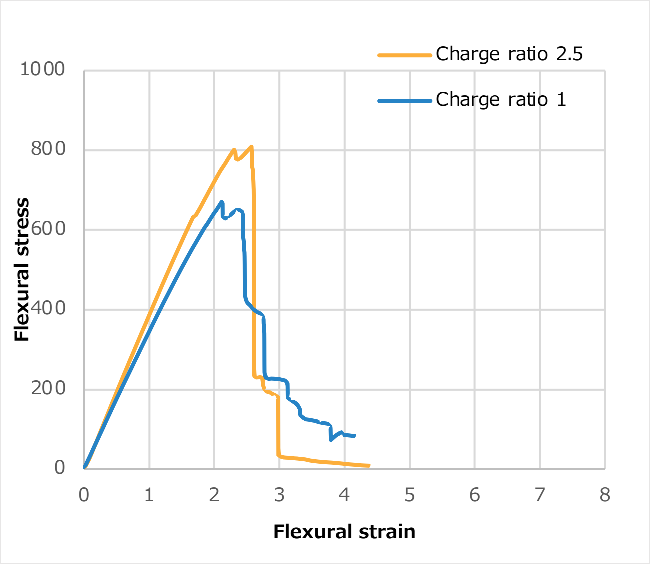


Flow direction

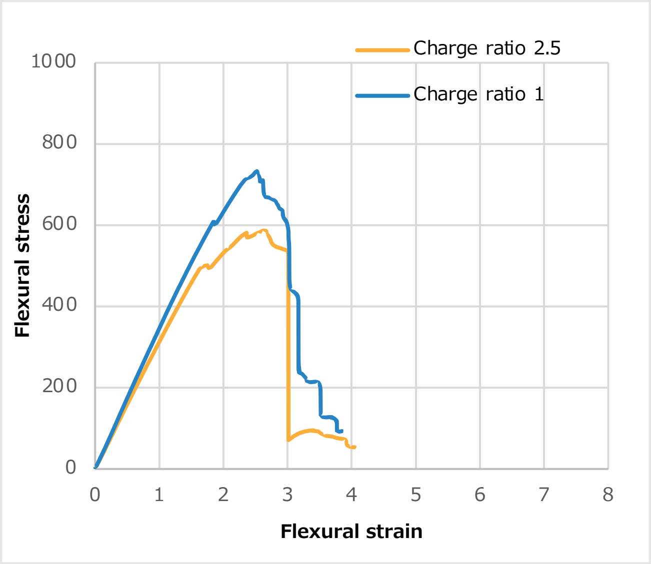
- Span x width x height: 40 x 10 x 2 mm
- Number: 4 for each area



Stress-strain curve:



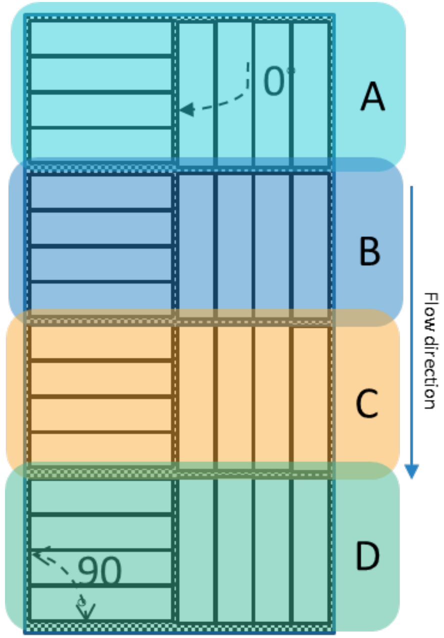
Length direction

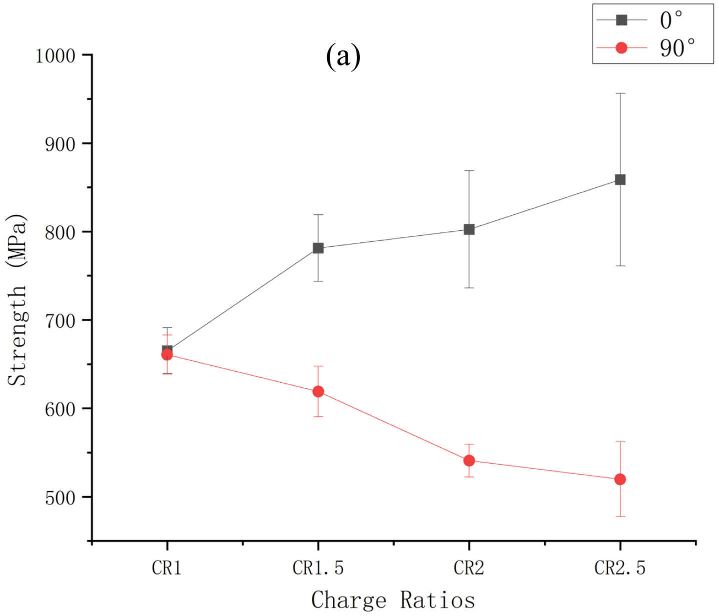


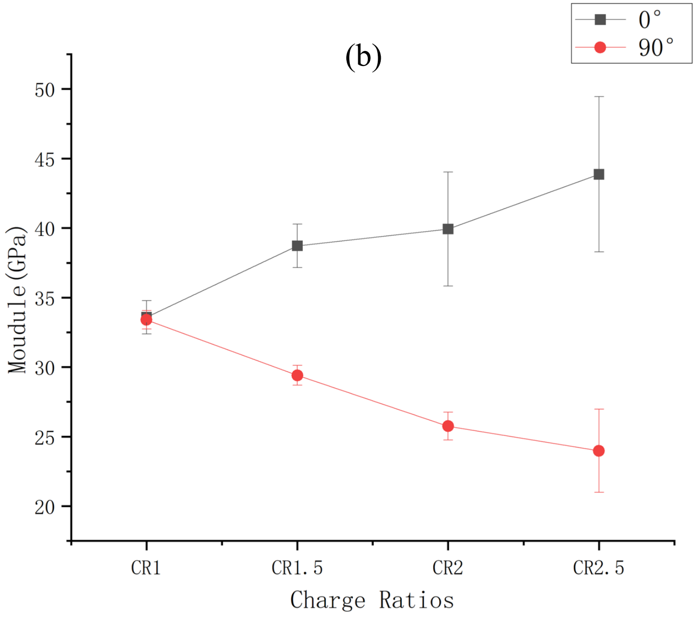
Width direction

- Flow seems to have little effect on the destruction process of CFRTP-SMC which is considered as a brittle material

- **Three-point bending tests results**



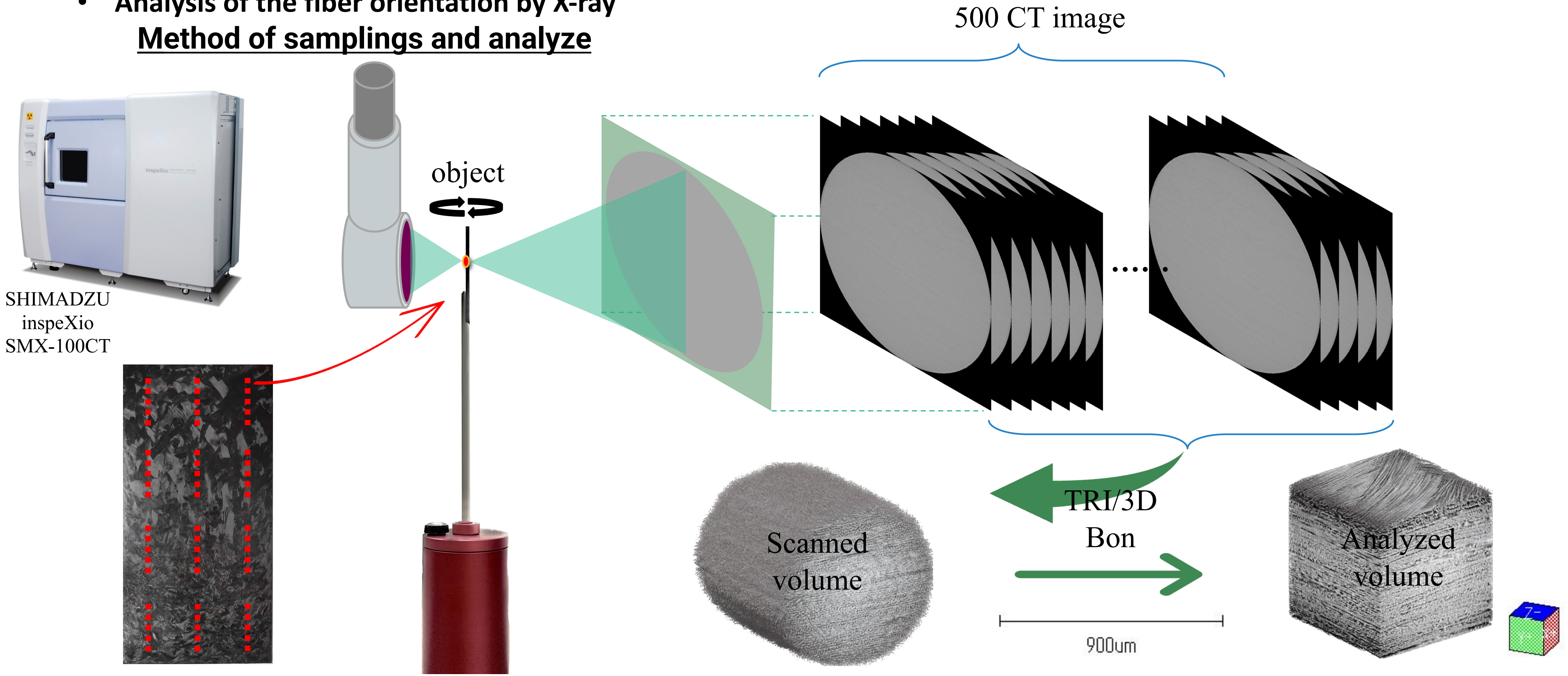




- <u>The modulus and strength in length directions has a tendency to increase and tend to decrease in width direction</u>

- **Analysis of the fiber orientation by X-ray**

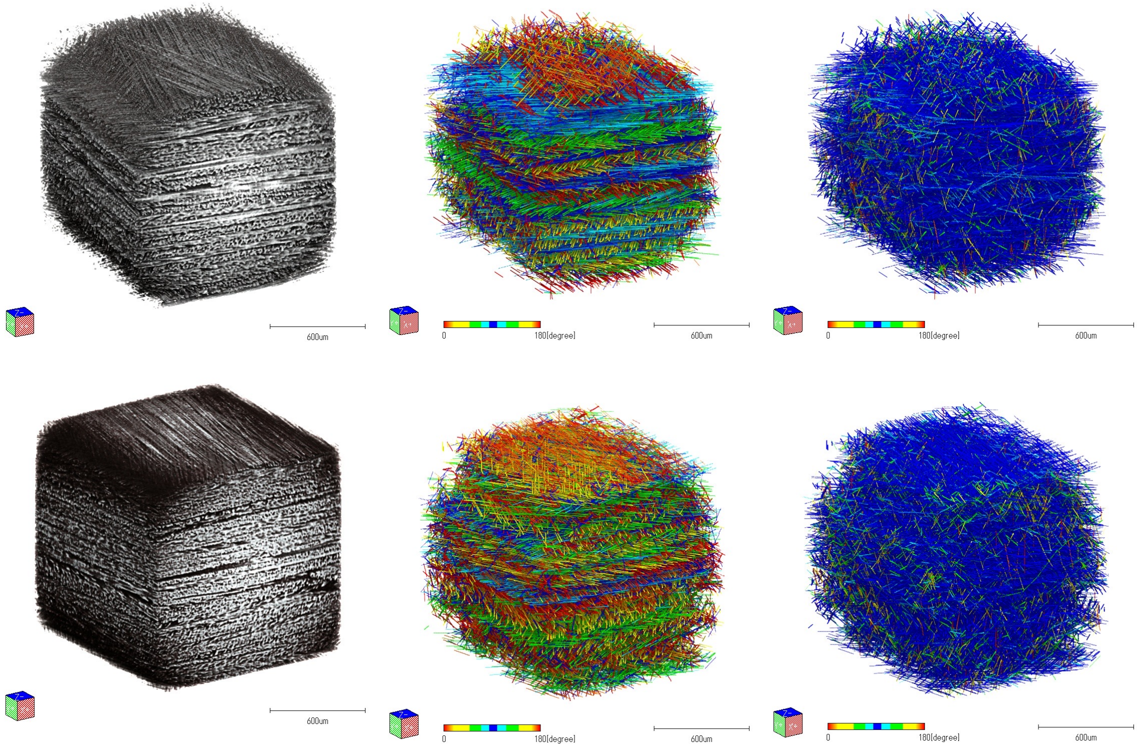
  <u>Method of samplings and analyze</u>

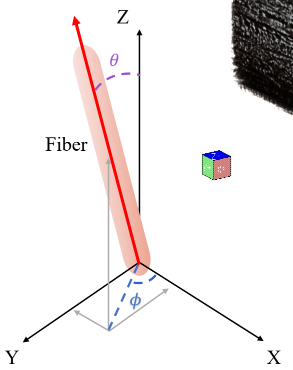


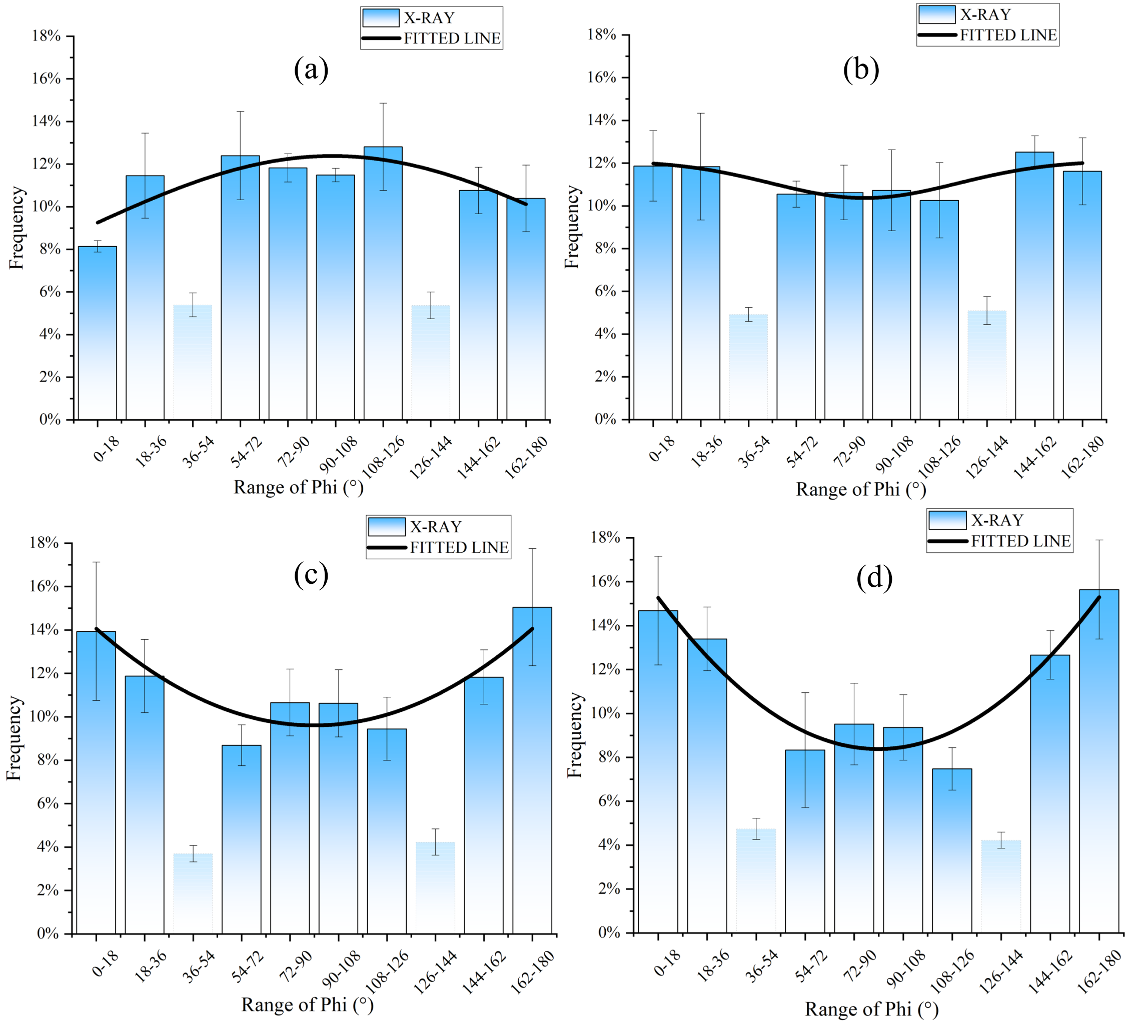
Internal structure characterization | FOD analysis

- **Analysis of the fiber orientation by X-ray**

  <u>FOD results</u>







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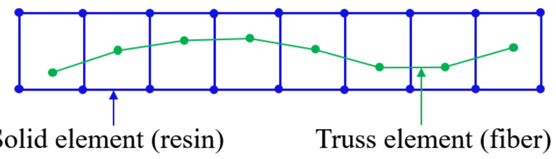
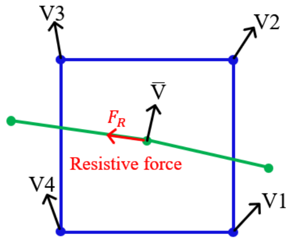
- **Method and model**

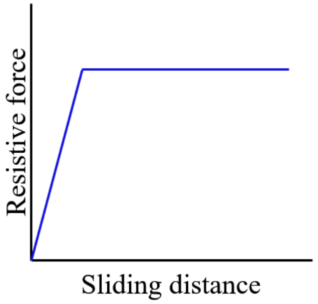
<u>beam-solid coupling method model simplification</u>



(a)

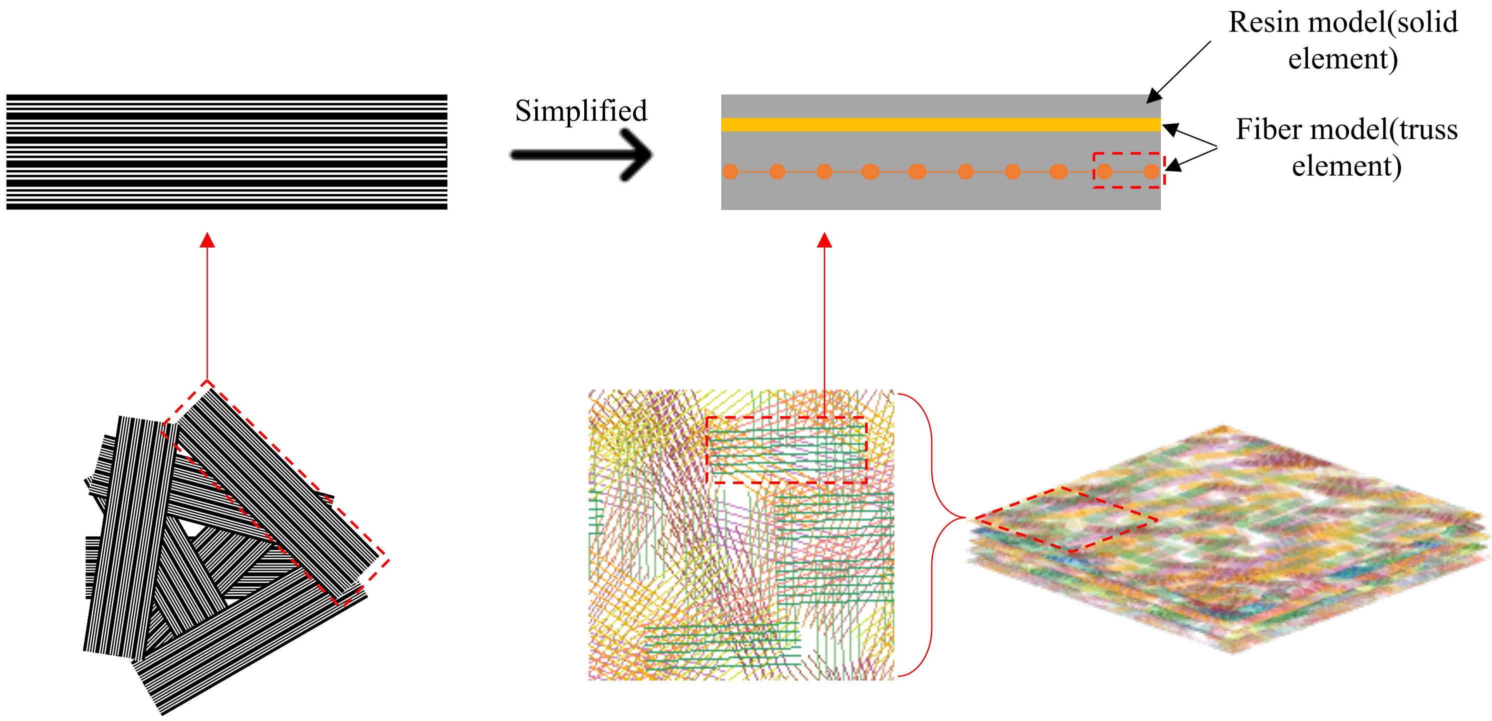


(b)



(c)

Use the **beam-solid coupling method** to create LS-DYNA models for analysis



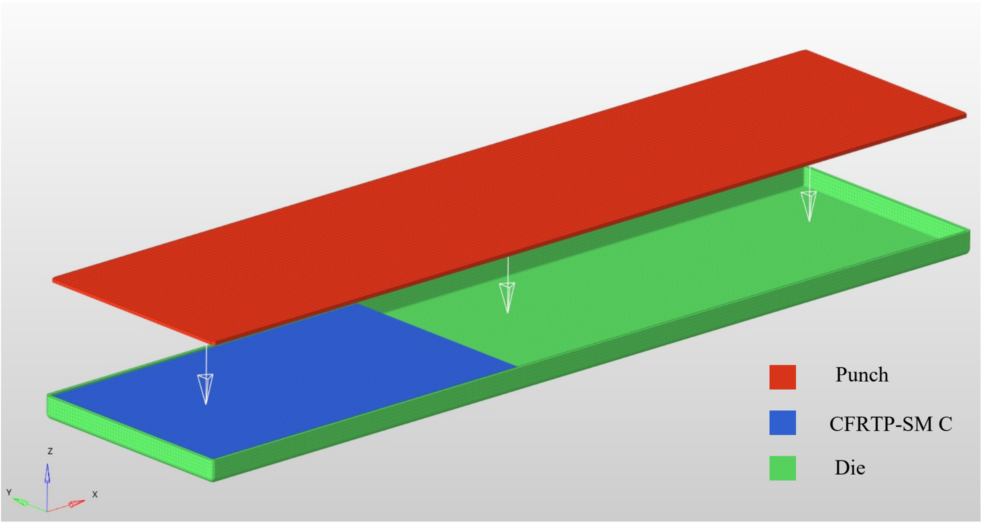
Schematic of the real CFRTP-SMC

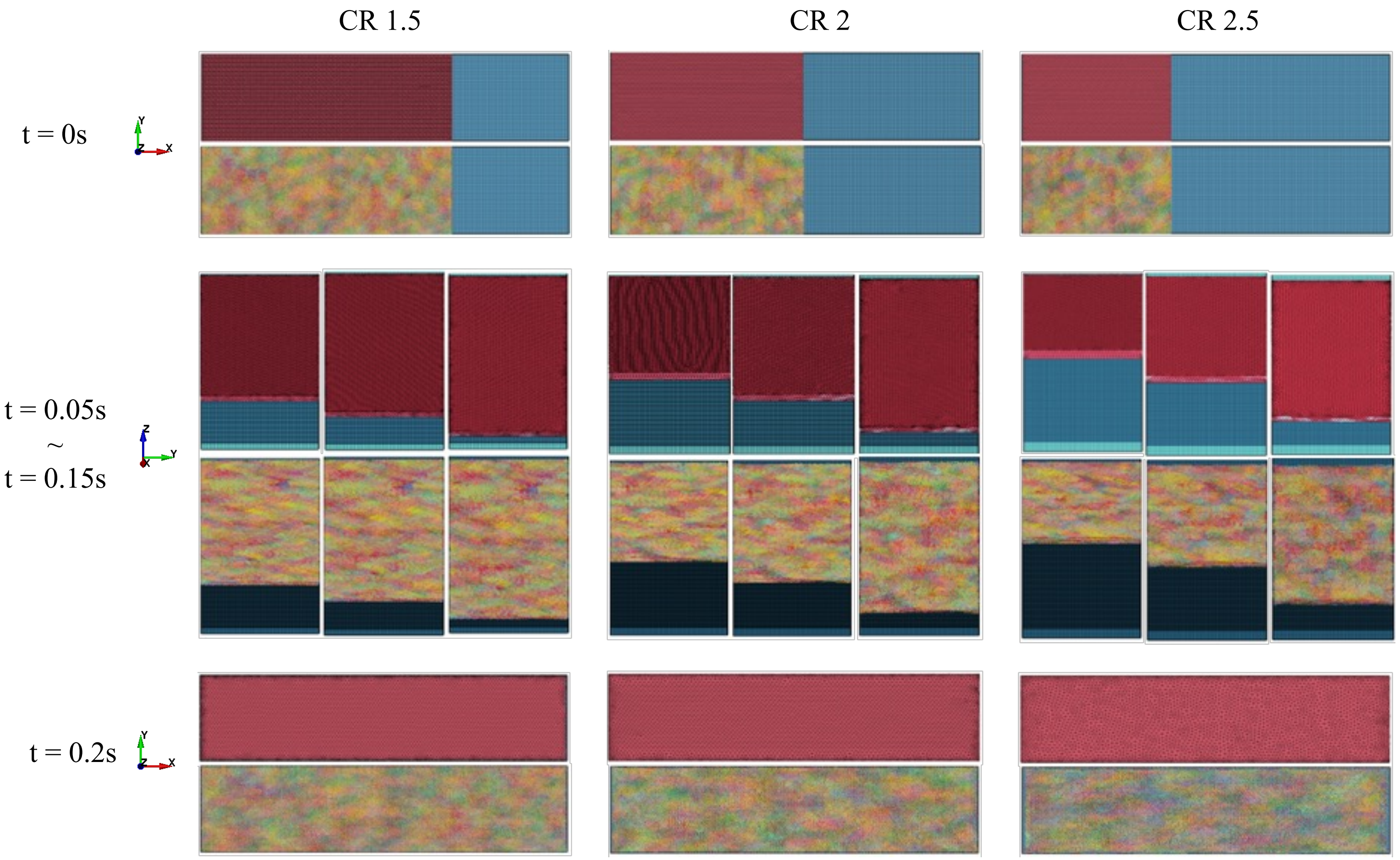
FE model

1. Hayashi S. New simulation technology for compression molding of long fiber reinforced plastics: Application to randomly-oriented strand thermoplastic composites. ECCM 2018 - 18th European Conference on Composite Materials, 2020, p. 24–8.
2. Hayashi S., Japan Patent 6584708

- **Method and model**

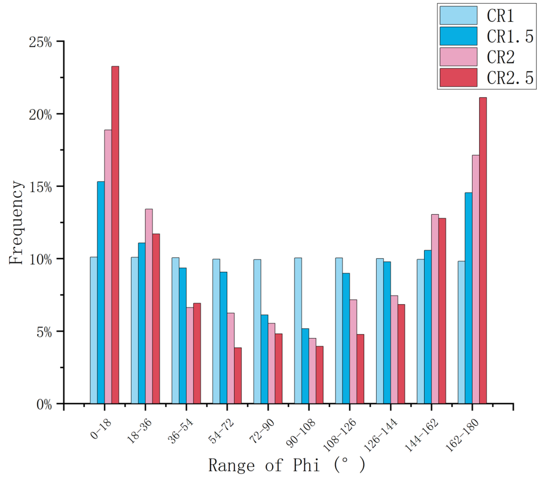
  FE model and simulation results

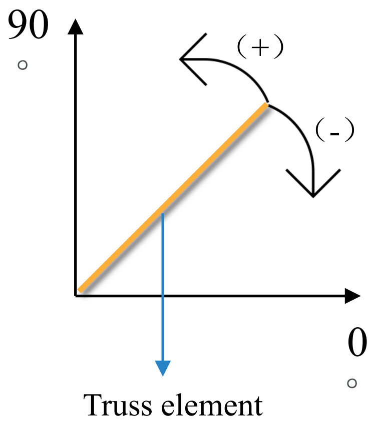


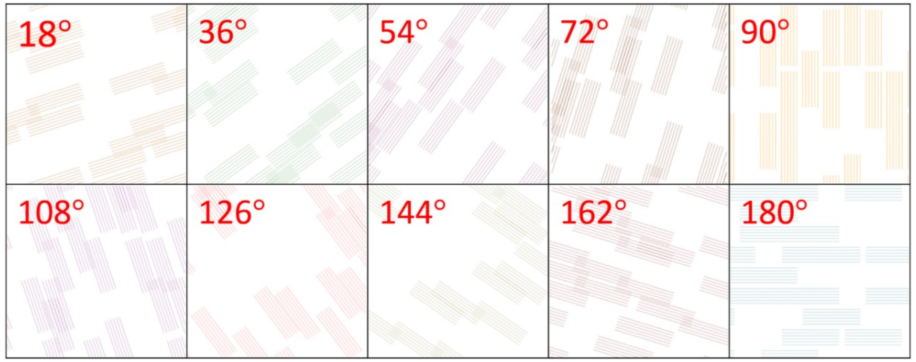


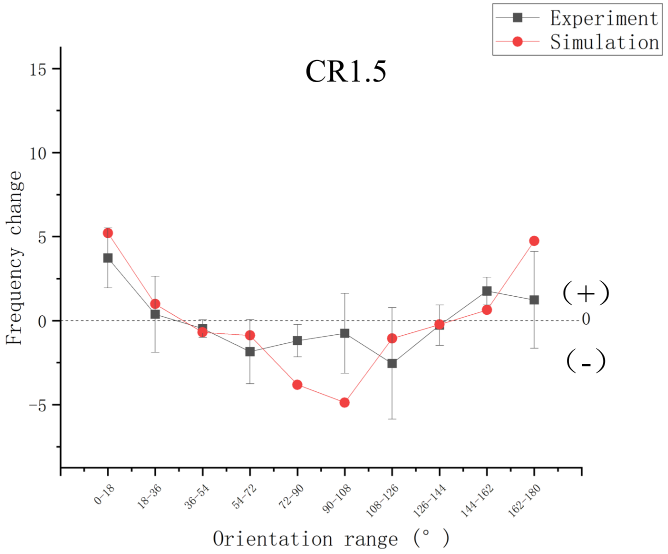
Numerical simulation | Simulation result

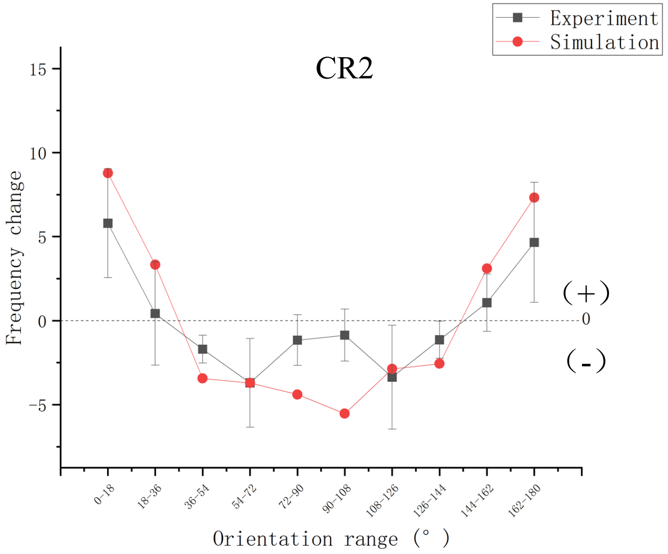
- **Simulation correlation on FOD**

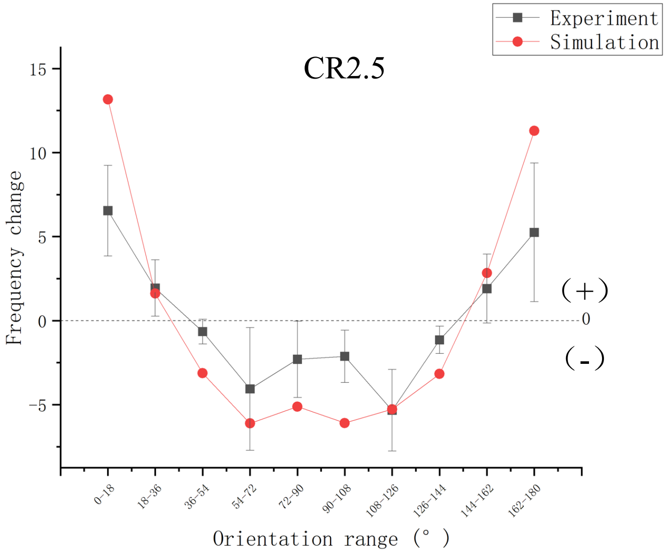












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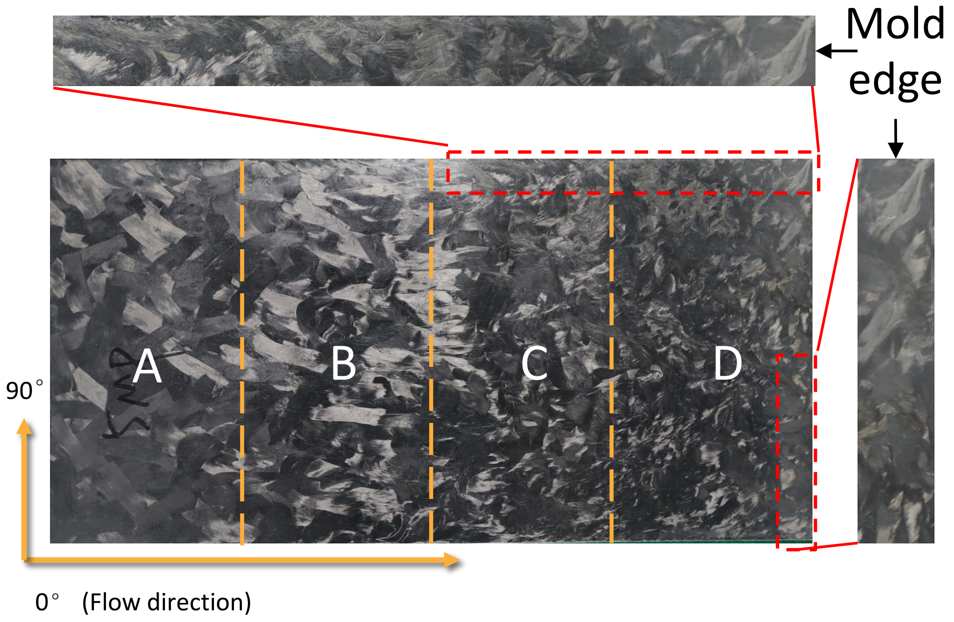
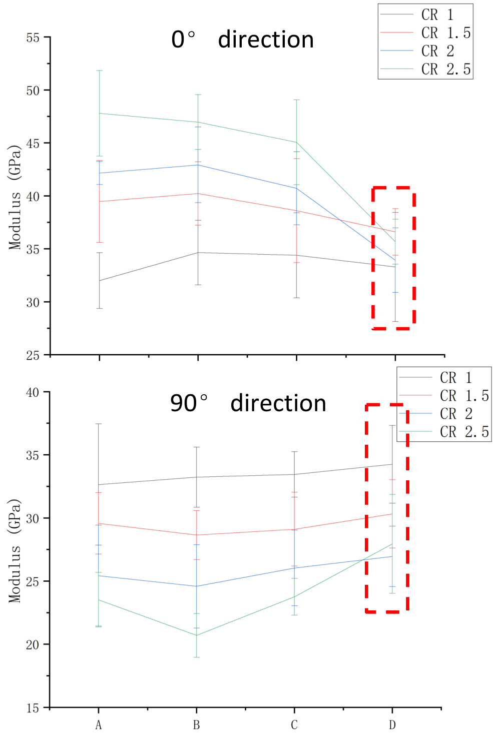
Correlation and tasks

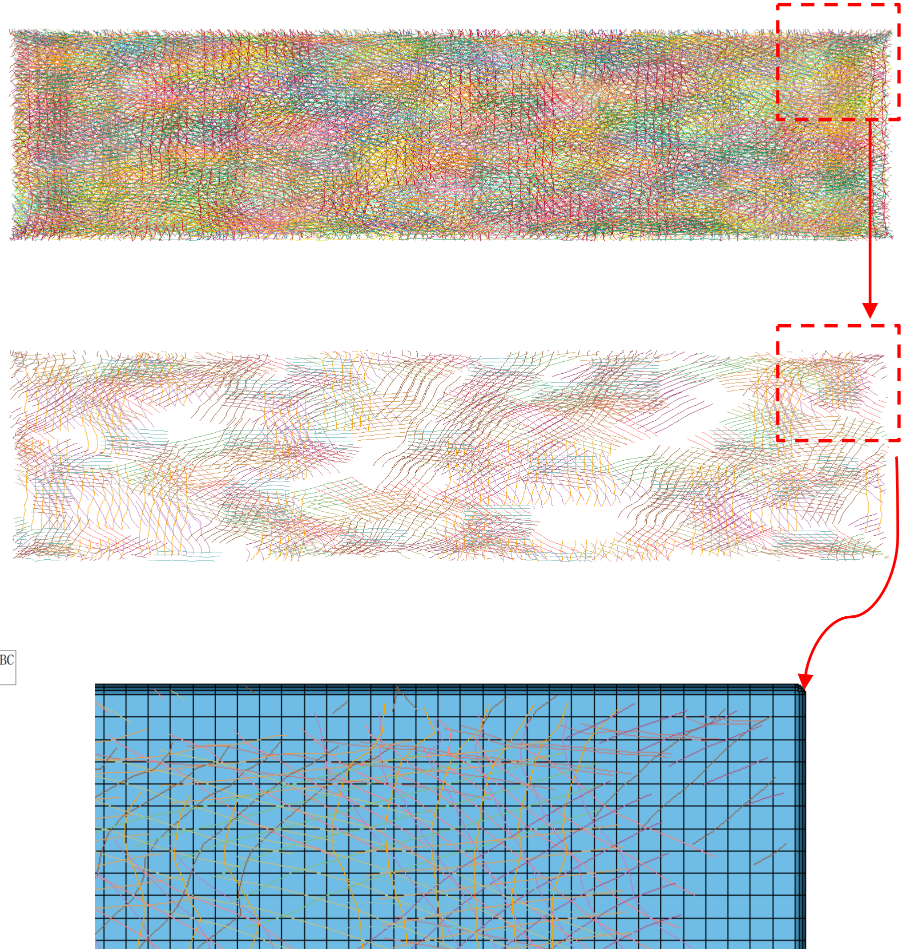
- **Area difference and edge effect**



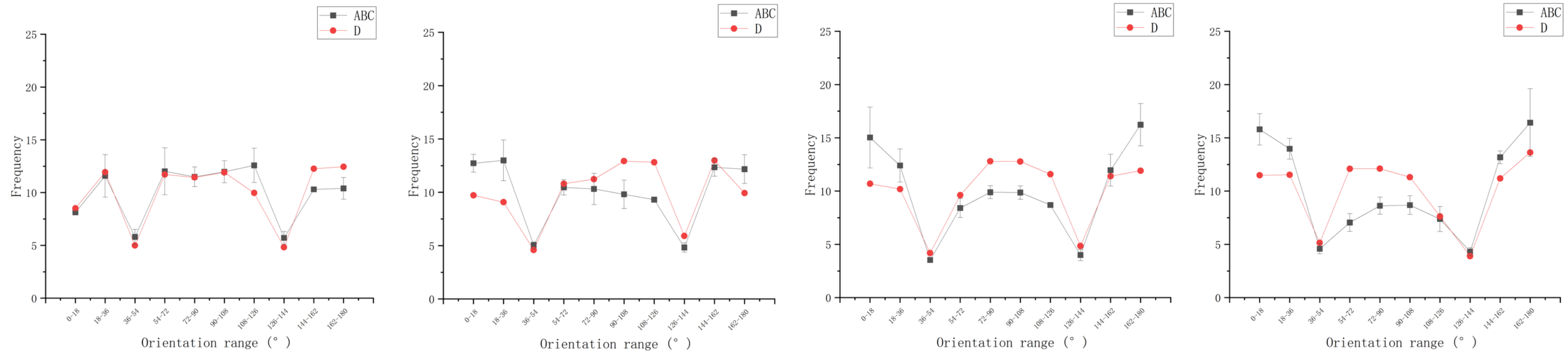
Modulus of different area



Fiber of edge part in simulation



FOD of different area



Conclusions

- **Mechanical test & Internal structure characterization**

✓ Found that for one direction flow molding, as the degree of flow increases, the material modulus will be enhanced in the direction of flow, while in the direction perpendicular to the material flow, the modulus will decrease.

✓ The internal structure of flowing CFRTP-SMC was studied by X-ray, and the change of fiber orientation was found.

- **Numerical simulation**

✓ CFRTP-SMC material flow molding simulation was realized and verified through a FEM simulation method.

✓ The fiber orientation distribution has been simulated based on different charge ratios

Reference

1. Favaloro, Anthony J., et al. "Simulation of prepreg platelet compression molding: Method and orientation validation." *Journal of Rheology* 62.6 (2018): 1443-1455.
2. Japan Meteorological Agency, Global Average Surface Temperature Anomalies, Retrieved from: https://ds.data.jma.go.jp/tcc/tcc/products/gwp/temp/ann_wld.html
3. Hannah Ritchie and Max Roser, “CO_2 and other Greenhouse Gas Emissions”, 2019, Published online at OurWorldInData.org. Retrieved from: https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions
4. “Mitsubishi Rayon's SMC adopted for rear door frame of Toyota's new Prius PHV”. Mitsubishi Rayon Co., Ltd. (2017).
5. Fujita M, Nakashima Y, Takahashi J. Influence of strand dispersion method on mechanical properties of hollow-S-shaped member made of randomly-oriented CFRTP strands. Proceedings of the 21st International Conference on Composite Materials (ICCM-21), Xi’an, China: 2017
6. Meyer, N., et al. "Direct Bundle Simulation approach for the compression molding process of Sheet Molding Compound." *Composites Part A: Applied Science and Manufacturing* 132 (2020): 105809.
7. Meyer, Nils, et al. "Non-isothermal direct bundle simulation of SMC compression molding with a non-Newtonian compressible matrix." *Journal of Non-Newtonian Fluid Mechanics* (2022): 104940.
8. Romanenko, V., et al. "Advanced process simulation of compression molded carbon fiber sheet molding compound (C-SMC) parts in automotive series applications." *Composites Part A: Applied Science and Manufacturing* 157 (2022): 106924.
9. Kim, Ho-Sang, and Seung-Hwan Chang. "Simulation of compression moulding process for long-fibre reinforced thermoset composites considering fibre bending." *Composite Structures* 230 (2019): 111514.
10. Teuwsen, Jan, Stephan K. Hohn, and Tim A. Osswald. "Direct Fiber Simulation of a Compression Molded Ribbed Structure Made of a Sheet Molding Compound with Randomly Oriented Carbon/Epoxy Prepreg Strands—A Comparison of Predicted Fiber Orientations with Computed Tomography Analyses." *Journal of Composites Science* 4.4 (2020): 164.
11. Li, Yang, et al. "Modeling and simulation of compression molding process for sheet molding compound (SMC) of chopped carbon fiber composites." *SAE International Journal of Materials and Manufacturing* 10.2 (2017): 130-137.
12. Hohberg, Martin. *Experimental investigation and process simulation of the compression molding process of Sheet Molding Compound (SMC) with local reinforcements*. KIT Scientific Publishing, 2022.
13. Song, Yuyang, et al. "A novel CAE method for compression molding simulation of carbon fiber-reinforced thermoplastic composite sheet materials." *Journal of Composites Science* 2.2 (2018): 33.
14. Hayashi S. New simulation technology for compression molding of long fiber reinforced plastics: Application to randomly-oriented strand thermoplastic composites. ECCM 2018 - 18th European Conference on Composite Materials, 2020, p. 24–8.
15. Hayashi S., Japan Patent 6584708

Thanks for Your Attention

ACKNOWLEDGEMENTS:

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Appendix

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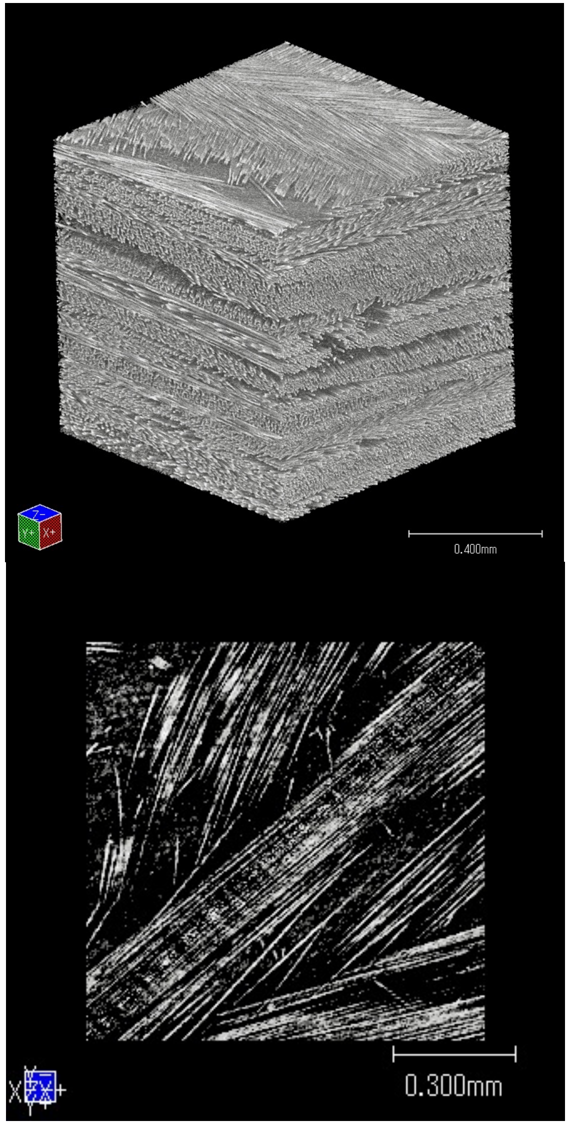

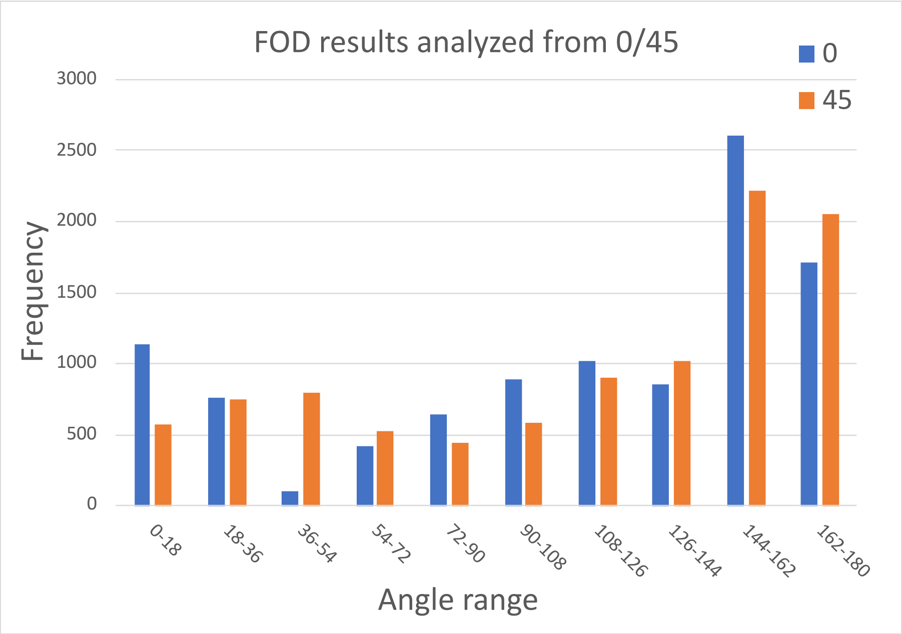

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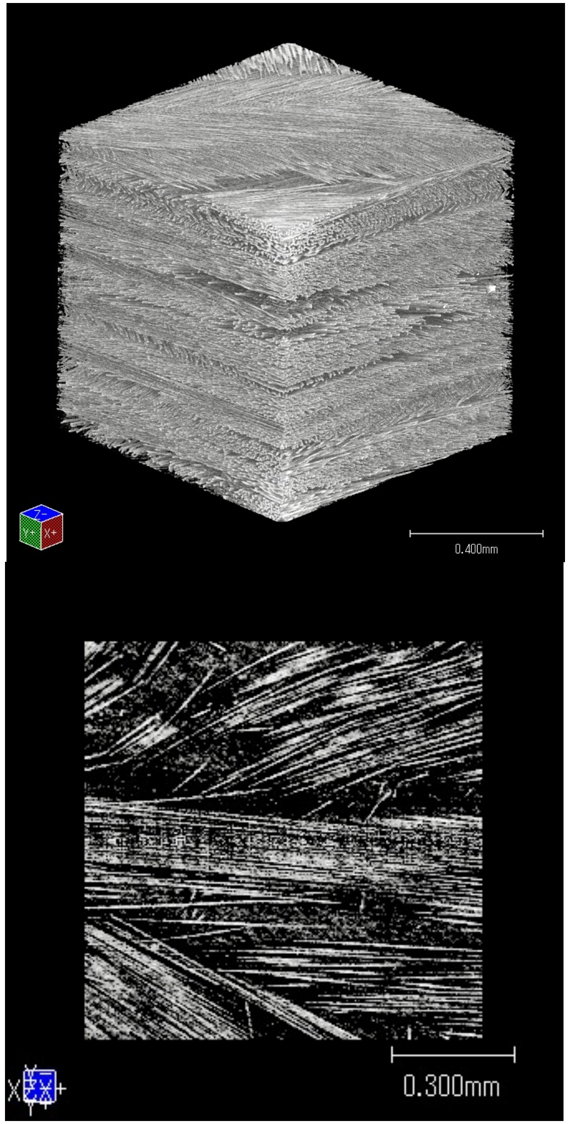

Appendix

Material parameters in simulation

Property	Value	Unit
Resin		
Young's Modulus	0.2	MPa
Mass Density	1e-09	ton/mm^3
Friction coefficient	0.05	-
Poisson's Ratio	0.49995	-
Yield Stress	0.0001	-
Stiffness	0.2	Mpa
Fiber		
Mass Density	1.82e-09	ton/mm^3
Young's Modulus	207	GPa
Poisson's Ratio	0.3	-
Interaction		
Resistive Force	0.05	N/mm
Start-up sliding amount	0.2	mm

Geometry model parameters

Property	Value	Unit
Strand length	19	mm
Strand width	5	mm
Fiber number in width direction	6	-
Beam length	1	mm
Strands per cluster	2	-
Cluster size	7	mm