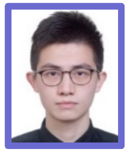
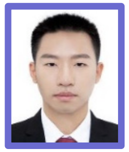
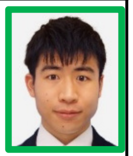
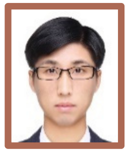
	Continuous Thermosetting CFRP	**CTT** Discontinuous Thermoplastics SMC	**CMT (CWT/CPT)** Discontinuous Thermoplastics Mat
Structural optimization			
Monte Carlo Simulation		 	 
X-ray CT Morphology/Damage		 	
Vibration/Buckling		 	
Sandwich Spring back			   
Mechanical Fastening		 	
Environmental effect			

Hollow Beam in Three-point-bending Test with CFRP

U-TOKYO

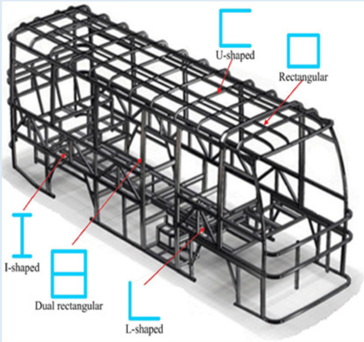
Background

Carbon fiber reinforced plastics (CFRP) composite components

- Outstanding mechanical properties
- Lightweight

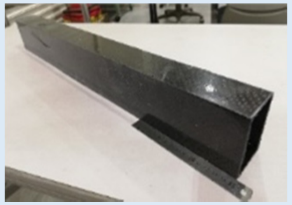
Design optimization

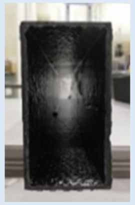
Hollow structures



Objective

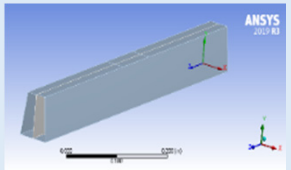
Anisotropic rectangular hollow beam with **inconstant** thickness





Approach

- Establishment of **Finite Element Mothed (FEM)**
- Verification by experiments



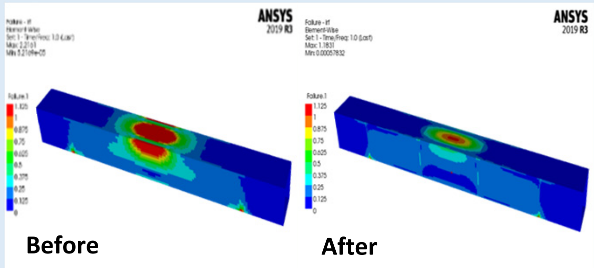
Purpose

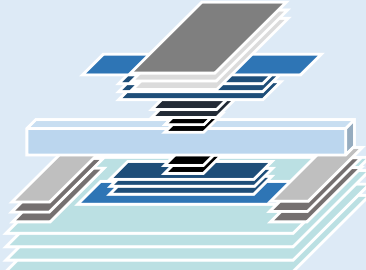
- Improvement of mechanical properties
- Fabrication and test of beam to realize design
- Extensive application to more complex structures

Achievements

Numerical Analysis

- Improvement of stiffness by reinforcements
- Prediction of failure progress
- Selection of Optimal height/width ratio **(8:5)**



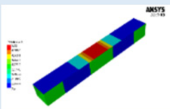


Experiments

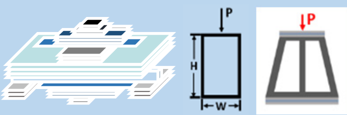
- Measurement of mechanical properties
- Fabrication of beam as design

Design

Modelling

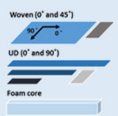


Optimization



Fabrication (hand layup)

Materials



Shaping

Curing (24h, RT)

Post-curing I (5h, 70˚C)

Post-curing II (4w, RT)

3-point bending test

Optimal structure design of anisotropic CFRTP components (CWT)

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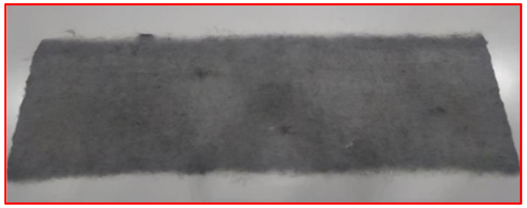
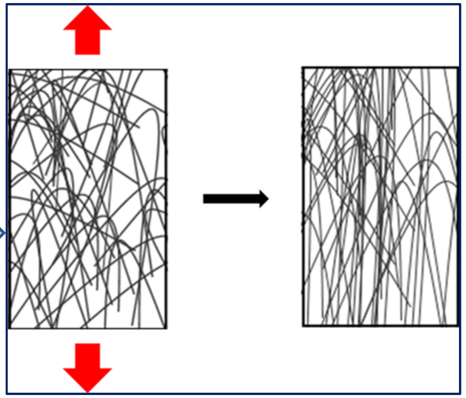


CWT is an approach for reusing recycled carbon fiber



Stretch treatment

Influence

Fiber orientation and stretch ratio:

$$S = \frac{L_2 + L_1}{L_1} \times 100\%$$

S: Stretch ratio

L_1: Length before stretch

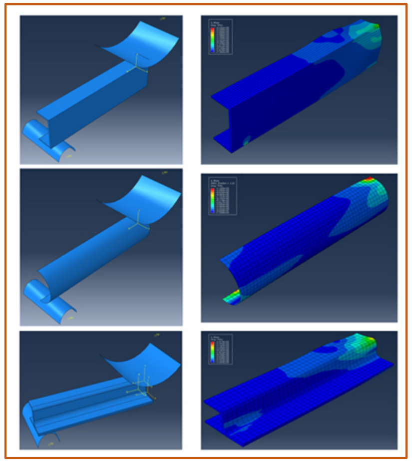
L_2: Additional length after stretch

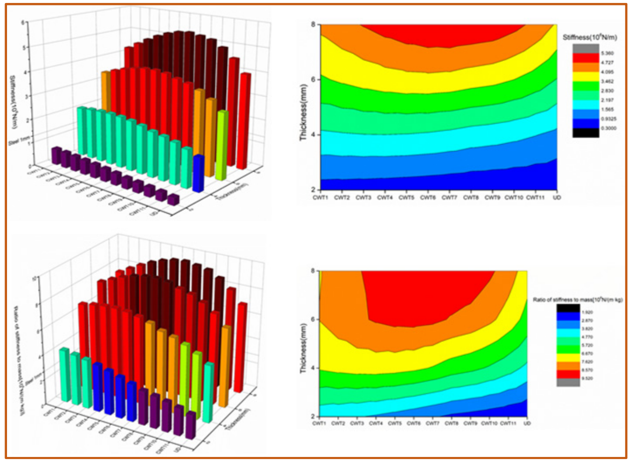
Impact on

Mechanical properties

Analyze

Optimize





FEM models

Provide a method to design structures on anisotropic CFRTP materials based on FEM

[1] Zhang, Yunqian, et al. "COMPARISON BETWEEN SPRINGBACKED CARBON FIBER CARD WEB REINFORCED THERMOPLASTICS AND CARBON FIBER PAPER REINFORCED THERMOPLASTICS SANDWICH STRUCTURES ON BENDING AND IMPACT PROPERTY."

Elucidation of the statistical properties of materials by stochastic digital twins (in case of CTT)

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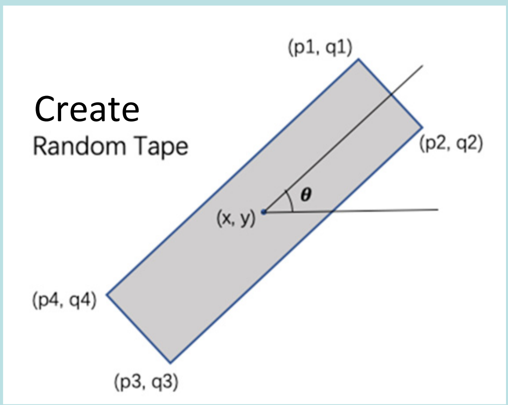
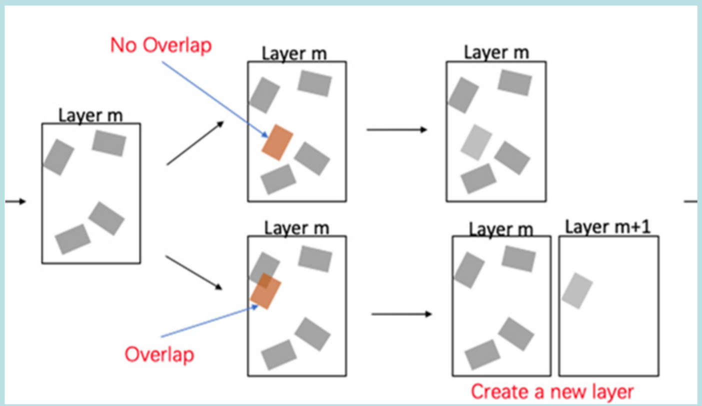
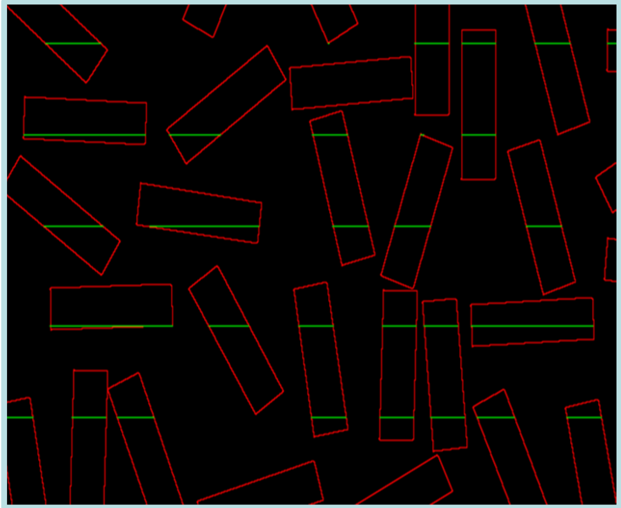
Predict the mechanical property of CTT using numerical simulation





Tape Dispersion Judgement

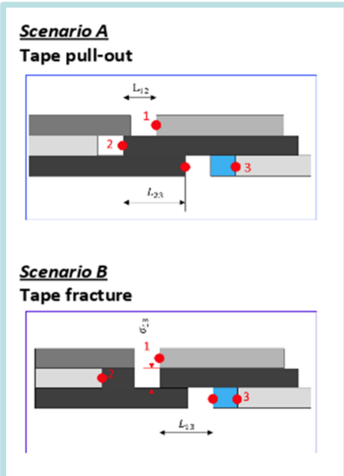
Python Coding



Monte-Carlo Simulation

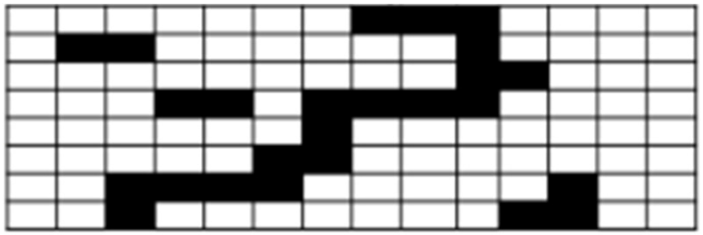
Search weakest area by Classical Laminate theory

Failure mode analysis based on Hashin criterion



Python Coding

Find Destruction Path



Based on **Dijkstra Algorithm**

Mechanical Property

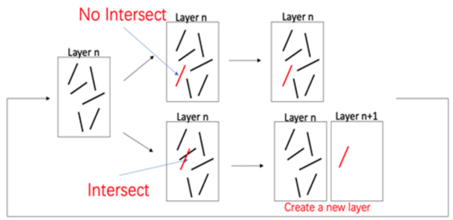
Aim to provide a reliable means to predict CTT property according the input parameters.

Elucidation of the statistical properties of materials by stochastic digital twins (in case of CMT)

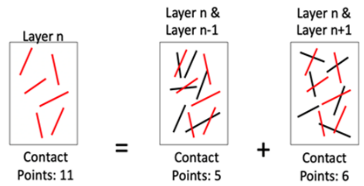
U-TOKYO

Predict the mechanical property of CWT using numerical simulation

Fiber Dispersion Judgement

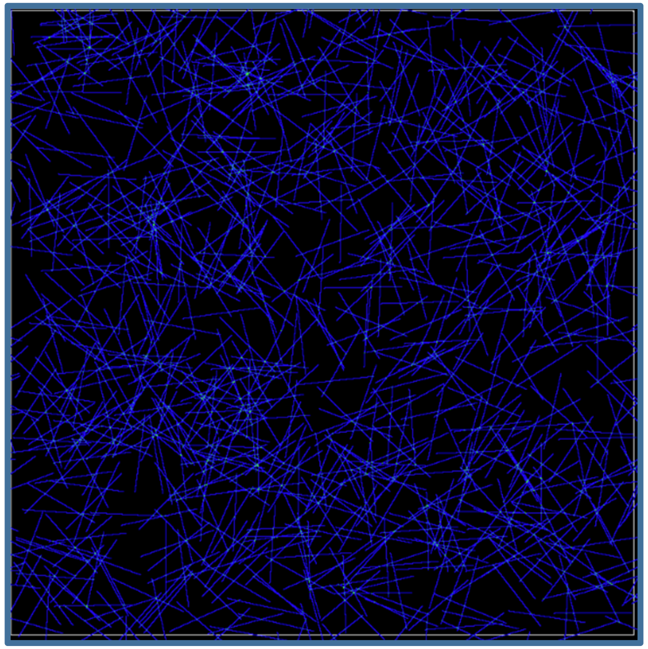


Calculation of Contact Points in layer n

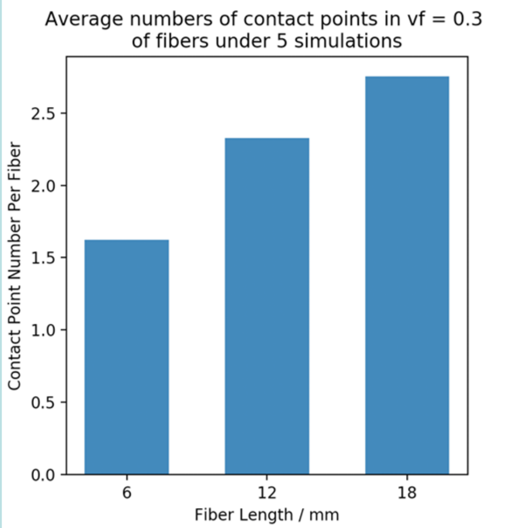


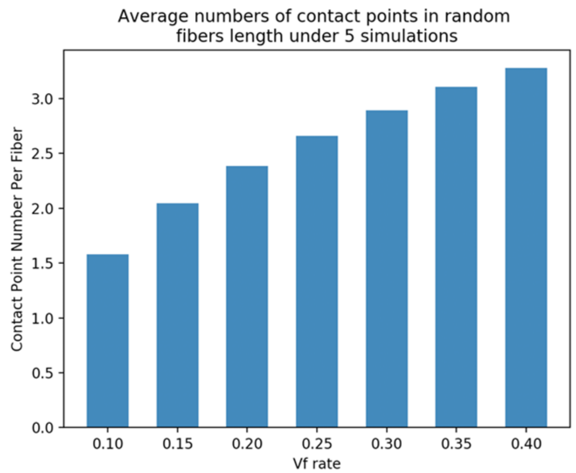
Python Coding

Monte-Carlo Simulation



Simulation Result





Relationship

Mechanical Property

Aim to provide a reliable means to predict CWT property according to the numbers of contact points from CWT simulation.

Monte Carlo simulation for strength / lifetime analysis of inhomogeneous CFRP

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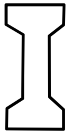
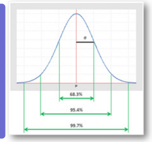
Previous research & Problems in strength estimation

STEP1
Experiment
n times



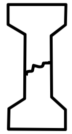
STEP2
Elastic properties
Certainty: △～○



STEP2
Strength
Certainty: ×～△

STEP2
Assume one failure criteria for entire structure

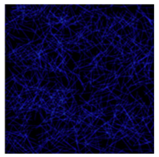
STEP3
One FE simulation
Validate qualitatively by mean strength and failure process



STEP4
Design structure
Estimate mean lifetime

Proposed research

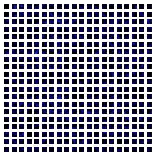
STEP1
Monte Carlo simulation N times
Validation of morphology by X-ray CT

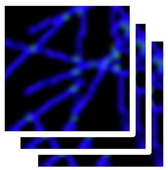


STEP2
Elastic properties
Statistical verification
Experimental validation
Certainty: ○

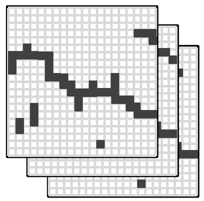
STEP4
Strength
Statistical verification
Experimental validation
Certainty: ○

STEP2
Divided into finite elements
&
Micro composite experiment to obtain failure criteria for each element





STEP3
Failure process simulation for each of the N times Monte Carlo simulations in STEP1
Validate by experimental strength distribution and fracture process



STEP5
Design structure
Estimate lifetime distribution

STEP5
Determine appropriate specimen size and number to obtain material properties

STEP5
Feedback on material improvement

Internal Geometry & Mechanical Property of CFRTP

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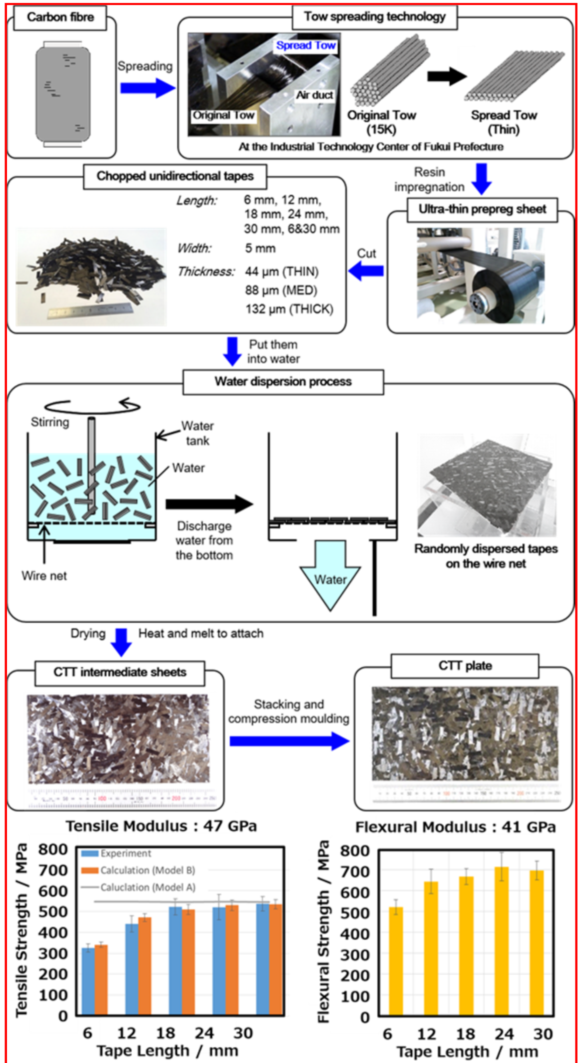
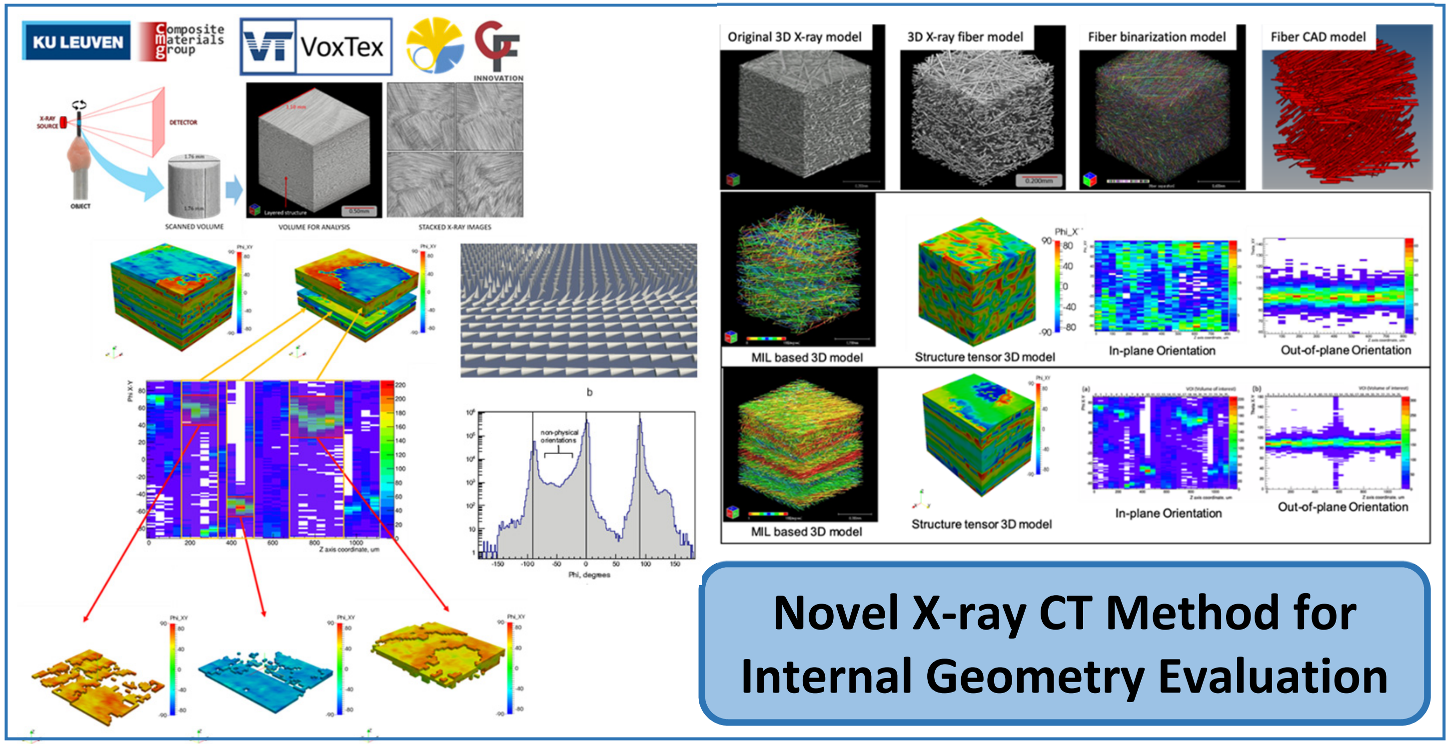
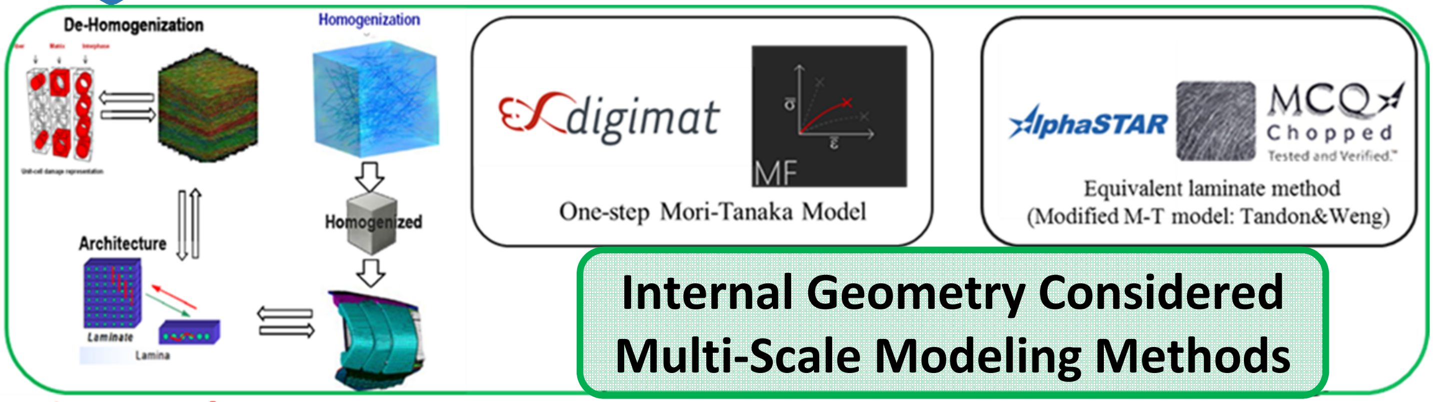


Internal Geometry and Stochasticity



Novel X-ray CT Method for Internal Geometry Evaluation

Internal Geometry Data



Internal Geometry Considered Multi-Scale Modeling Methods

Experimental Data

Solution Methodologies

Provide appropriate CFRTP characterization methodologies

(material researches & industrial applications)

X-ray CT and image processing on measuring FOD of CFRTP

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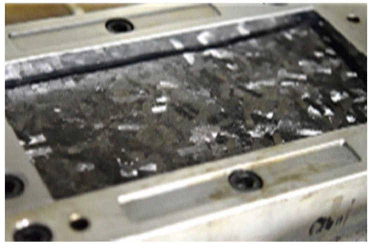
Mechanical property

Fracture behavior

- Fiber volume fraction
- Fiber length distribution
- Fiber orientation distribution (FOD)

Molding



X-ray CT

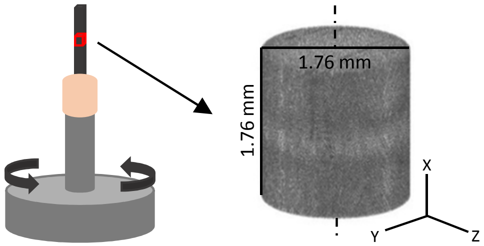
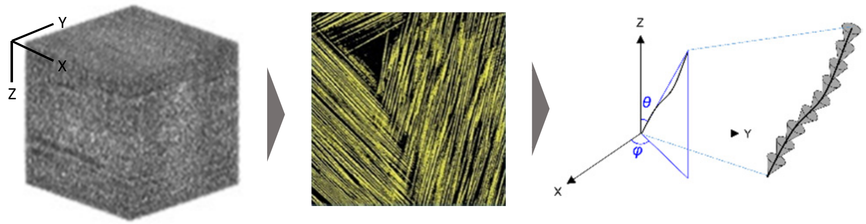
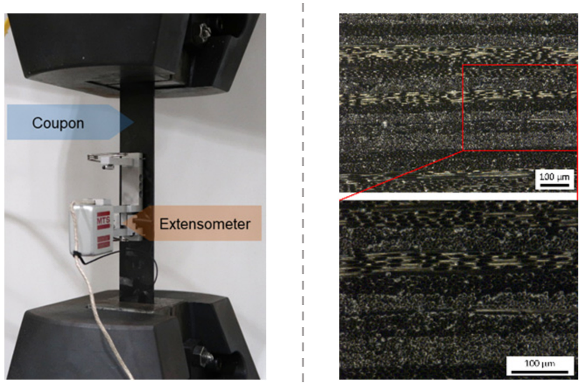


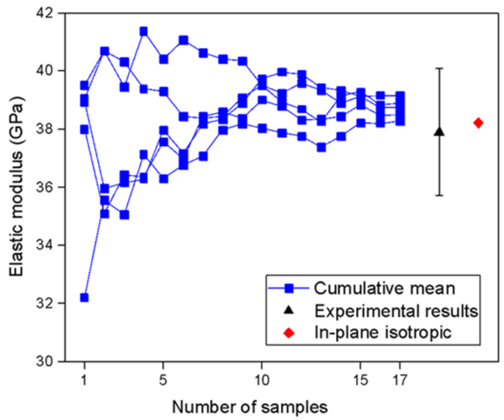
Image processing



Experimental

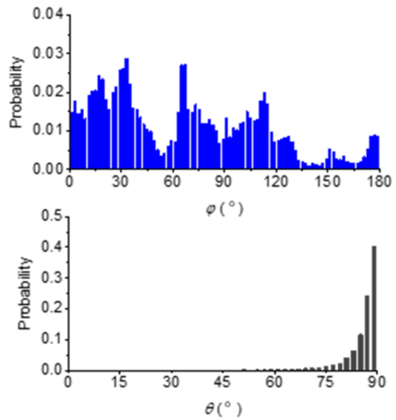


Verification



Analytical approaches

FOD



東京大学 THE UNIVERSITY OF TOKYO

Provide an optimal methodology for describing FOD of CFRTP

ICC Innovative Composite Center

- G. Cai, T. Shirai, Y. Wan, K. Uzawa and J. Takahashi, "Application of X-ray computed tomography on measuring fiber orientation distribution of chopped carbon fiber tape reinforced thermoplastics", *Applied Composite Materials*, (under review).

Influences of material flow and thermoforming of CTT on microstructure and mechanical properties

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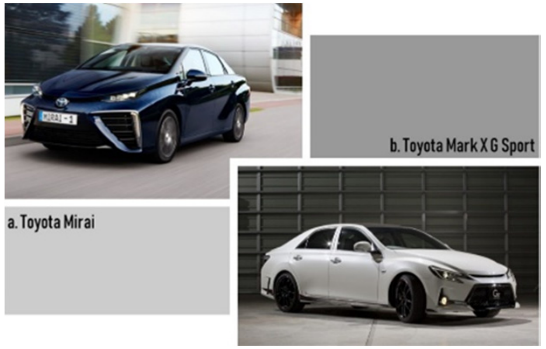
Since thermoforming is an important appeal point as a differentiation from thermosetting resins, I think it would be good to add changes in physical properties after thermoforming .



CTT was developed for forming complex structures. But most of our current research is focused on tablets

The malleable nature of the CF-SMCs sheets allows its adoption in complex geometries.

The need to investigate the impact of material flow in depth

Fabricate CTT plate with different charge ratio

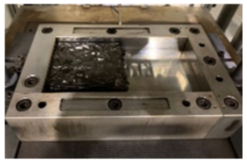
Mechanical test

X-ray observation

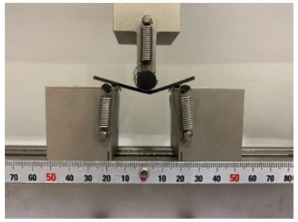
Molding simulation by LS-DYNA

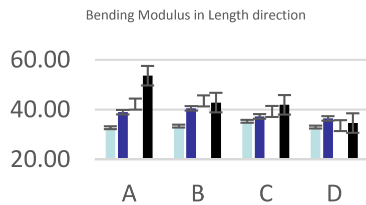
$$\text{Charge ratio} = \frac{\text{Area after moulding}}{\text{Area before moulding}}$$

Molding

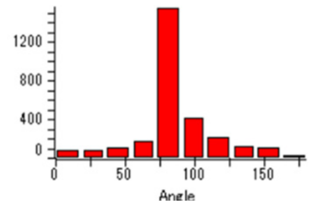


Mechanical test





FOD(fiber orientation distribution)



FEM...

Observe various characteristics before and after the flow → **Explore the characteristics of CTT flow behavior, predict and simulate its flow process**

Vibration response of CTT structure with complex shape

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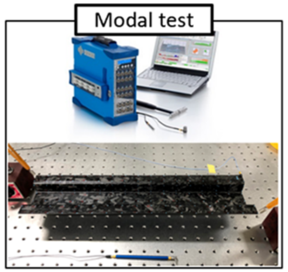
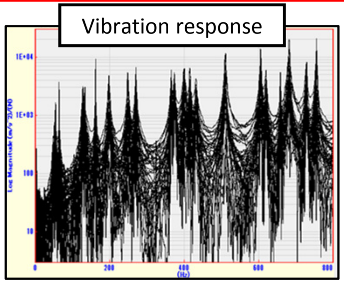
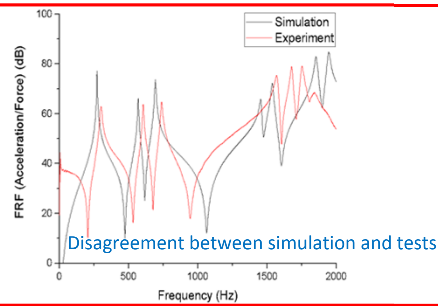
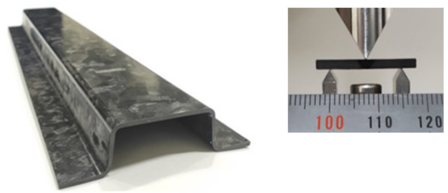
Uncertain modulus distribution in complex-shape CTT structures results in difficulty in simulating its vibration response accurately.





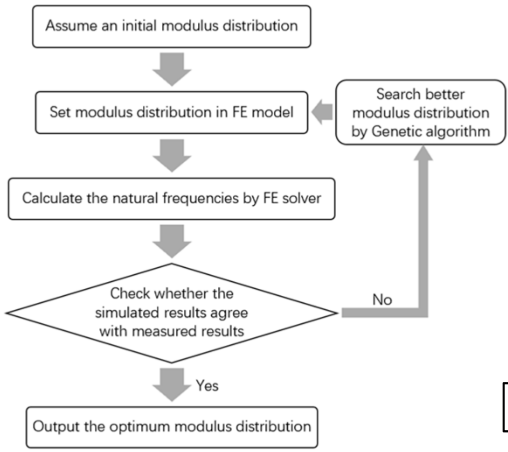


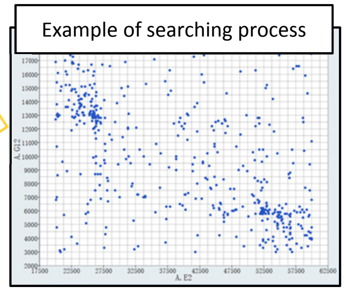
Modulus distribution measurement. Ensure the reliability for measurement based on small size specimens

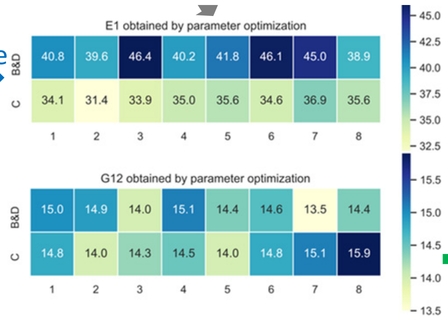


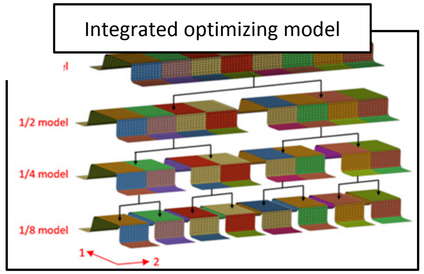
Validate

Natural frequencies based reverse analysis in determine modulus distribution.

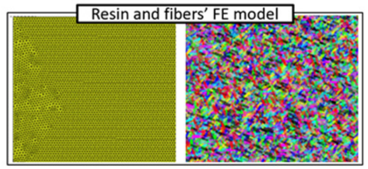








Molding simulation + vibration simulation



LS-DYNA

Simulation based on equivalent microscale model

Post-processing

Modulus distribution

Vibration response simulation based on macroscale FE model

Accurate vibration response simulation → Contribute to the vibration control and fatigue lifespan design for automobile development when CTT is applied

Buckling Analysis on Chopped Carbon Fiber Tape Reinforced Thermoplastics (CTT)

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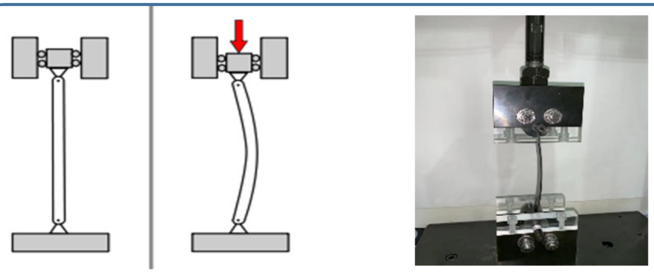
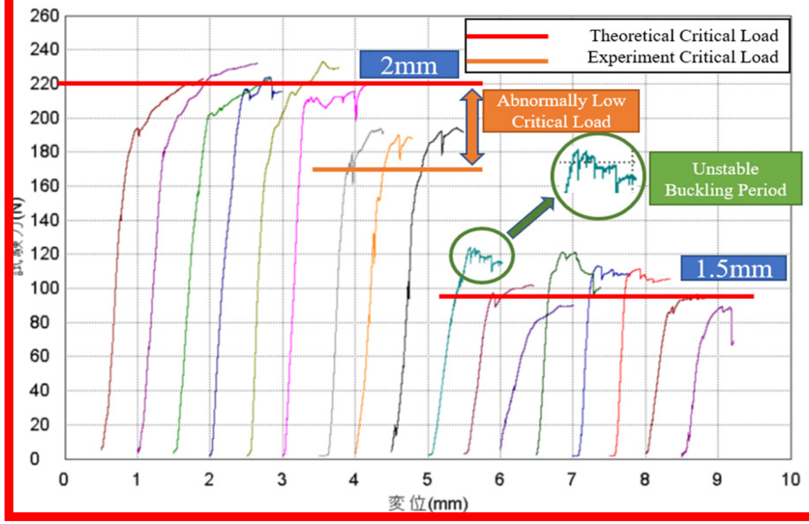


Buckling failure of specimen

Problem: the anisotropic property of the CTT materials makes it hard for designers to predict the buckling failure of a certain mechanism.



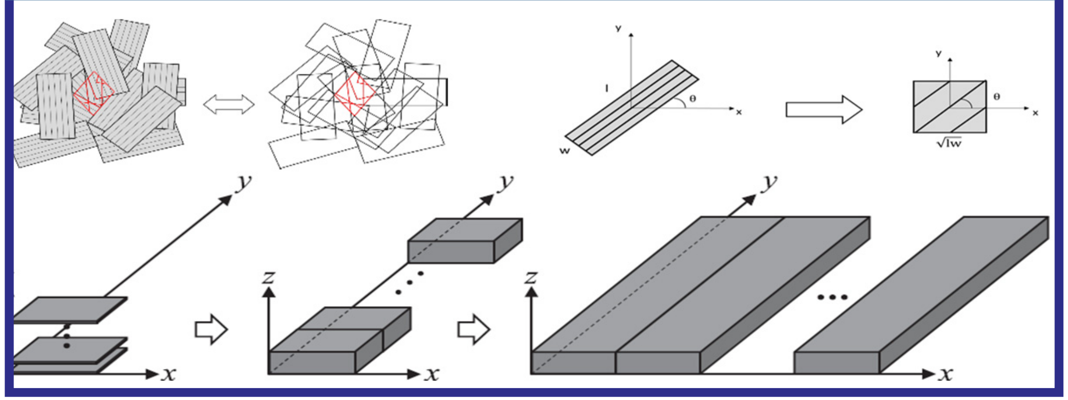
Input

Data

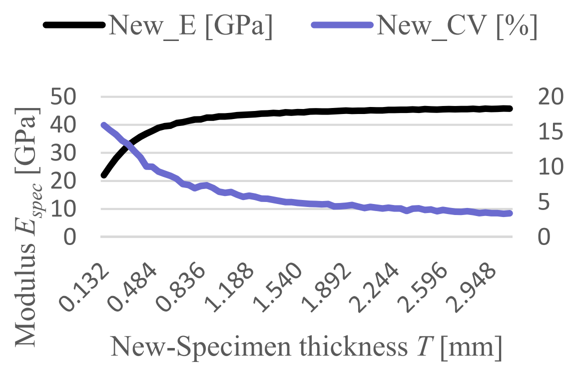
FEM

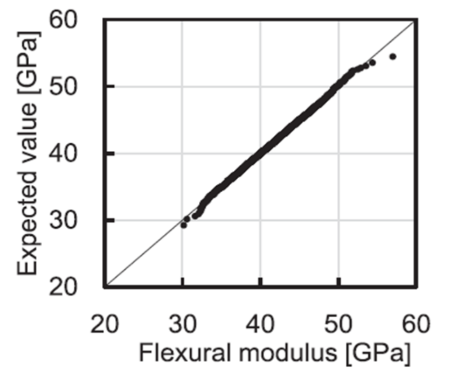
Output: Predict Buckling Failure

Analytical Model

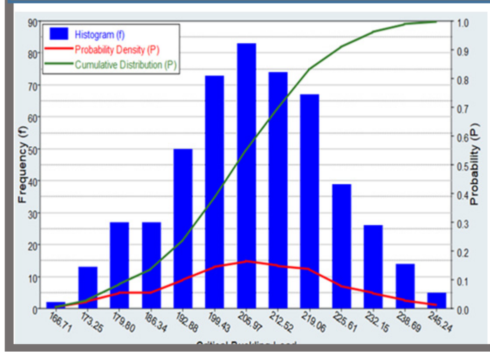


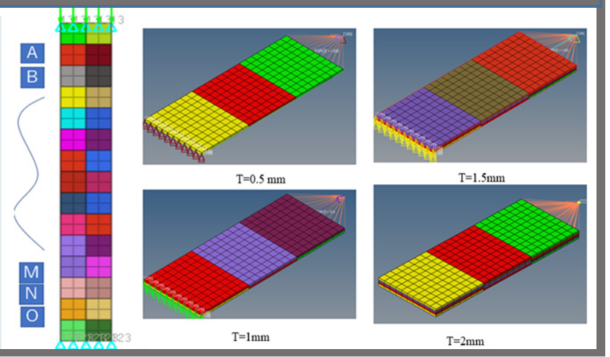
Calculation on Elastic Modulus





Simulation on Buckling Failure





Discontinuous recycled carbon fiber sheet reinforced thermoplastics

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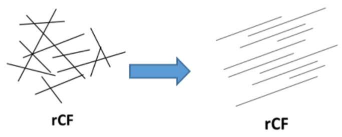
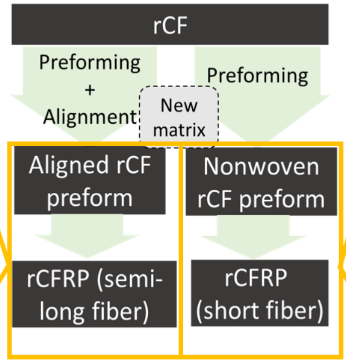
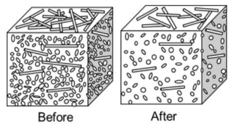
Semi-long rCF
50mm-200mm



Fiber alignment
- Increase rCF volume fraction
- Improve mechanical property



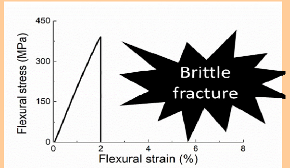
Short rCF
＜40mm

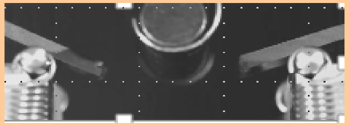


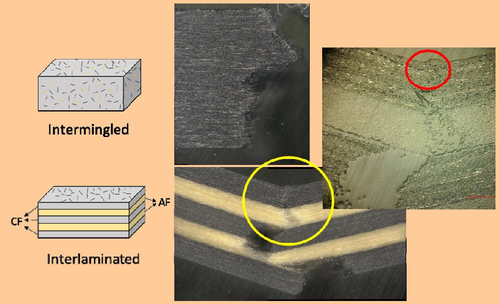
Overcome weaknesses
- Reduce brittleness
- Solve the critical problem during post thermal forming

CPT

Improvement on brittleness of short rCF reinforced thermoplastics



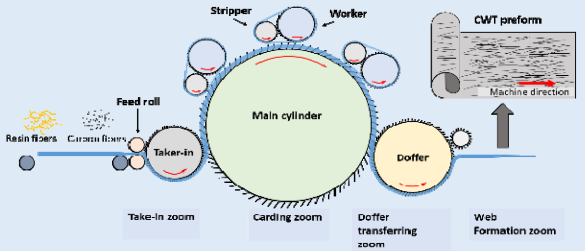


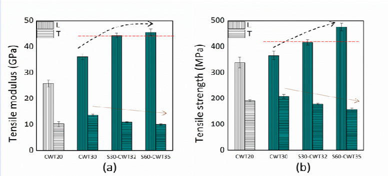


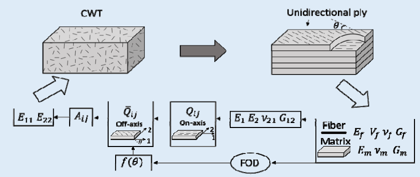
1) B. Xiao, I. Ohsawa, S. Naruse and J. Takahashi, "Hybrid reinforcement effect of discontinuous carbon/aramid fiber paper reinforced thermoplastics", Proceedings of JSCM43- 43rd Japanese Symposium on Composite Material, Toyama, Japan, No. B1-1-1, (2018-9).
2) B. Xiao, H. Matsuda, I. Ohsawa and J. Takahashi, "Hybrid effect on carbon paper reinforced thermoplastics with aramid papers", Proceedings of JCCM10- 10th Japanese Conference on Composite Materials, Tokyo, Japan, No. 1D-16, (2019-3).

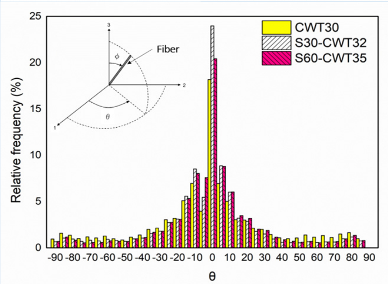
CWT

A carding and stretching process for semi-long recycled carbon fibers (rCF) on thermoplastics



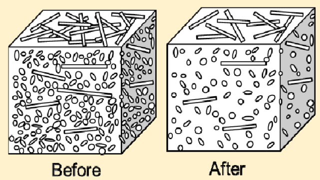


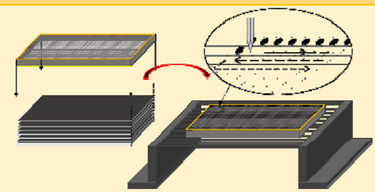


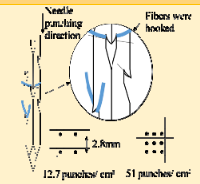


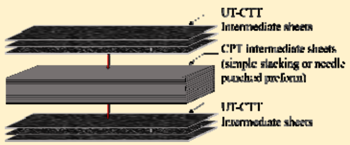
1) B. Xiao, T. Zaima, K. Shindo, T. Kohira, J. Morisawa, Y. Wan, G. Yin, I. Ohsawa and J. Takahashi, "Characterization and elastic property modeling of discontinuous carbon fiber reinforced thermoplastics prepared by a carding and stretching system using treated carbon fibers", Composites Part A, Vol. 126, (2019-11), 105598.

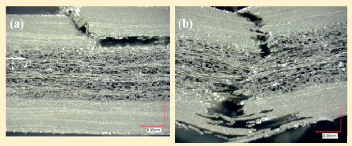
Deconsolidation of short rCF reinforced thermoplastic and its application

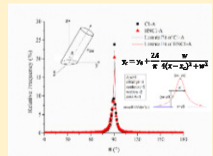












1) B. Xiao, Y. Wan, I. Ohsawa and J. Takahashi, "Effect of needle punching on flexural behavior of carbon fiber-reinforced thermoplastic sandwich panel with spring-backed core", Composites Part A, Vol.118, (2019-3), pp.57-66.
2) B. Xiao, Y. Mochizuki, Y. Mizutani, M. Okoshi, Y. Yang and H. Hamada, "Mechanical properties of cardboard sandwiched glass fiber reinforced plastics", Proceedings of JSCM40- 40th Japanese symposium on composite material, Kanazawa, Japan, No. C2-10, (2015-9).
3) B. Xiao, Y. Wan, I. Ohsawa and J. Takahashi, "Needle punching effect on carbon fiber reinforced thermoplastic sandwich panels", Proceedings of ICCM21- 21st International Conference on Composite Materials, Xi'an, China, No. 4062, (2017-8).
4) B. Xiao, I. Ohsawa and J. Takahashi, "Manufacturing and flexural behavior of carbon fiber reinforced thermoplastic sandwich panels with springback cores", Proceedings of JCCM9- 9th Japanese Conference on Composite Materials, Kyoto, Japan, No. 3B-09, (2018-3).
5) B. Xiao, I. Ohsawa and J. Takahashi, "The manufacturing of carbon-fiber paper reinforced thermoplastic core sandwiched panels under several degrees of consolidation", Proceedings of ECCM18- 18th European Conference on Composite Materials, Athens, Greece, No. 155, (2018-6).
6) B. Xiao, Y. Wan, I. Ohsawa and J. Takahashi, "Deconsolidation behavior of carbon fiber reinforced thermoplastics as core in sandwich structure", Proceedings of ICCM22- 21st International Conference on Composite Materials, Melbourne, Australia, No. P4212-3, (2019-8).

Springbacked carbon fiber reinforced thermoplastic sandwich structures

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Carbon fiber sandwich structure with springbacked CWT core

The influence of springback ratio, molding parameters and material set was studied

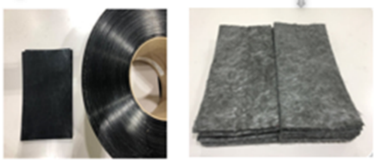
· Springback phenomenon

Springback ratio: the thickness changed during the heating process.

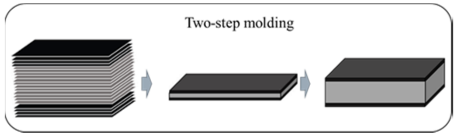
· Sandwich structure

Uni-directional carbon fiber reinforced thermoplastics

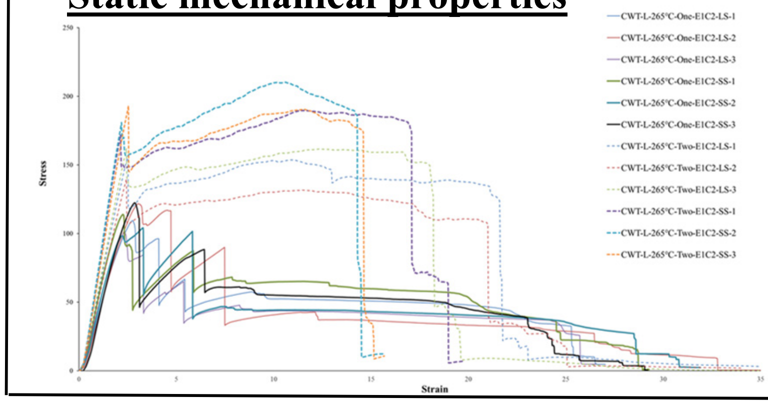
Carbon fiber card web reinforced thermoplastics



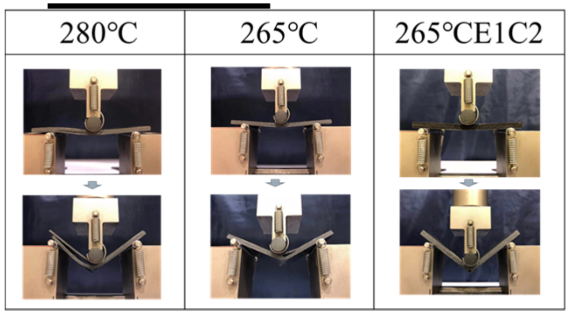
E1: One PA6 film for each CWT sheet
C2/4: Two/Four PA6 films between skin and core

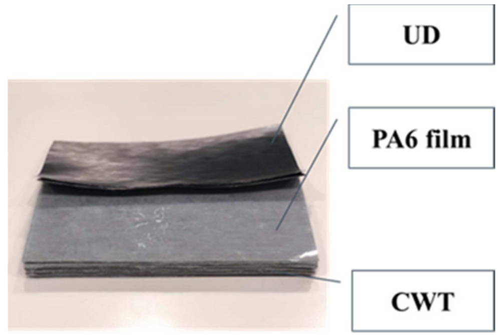


· Static mechanical properties

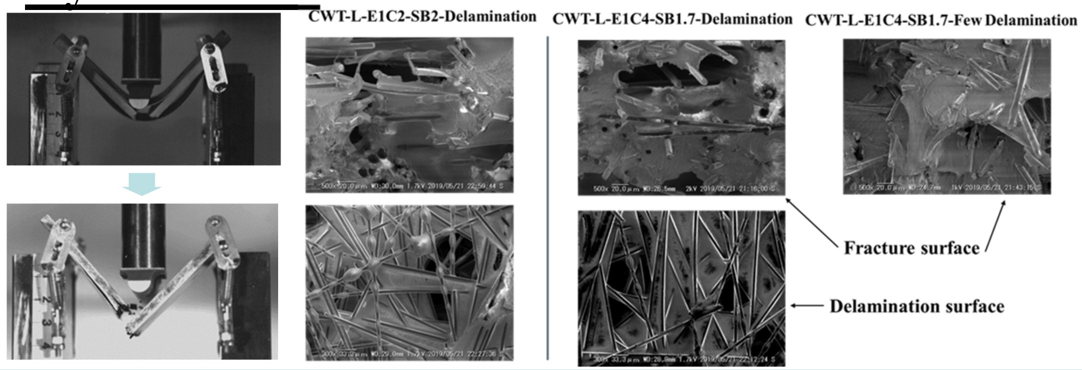


· Static test





· Dynamic test



Salient specific mechanical properties especially energy absorption ability / Low density

$\rho \approx 0.85\ g/cm^3$

Improvement of static and dynamic mechanical properties of CFRTP sandwich structures (Novel method for recycling carbon fibers)

Aramid hybridization of carbon fiber paper reinforced thermoplastics

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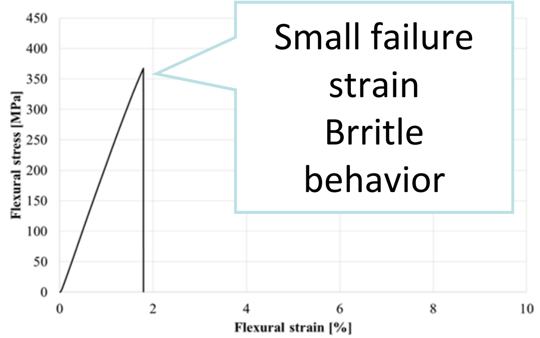
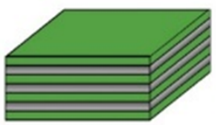
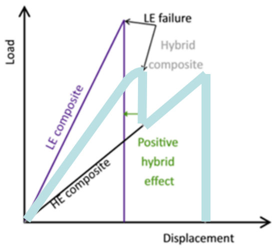
Research background

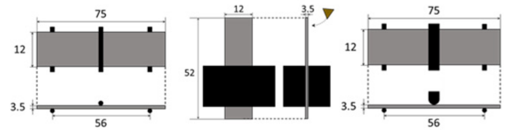


✔Recycled CFRP has limited toughness with small failure strain and brittle failure behavior.
✔One of the solutions is hybridization with ductile fibers.

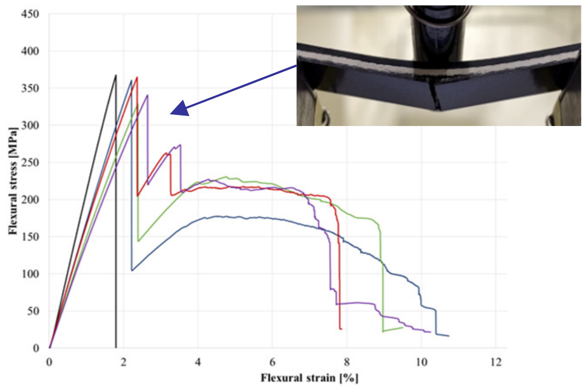


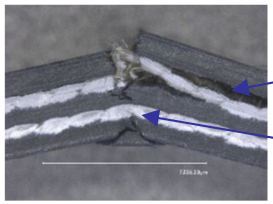


Experimental approach



Test	Three-point bending	Izod impact	Three-point impact
Standard	ASTM D7264	JIS K7100	JIS K7084
Speed	1 mm/min	1.6m/s	3.8 m/s



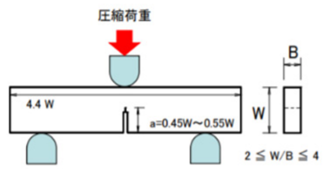


Delamination

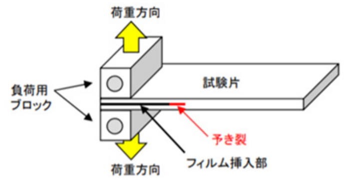
Crack stopper

Theoretical approach

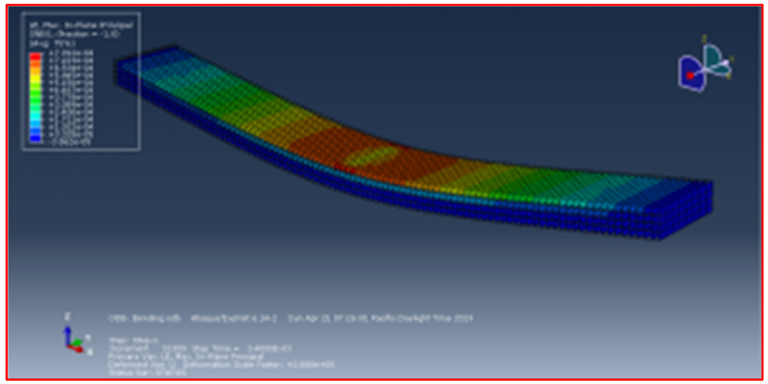
SENB test



DCB test



FEA simulation



✔Investigation for the impacts of (stacking sequence, Vf, thickness) on mechanical properties
✔Optimization of design with FEA

Failure analysis of mechanically fastened CFRTP

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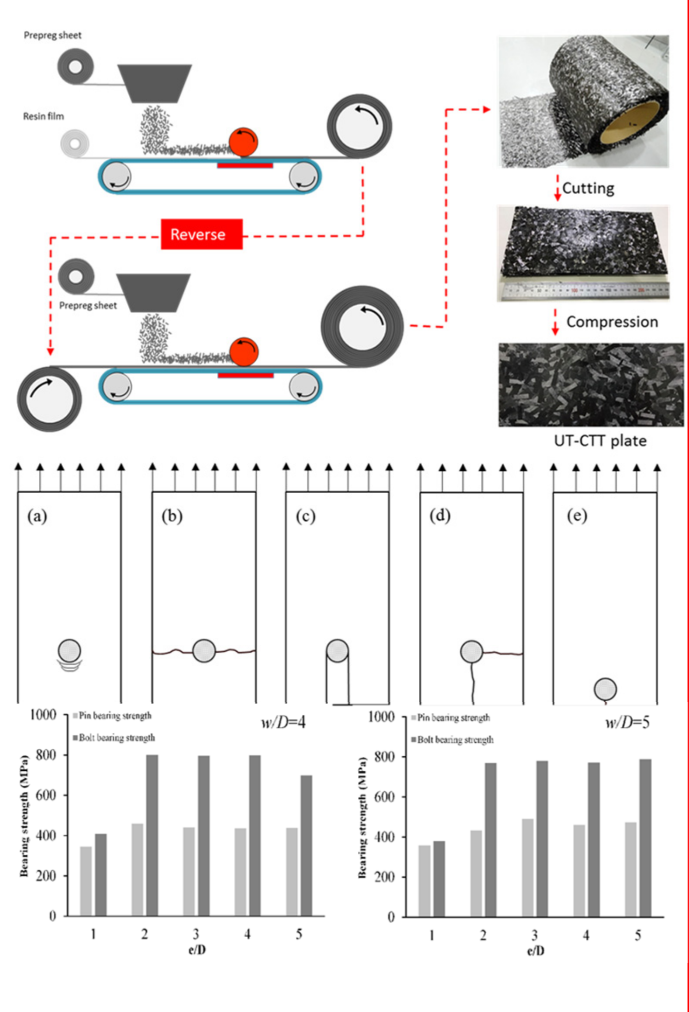
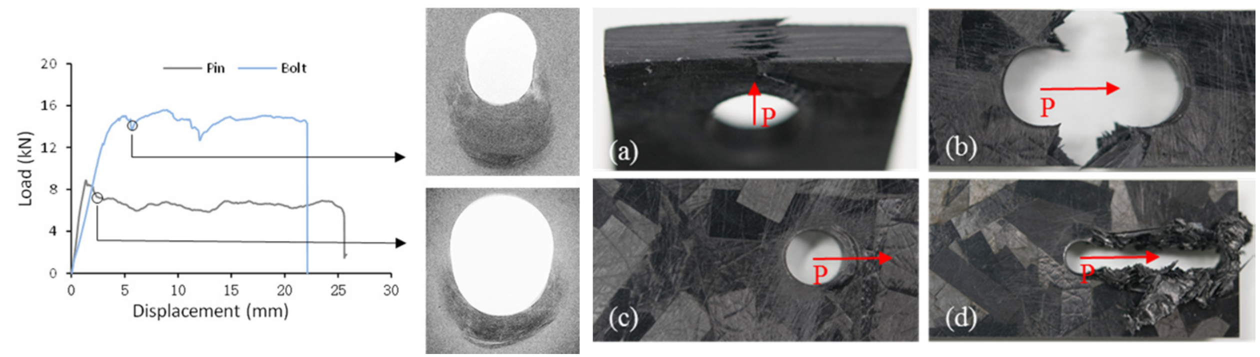
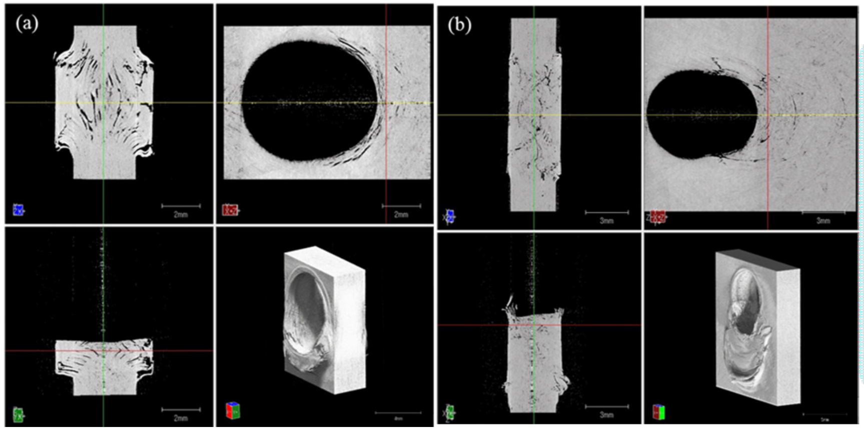
Material fabrication and typical failure of mechanically fastened CFRTP.

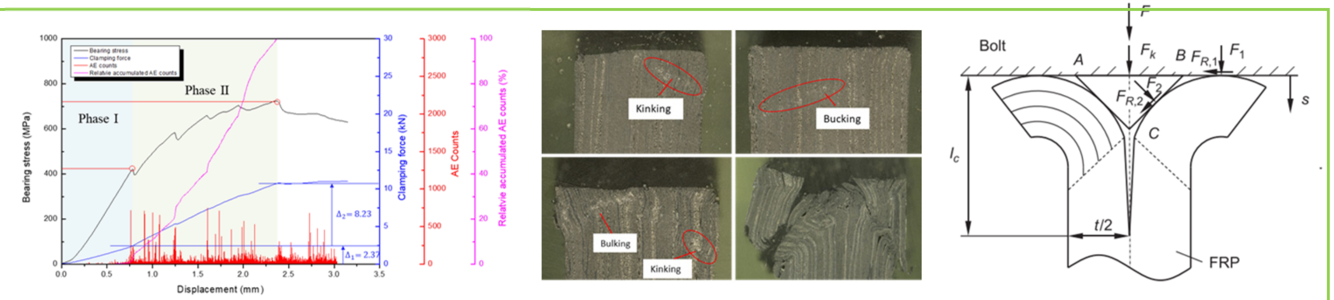






Comprehensive 3D X-ray CT observation and failure analysis

Failure mechanism characterization



Comprehensive analysis of failure process of mechanically fastened CFRTP

(For basic researches and industrial applications)

Preload relaxation in bolted carbon fiber reinforced thermoplastics joints

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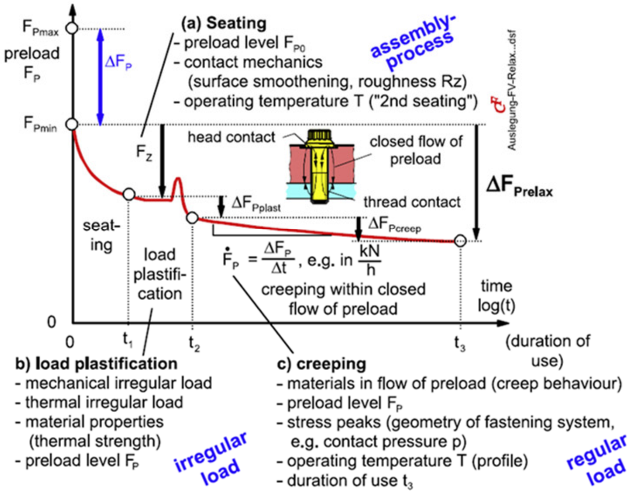
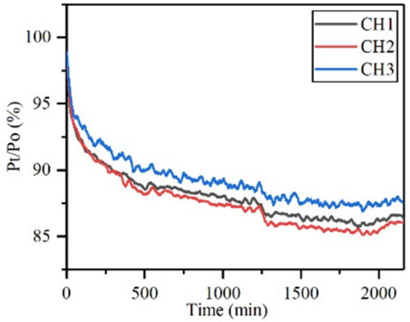
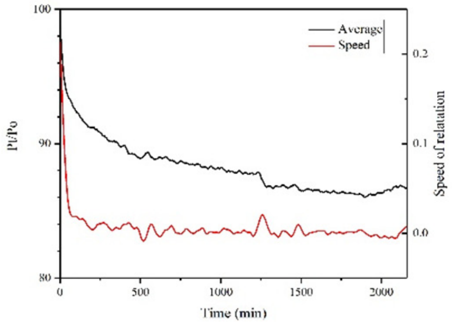
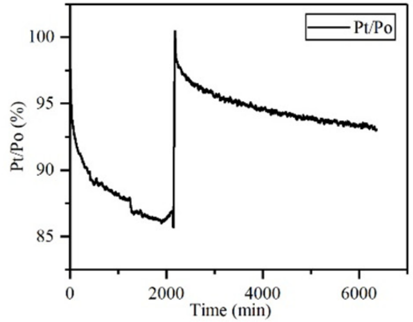


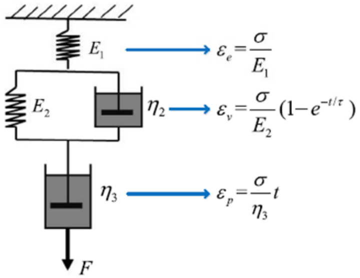
- Bolted structure and preload relaxation behavior [1]







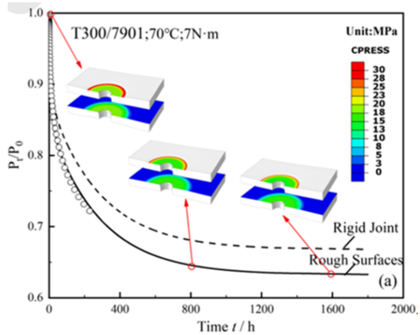
- **Influence of different factors (preload, temperature, humidity etc.)**



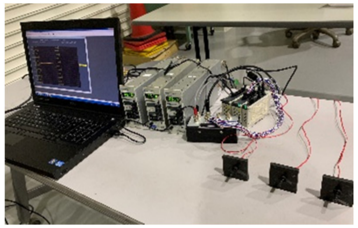
$$\frac{P_t}{P_0} = \frac{1}{1 + K_1 \cdot t^n}$$

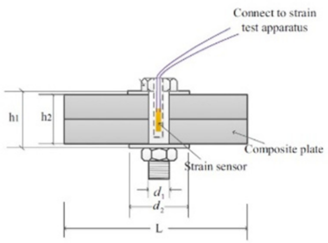
$$P_t = P_0 \cdot (1+t)^{-\alpha}$$

$$P_t = \beta \cdot P_0 \cdot (1+t)^{-\alpha}$$



- **Numerical and FEM simulation [2] (prediction and evaluation)**





- **Testing setup**

Improve the long-term durability

[1] Friedrich, C., and H. Hubbertz. "Friction behavior and preload relaxation of fastening systems with composite structures." Composite Structures 110 (2014): 335-341.
[2]Xie, Yuanhong, et al. "Influence of creep on preload relaxation of bolted composite joints: Modeling and numerical simulation." Composite Structures (2020): 112332.

Effects of environmental factors on CFRTP

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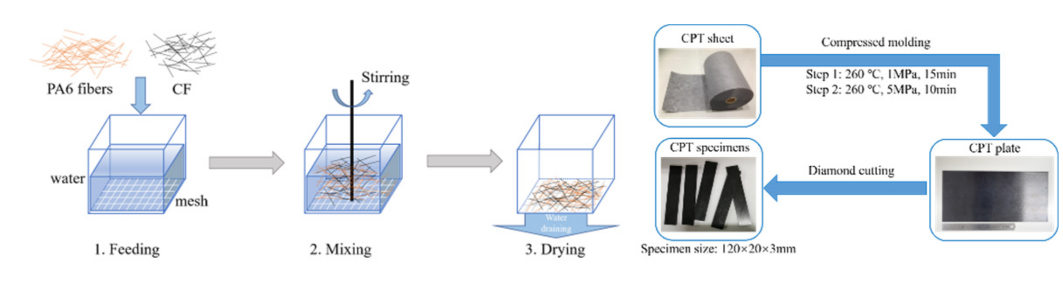
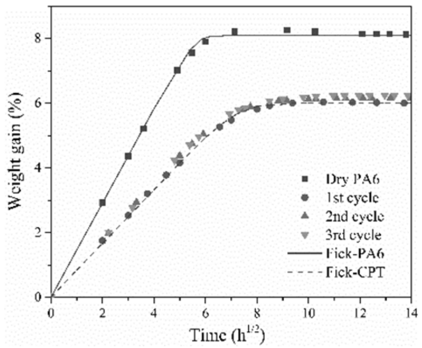
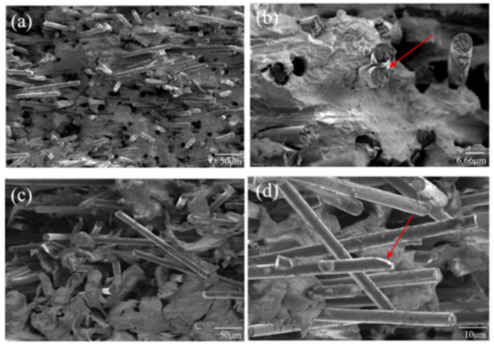
Environmental factors will accelerate the aging of plastics, leading to performance degradation of CFRTP.

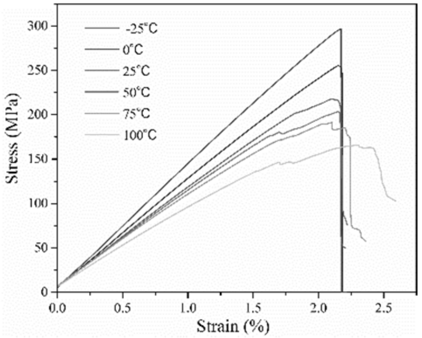


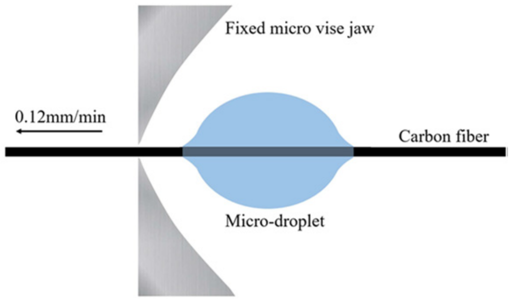
Water absorption and cyclic moisture absorption-desorption analysis of CPT

- Water absorption process of CPT in fresh and sea water
- Cyclic absorption-desorption process
- Flexural properties analysis
- Interfacial shear strength analysis

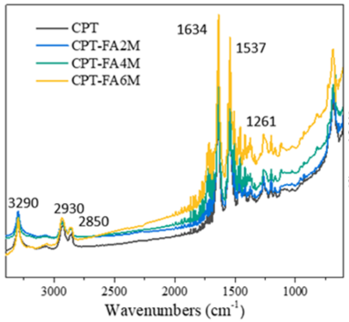


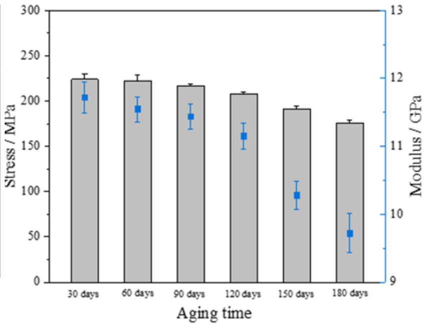


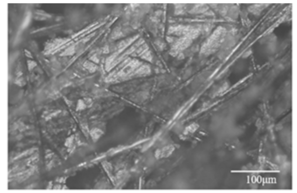


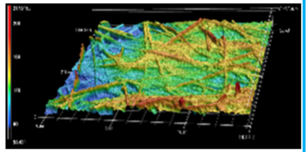


Performance analysis of CPT after long-term aging



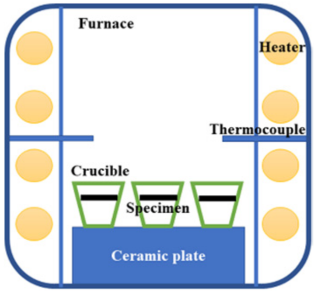


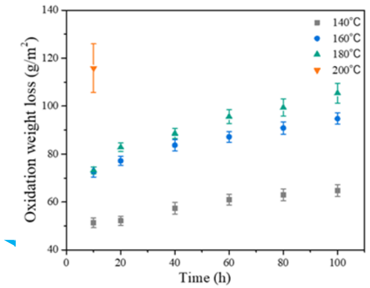


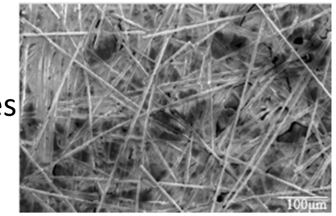


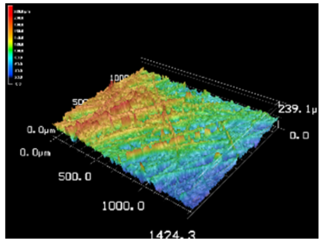
Analysis of CPT after thermo-oxidized aging

- Thermo-oxidized aging in different temperatures
- Flexural properties and morphology









The performance of CFRTP in moisture, sea water, hydrothermal environment, thermo-oxidation has been confirmed. The application of this material in marine field and fire-fighting field is expected.

Evaluate the performance of CFRTP in different environment

(material researches & industrial applications)

Effect of Water on the Mechanical Properties of CTT

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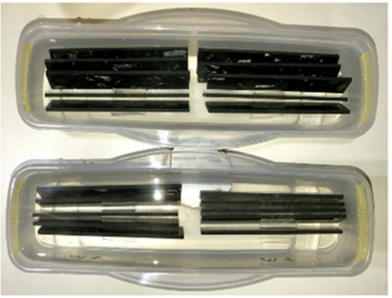
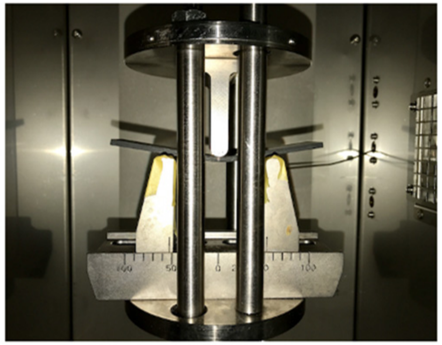
Usage of CFRTP

70℃ water

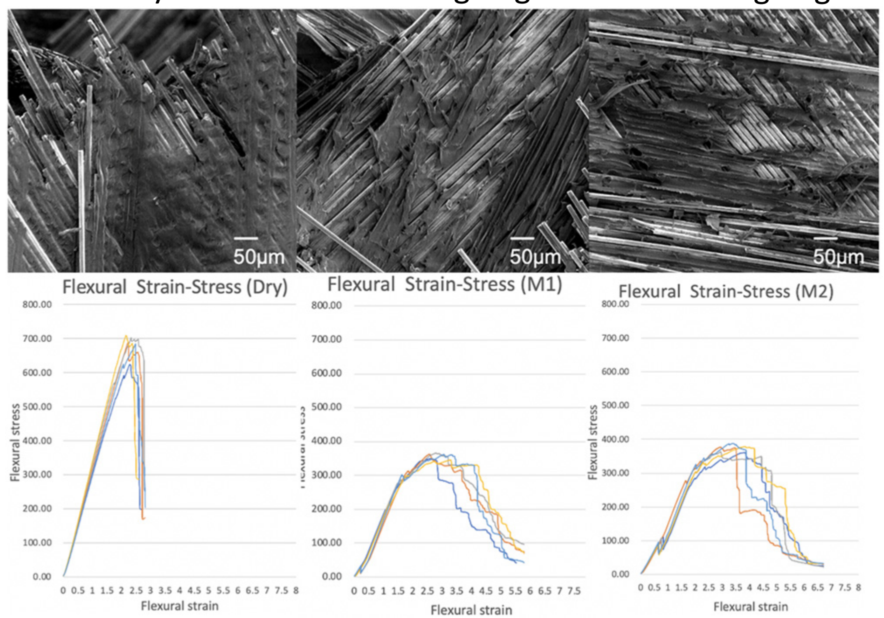




- Three-point bending test
- DSC Test
- SEM

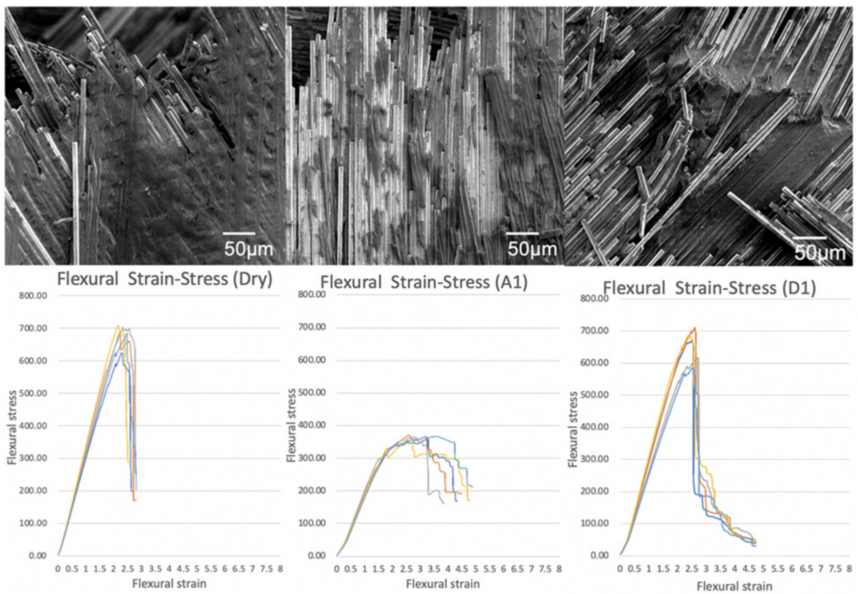
Long-term water aging of UT-CTT

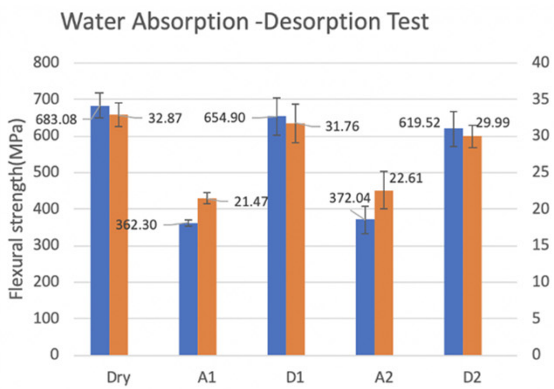
Dry ⟹ 1-month ageing ⟹ 2 months ageing ⟹ …

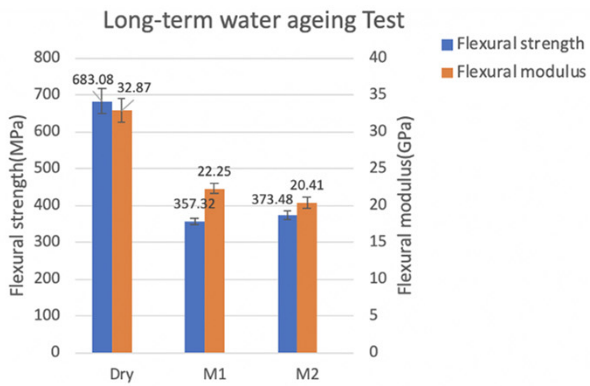


Cyclic water absorption-desorption test

Dry ⟹ Absorbed water ⟹ Desorbed water







Find out why mechanical properties of samples saturated with water drop down severely