Inversing spatial modulus distribution of CFRTP by a vibrational method and its hydrothermal aging application

1305

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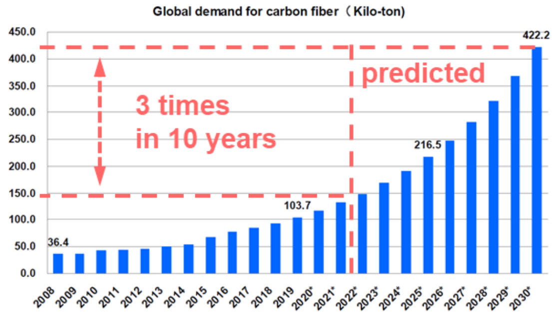
CONTENT

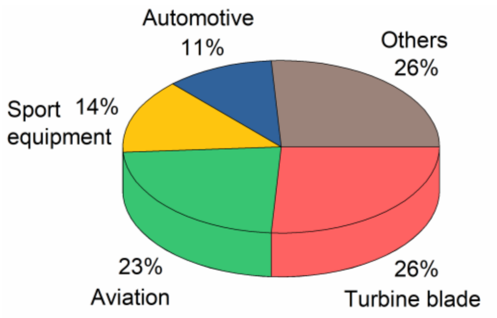
Introduction

Clean energy
&
Reduce pollution

Sustainable Development Goals

Carbon Fiber Reinforced ThermoPlastic





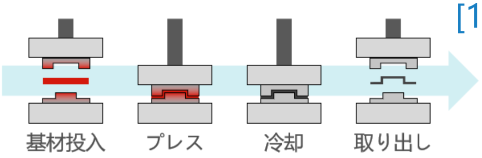
Automotive back door

Offshore wind turbine

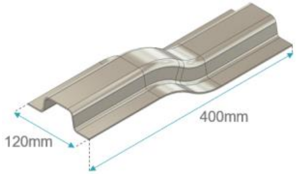
[1] https://www.plasticstoday.com/automotive-and-mobility/smc-adopted-rear-door-frame-toyotas-new-prius-phv
[2] https://finance.sina.com.cn/chanjing/cyxw/2020-06-19/doc-iirczymk7818106.shtml

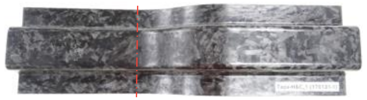
Introduction

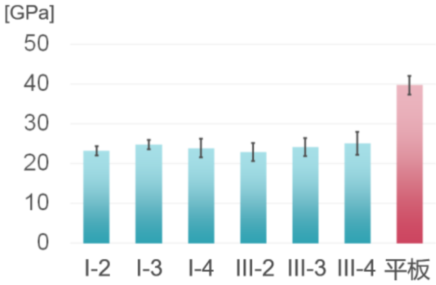
➢ Problem – uncertain material properties



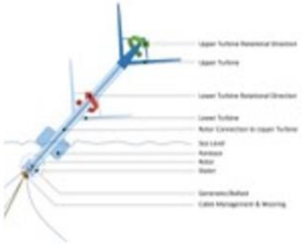
[1]



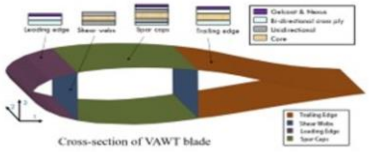




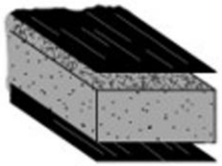
- Modulus distribution become uncertain after molding process for complex-shape SMC structures.
- Modulus measured based on SMC plate cannot be used for CAE of complex-shape SMC structures directly.



[2]



[3]

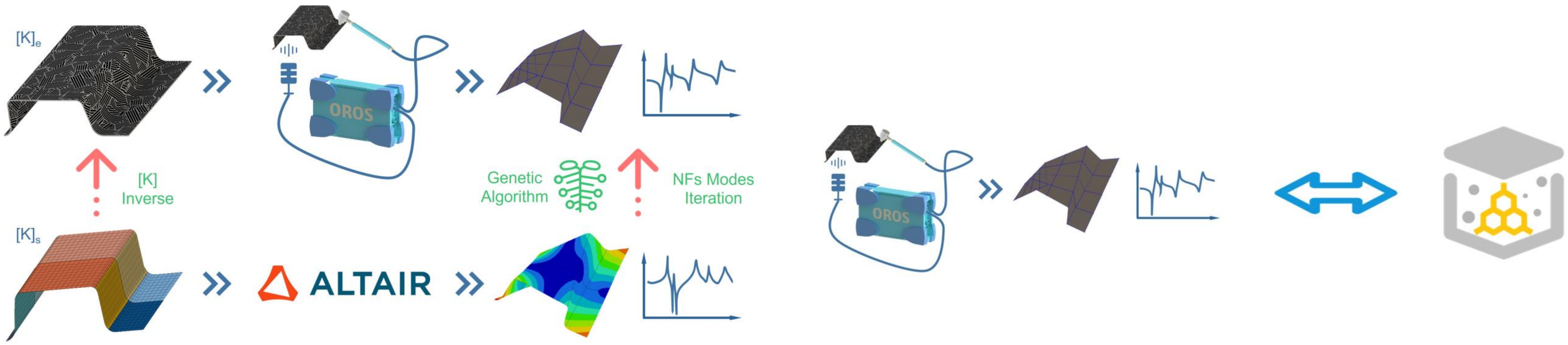


- Hydrothermal aging from small salt powder, sunlight irradiation, humidity and spray of sea water.
- The mat material from recovered carbon fiber can be used as core of the sandwich materials to ensure the economic benefits.

[1] Yuto Nakashima. Master Thesis. The university of Tokyo. 2018.
[2] https://byteclicks.com/41010.html
[3] P. Xue. JSCM 47. September, 2022.

Introduction

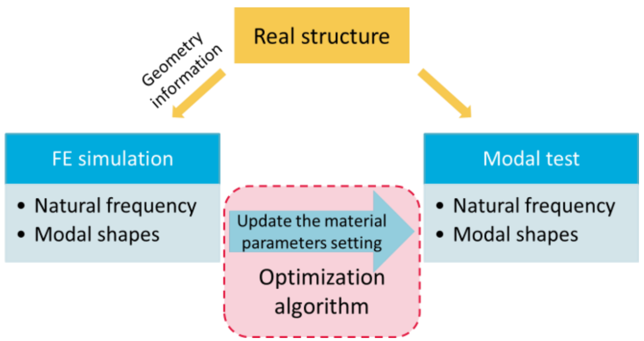
➢ Research objectives



- Obtain detailed special distribution of modulus of CFRTP composites;
- Monitoring the aging process of components by non-destructive vibrational method.

Accuracy comparison

Modulus spatial distribution ⇄ Vibration natural frequencies



Simulation object:[1]

$$\mathrm{Obj} = \mathrm{Min} \sum_{i=1}^{N} \mathrm{abs}\left(\frac{f_i^s(X) - f_i^e}{f_i^e}\right)$$

f_i^s: Simulated frequencies

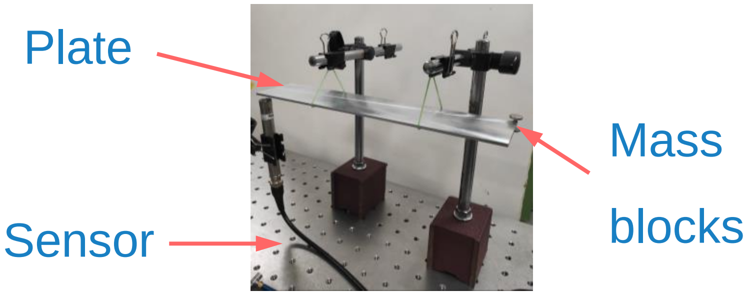
f_i^e: Experimental frequencies

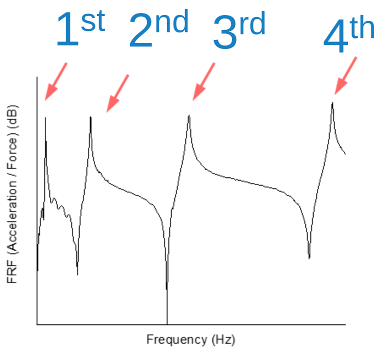
Genetic algorithm:

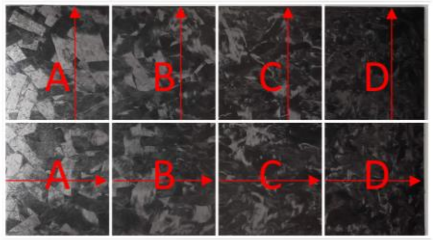
$$\left|F^k - F^{k-10}\right| \leq 0.001$$

Advantages in identifying modulus:

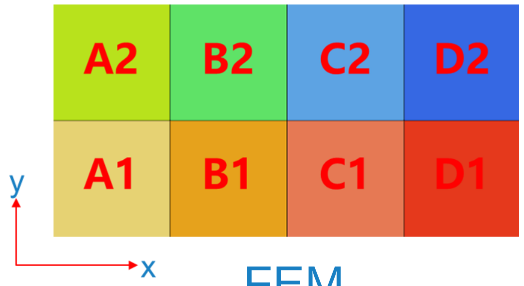
- Non-destructive.
- Fewer requirements on geometric shapes.
- Obtain parameters based on one specimen.







CFRTP

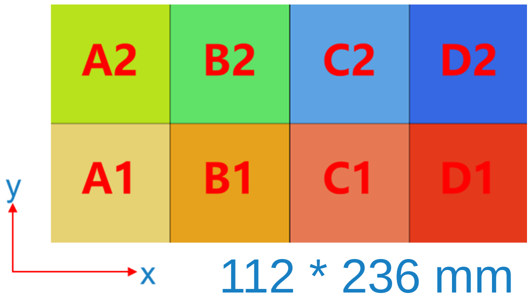


FEM

[1] Ye Zhang. Doctoral Thesis. The University of Tokyo. 2021.

Accuracy comparison

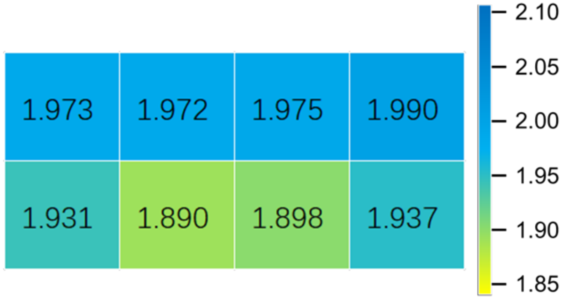
➢ Numerical simulation



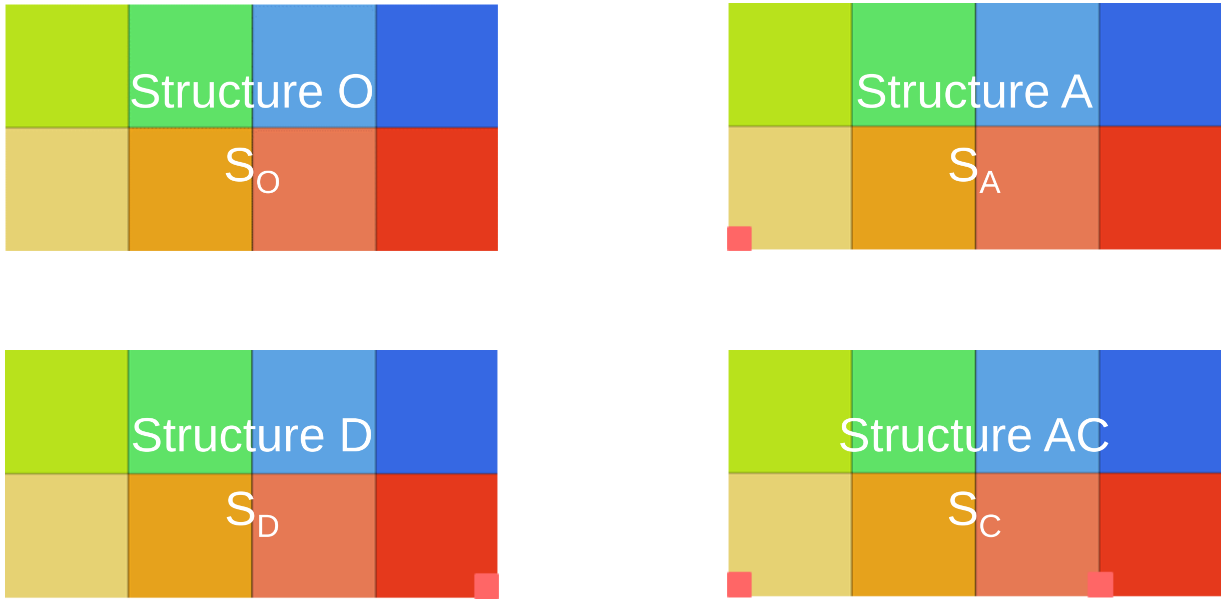
112 * 236 mm

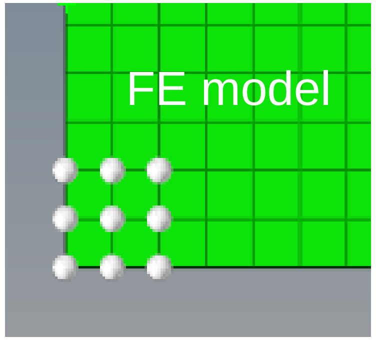
		A	B	C	D
Ex	1	59	46	53	40
	2	53	52	47	34
Ey	1	27	28	28	31
	2	31	24	32	35
Gxy	1	12	13.5	14	15.5
	2	12.5	13	14.5	15

Randomly initial modulus distribution



Thickness distribution





Order	S_O	S_A	S_D	S_C
1	166	154	151	127
2	210	198	194	199
3	493	402	401	366
4	806	481	488	456
5	845	684	687	613
6	928	810	806	787

Accuracy comparison

➤ Numerical simulation

S_O

Worst		A	B	C	D
Ex	1	26.1	38.7	59.7	51.8
	2	52	48.9	54.3	46.5
Ey	1	33.7	25.8	24.9	45.6
	2	22.8	35	24.9	27.5
Gxy	1	14	11.8	15.9	16.2
	2	12.2	12.7	13.9	12.6

S_A

Worst		A	B	C	D
Ex	1	37.9	55.2	50.8	30.6
	2	49.9	46.2	52.3	41
Ey	1	41.1	33.8	50.6	22
	2	21.8	38.5	26.7	38.3
Gxy	1	16.3	12.9	14.9	13.5
	2	13.6	8.9	17.3	11

S_D

Worst		A	B	C	D
Ex	1	57.8	39.6	49.3	43.5
	2	36	53.4	53.3	44.7
Ey	1	28.5	38.9	36.5	36.6
	2	21.8	23.6	38.7	25.6
Gxy	1	14.9	7.6	17	13.3
	2	15.8	15.2	13.7	15.3

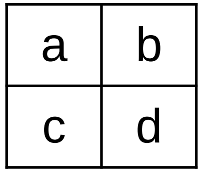
S_C

Worst		A	B	C	D
Ex	1	24.6	55.1	49	37.9
	2	28.1	56.2	54	53.3
Ey	1	40	39.8	45.7	51.6
	2	24.2	44.6	31.8	28.7
Gxy	1	15.1	9.8	11.9	11
	2	13.1	15.1	14.2	12.8

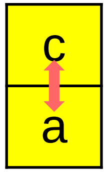
Target:

		A	B	C	D
Ex	1	59	46	53	40
	2	53	52	47	34
Ey	1	27	28	28	31
	2	31	24	32	35
Gxy	1	12	13.5	14	15.5
	2	12.5	13	14.5	15

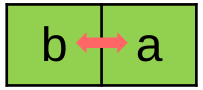
Problems: Poor accuracy and disorder



Correct order

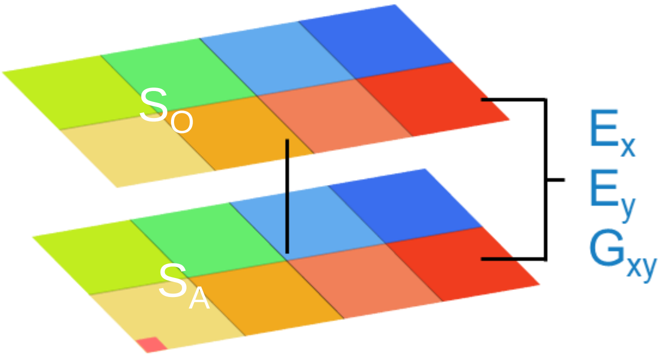


Upside down



Left and right

Strategy: Integrating and re-search



Accuracy comparison

➢ Numerical simulation

Worst		A	B	C	D
Ex	1	49.5	47.4	46.6	43.4
	2	45.6	55.6	49.1	35.8
Ey	1	27.9	29	35.3	26.9
	2	28.1	26.4	29.3	37.7
Gxy	1	11.4	14.6	11.6	16.8
	2	12.5	12.5	15.7	14.4

		A	B	C	D
Ex	1	14.75%	0.65%	11.13%	0.50%
	2	16.42%	2.88%	12.98%	13.82%
Ey	1	4.81%	8.93%	8.93%	7.10%
	2	7.42%	27.08%	7.50%	7.14%
Gxy	1	14.17%	4.00%	10.71%	9.03%
	2	0.00%	0.77%	10.34%	6.00%

Worst		A	B	C	D
Ex	1	50.3	45.7	47.1	40.2
	2	44.3	53.5	53.1	38.7
Ey	1	28.3	25.5	30.5	33.2
	2	28.7	30.5	29.6	32.5
Gxy	1	13.7	13	12.5	14.1
	2	12.5	12.9	16	14.1

		A	B	C	D
Ex	1	16.10%	3.04%	12.08%	8.50%
	2	13.96%	6.92%	4.47%	5.29%
Ey	1	3.33%	3.57%	26.07%	13.23%
	2	9.35%	10.00%	8.44%	7.71%
Gxy	1	5.00%	16.80%	17.14%	8.39%
	2	0.00%	3.85%	8.28%	4.00%

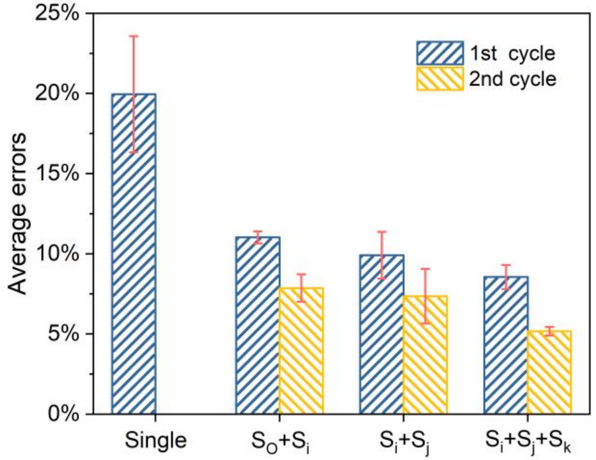
Integrating 3 components

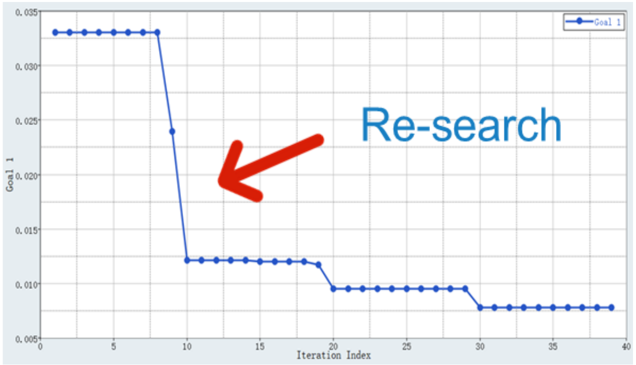
		A	B	C	D
Ex	1	16.10%	3.04%	12.08%	8.50%
	2	13.96%	6.92%	4.47%	5.29%
Ey	1	3.33%	3.57%	26.07%	13.23%
	2	9.35%	10.00%	8.44%	7.71%
Gxy	1	5.00%	16.80%	17.14%	8.39%
	2	0.00%	3.85%	8.28%	4.00%

$S_O + S_A + S_D$

		A	B	C	D
Ex	1	9.32%	1.96%	0.57%	10.00%
	2	12.83%	0.77%	2.98%	7.06%
Ey	1	2.59%	16.43%	5.71%	5.48%
	2	2.90%	22.50%	5.31%	3.14%
Gxy	1	3.33%	4.00%	2.86%	1.94%
	2	1.60%	6.15%	0.00%	2.00%

Re-search treatment

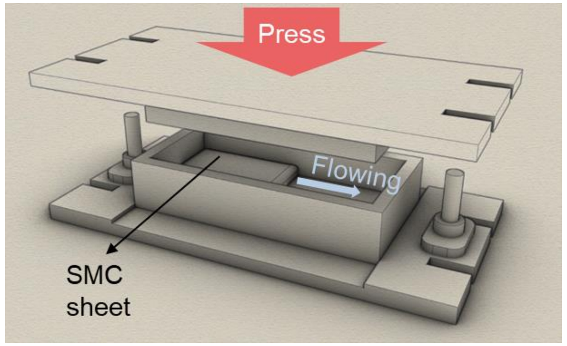




Accuracy comparison

➢ Experiments

SMC pieces size: 125*250 mm



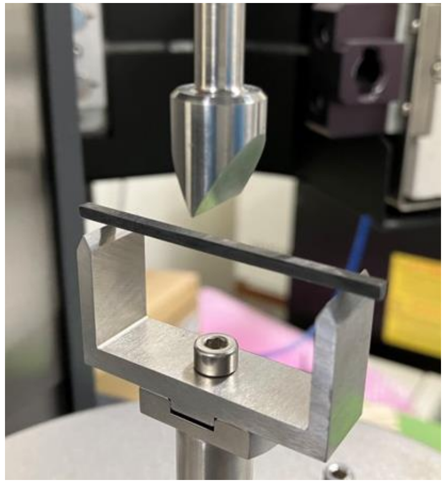
- Resin: PA6
- V_f: 50%
- Tape size: 5 x 19 x 0.044 mm

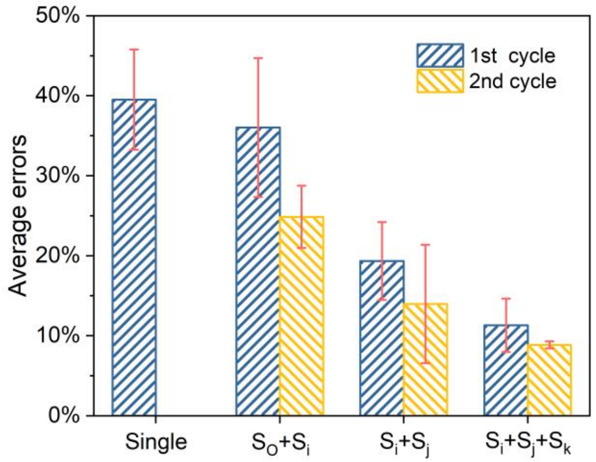
	Part	A	B	C	D
Ex	1	34.13	34.54	33.86	33.79
	2				
Ey	1				
	2	35.26	36.55	37.53	34.33
Gxy	1				
	2				

Tested modulus

	Part	A	B	C	D
Ex	1	60	22	46	60
	Error	75.80%	36.30%	35.26%	77.58%
Ey	2	51	41	54	52
	Error	44.36%	12.18%	44.94%	50.90%

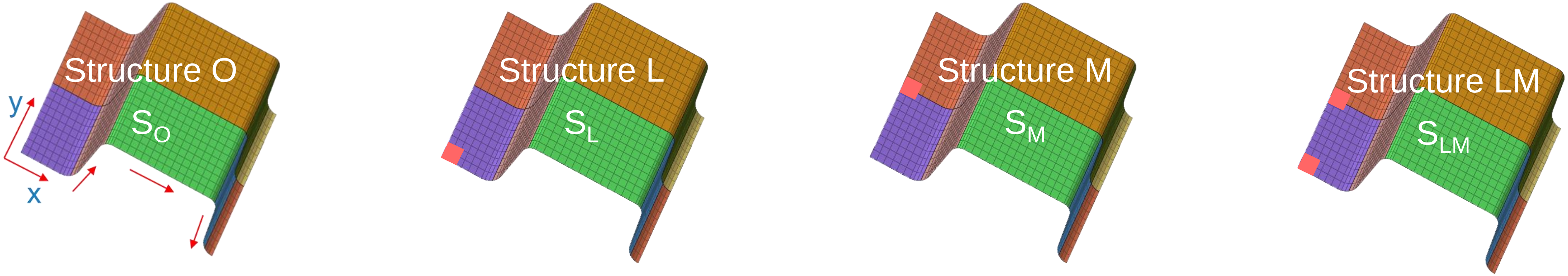
Errors of direct inversing

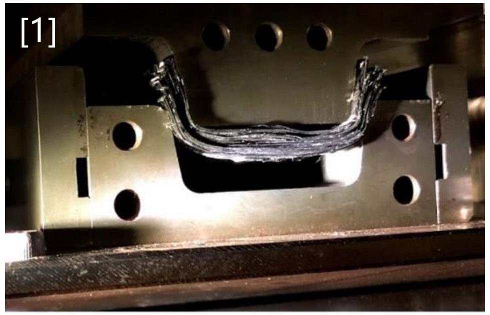




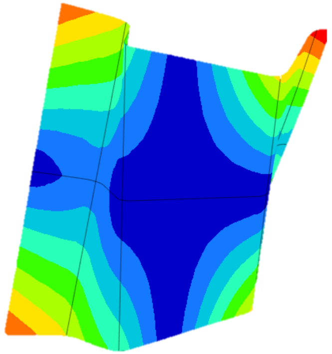
Accuracy comparison

➢ Experiments

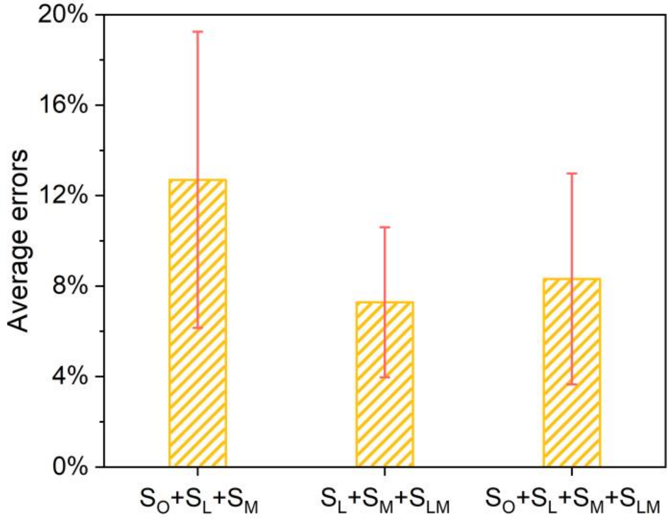




Modeling process



1st vibration mode



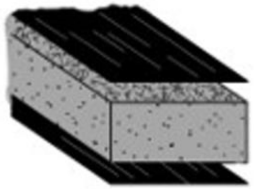
[1] Ye Zhang. Doctoral Thesis. The university of Tokyo. 2021.

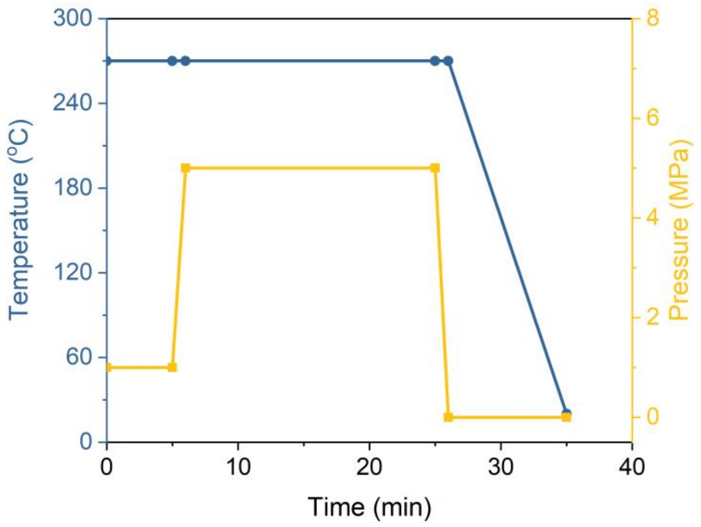
Verification to universal materials

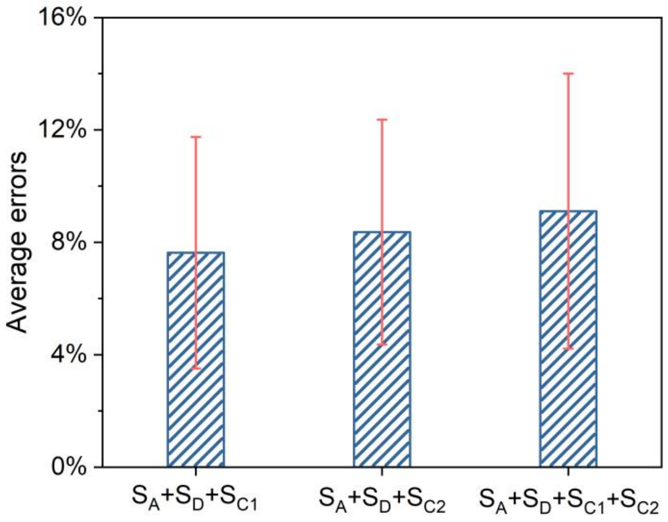
➢ Sandwich

Core: CPT

Skin: UD

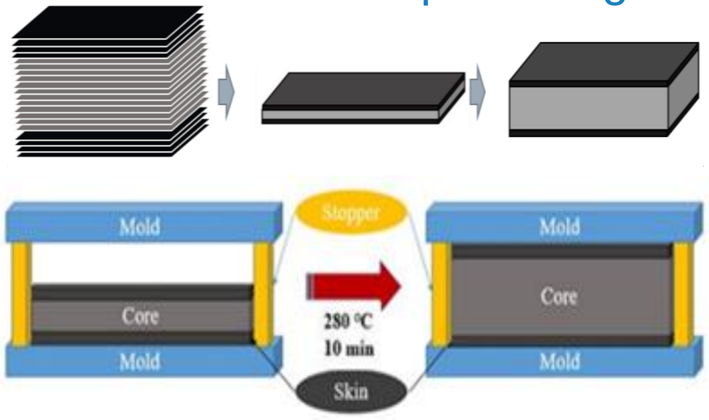






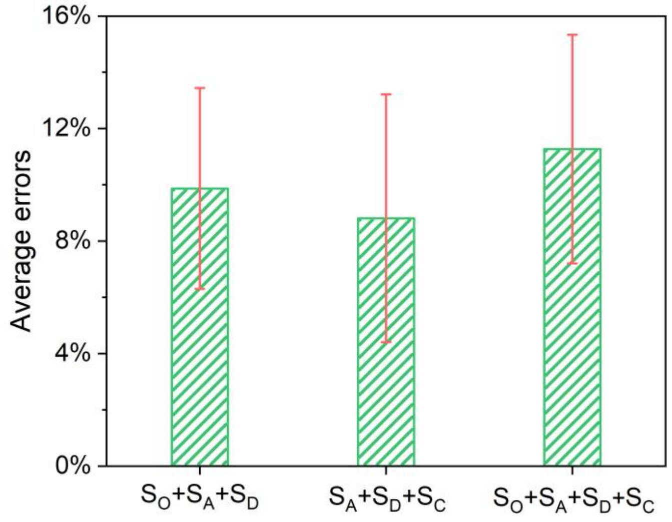
➢ Springback

Two-step molding



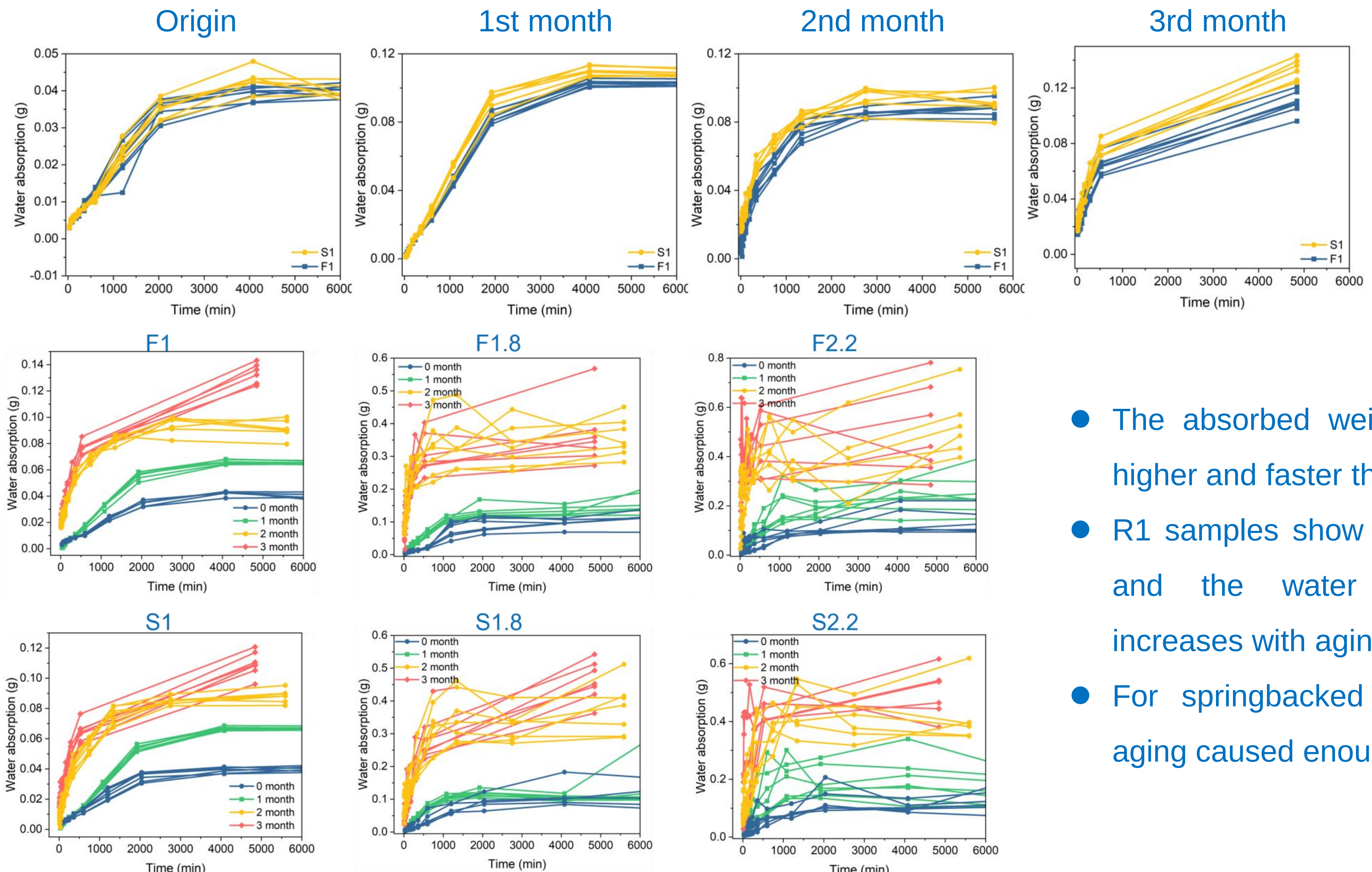
[1]

SB ratio	Thickness (mm)
R1	1.58
R1.8	3.01
R2.2	3.68



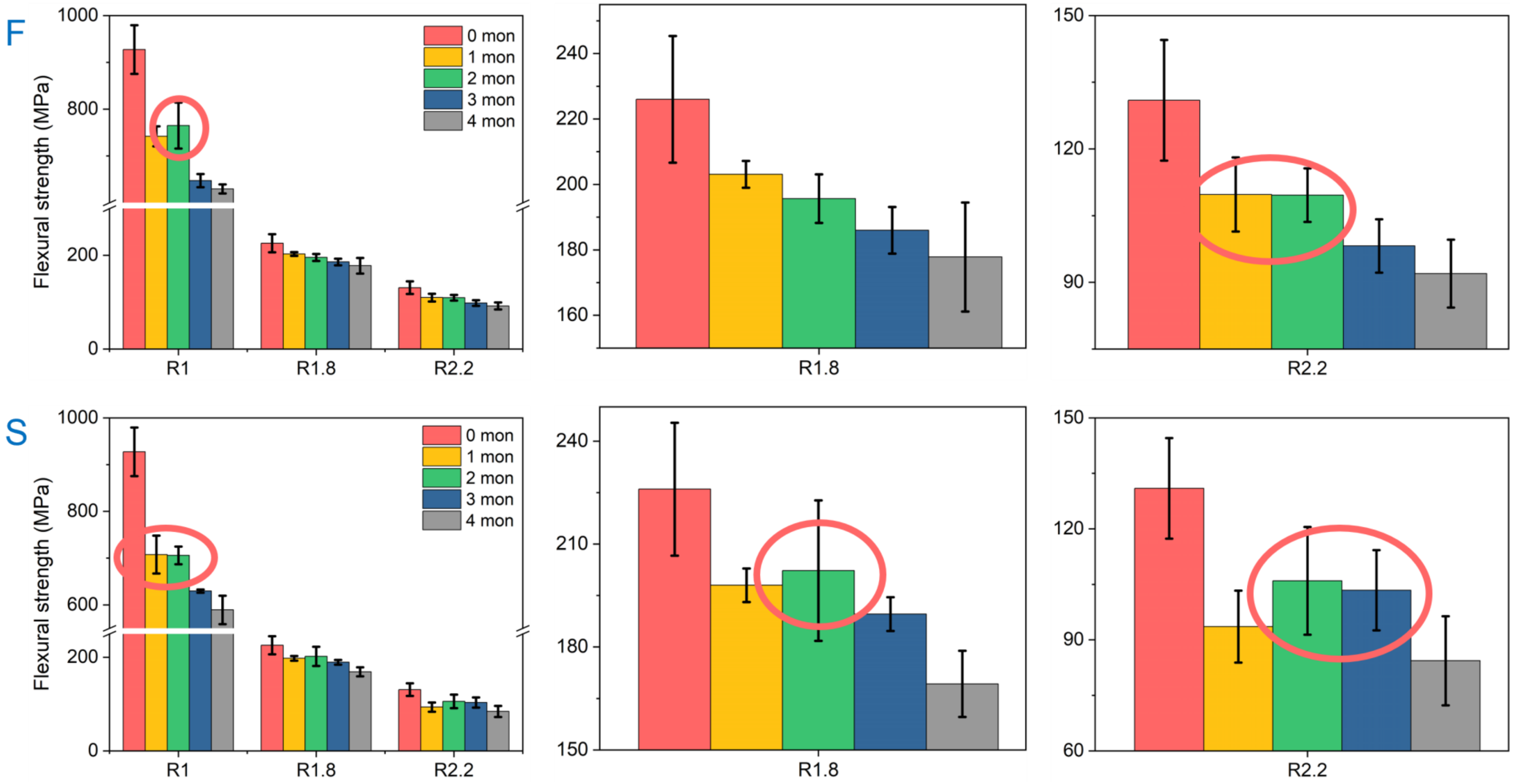
[1] Yunqian Zhang. Doctoral Thesis. The University of Tokyo. 2022.

Hydrothermal aging monitoring



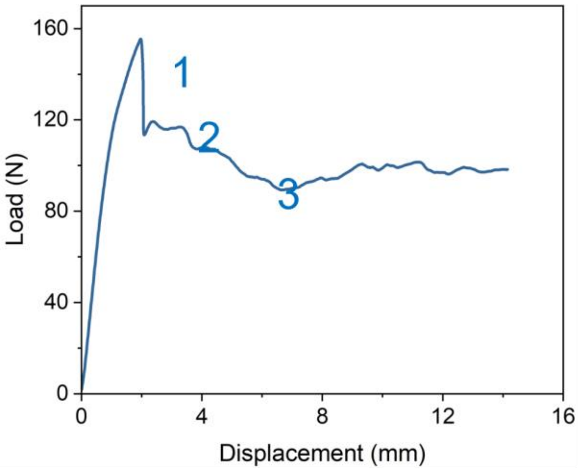
- The absorbed weight of sea water is higher and faster than the fresh water;
- R1 samples show higher concentration and the water absorption speed increases with aging time.
- For springbacked samples, long-time aging caused enough influence.

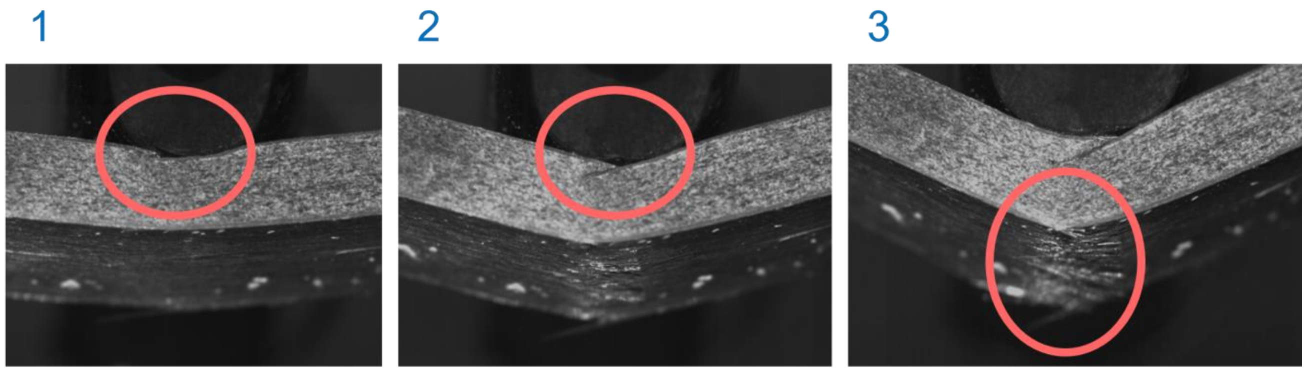
Hydrothermal aging monitoring



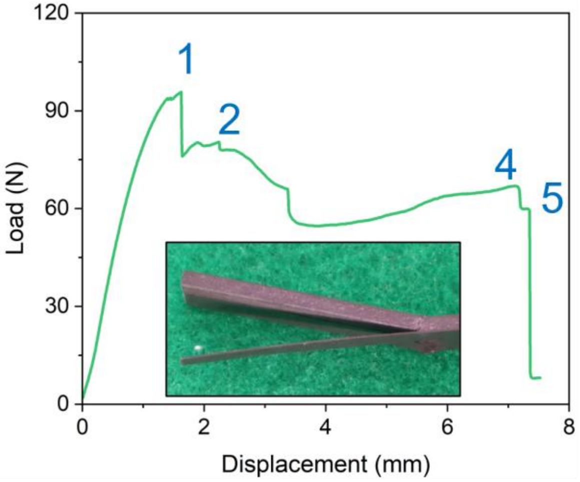
- The strength generally decrease with the aging time, and the reduction ratio of the first month is the highest.
- Abnormal values exist, resulting from the scatter of the composites.

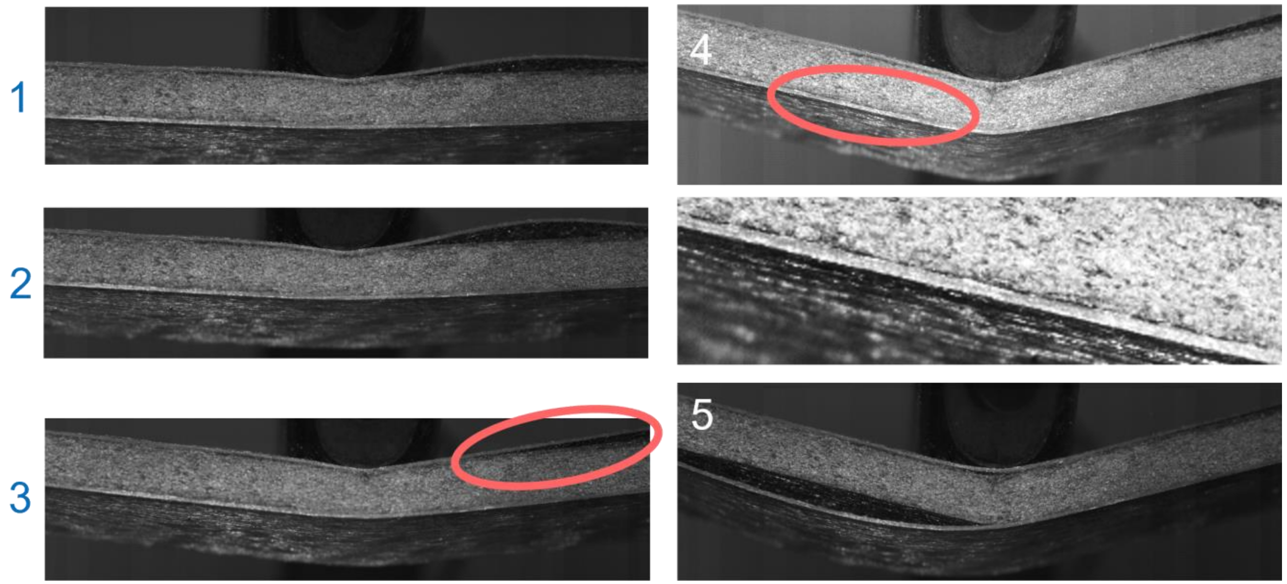
Hydrothermal aging monitoring





4 month S2.2 Specimen 1



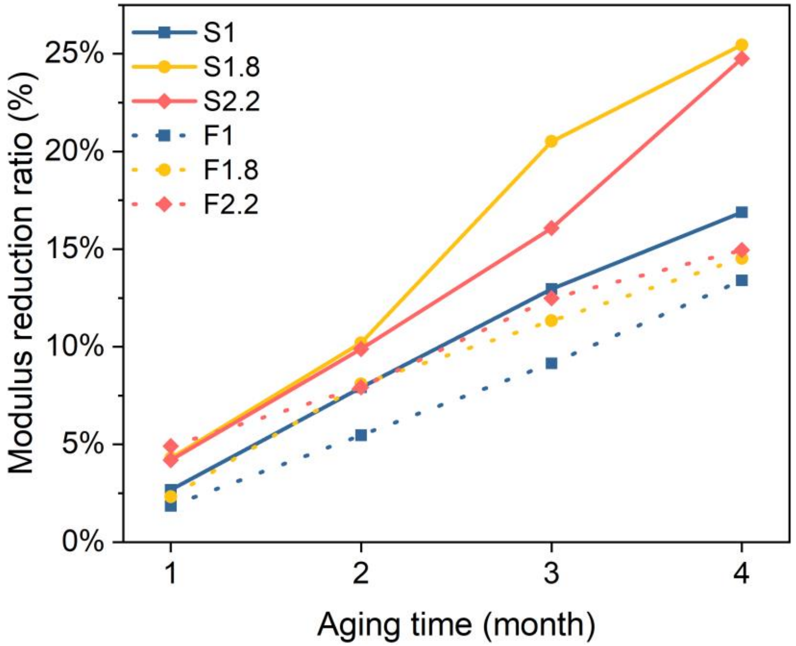


4 month S2.2 Specimen 3

Hydrothermal aging monitoring

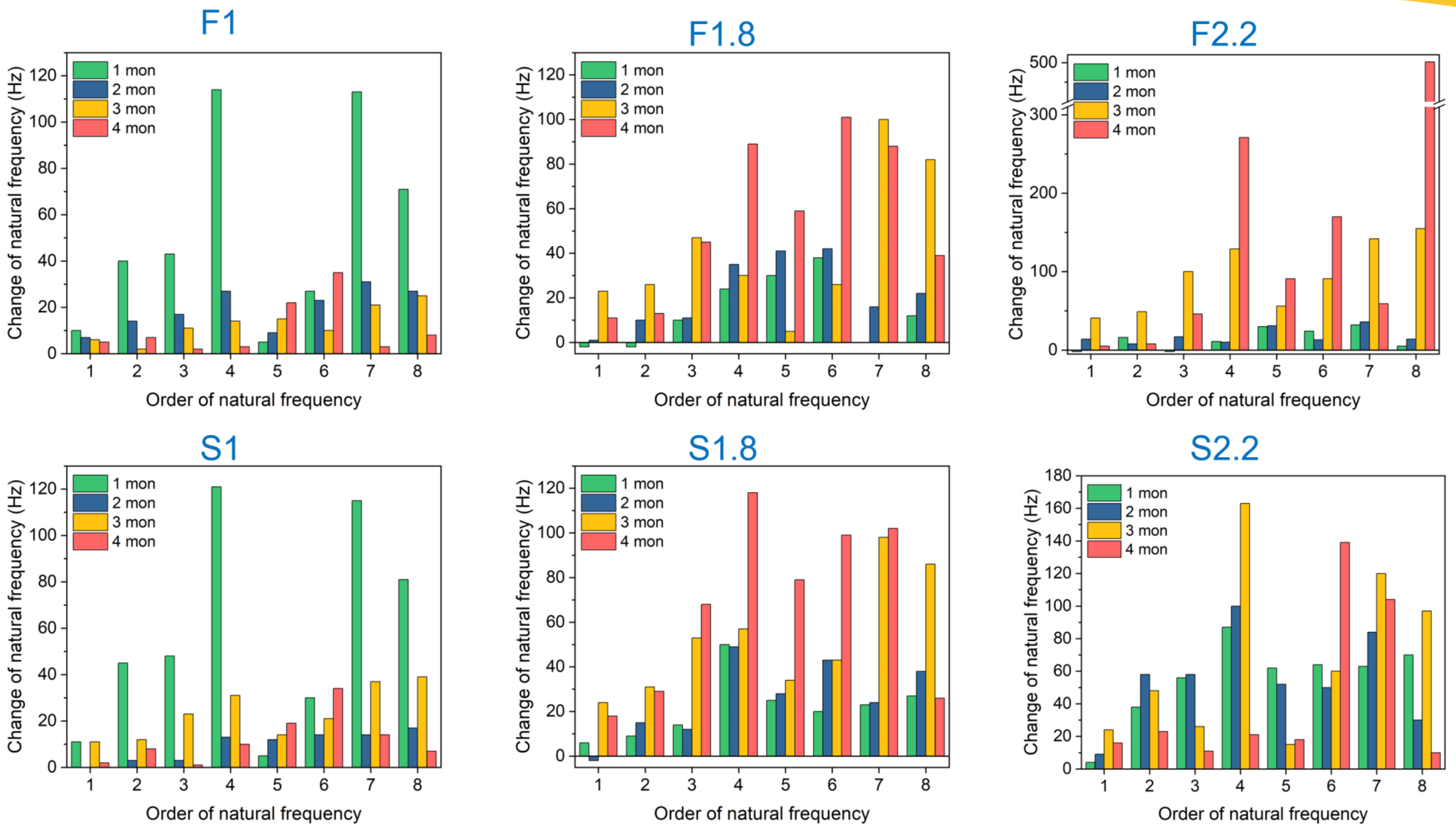
Sea	0	1	2	3	4
R1	0	0	0	0	0.5
R1.5	0	0	0	0	2
R2	0	0	1	1	3

Fresh	0	1	2	3	4
R1	0	0	0	0	1
R1.5	0	0	0	0.5	1.5
R2	0	0	2	3	4



- With aging time and springback ratio increasing, more delamination-caused fracture occurs.
- The influence of sea water is severer on both delamination and mechanical properties..
- The modulus reduction ratio shows the similar trend with the strength.
- The modulus reduction of R1.8 and R2.2 is difficult to be distinguished.

Hydrothermal aging monitoring



- The variation in higher orders was more apparent, which is consistent with FEM.
- Sea water aging environment cause higher reduction in natural frequencies.

Summary and future tasks

➢ Summary

- The vibrational method can inverse the spatial modulus distribution with a limited error;
- The natural frequencies reflects the reduction of mechanical properties after long-time aging;
- This non-destructive vibrational method could be applied for the aging monitoring of CFRTP materials.

➢ Future tasks

- Apply the method to the serving environment of automotive and offshore wind turbines, including fatigue, artificial defects and thermo-oxidative aging.

Acknowledgement

- The authors would like to thank the Industrial Technology Center of Fukui Prefecture for providing the materials used in this study.

- The authors also would like to thank the WINGS-CFS of the University of Tokyo for the supporting.

Presentations from Takahashi-Wan lab

Name	Date	Venue	Room	Title
Zhiyu WANG	Mon	Process modelling - S1	Studio	A state-based peridynamic model for progressive damage analysis of CFRTP-SMC base
Peng XUE	Mon	Structural analysis and optimization - S2	3B	Optimization of floating vertical axis wind turbine structures using recycled carbon fiber reinforced thermoplastic
Xiaohang TONG	Tue	Mechanics of composites - S2	3A	The influence of tape geometry on the mechanical performance of bolted CFRTP-SMC joints
Zihao ZHAO	Tue	Liquid composites moulding - S2	2A	Simulation of fiber orientation during compression molding process of CFRTP-SMC
Ruochen XU	Wed	Multiscale modelling - S5	Studio	Morphology analysis and shape optimal of CFRTP-SMC based on Monte-Carlo simulation
Qian GAO	Wed	Recycling and sustainability - S3	1B	Prediction of strength and its variation of carbon fiber mat reinforced thermoplastics using Monte-Carlo method
Weizhao HUANG	Thu	Structural health monitoring - S1	Arc	Inversing spatial modulus distribution of cfrtp by a vibrational method and its hydrothermal aging application

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INNOVATION

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