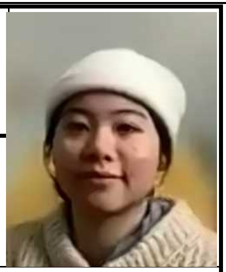
2-6. Internship Researchers

No.	Name	Project Title / Period
2-6-1	**Qun CHEN** Zhengzhou University (China)	Effect of steel fiber volume fraction and repeated loading on flexural behavior of ultra-high-performance concrete beams reinforced with CFRP bars December 21, 2022- January 20, 2023 (Online only)
2-6-2	**Rahmat HIDAYAT** Politeknik Negeri Lampung (Indonesia)	Flow-based photodecomposition system for radioactive metal purification November 25, 2022- January 31, 2023 (Onsite: December 5, 2022- January 25, 2023)
2-6-3	**Hsiu-Chin HUANG** National Kaohsiung of Science and Technology (Taiwan)	Application of silk fibroin as medical materials シルクフィブロインの医療応用に関する研究 November 29, 2022- January 27, 2023 (Onsite: January 5, 2023- January 18, 2023)
-	**Zhe ZHANG** Shandong University of Science and Technology (China)	(The 1st Term) December 6, 2022 – December 7, 2022 (The 2nd Term) Postponed to FY2023*
-	**Yang ZHAO** Shandong University of Science and Technology (China)	(The 1st Term) December 6, 2022 – December 7, 2022 (The 2nd Term) Postponed to FY2023*

*The 2nd term scheduled in March has been postponed to FY2023 due to unavoidable reasons. Therefore, their final reports will be posted in “Annual Report for FY2023”.

<table>
<tr><td>No.6-1</td><td colspan="3">Effect of steel fiber volume fraction and repeated loading on flexural behavior of ultra-high-performance concrete beams reinforced with CFRP bars.</td><td rowspan="2"></td></tr>
<tr><td>Name</td><td>Qun CHEN</td><td>Title</td><td>Graduate student</td></tr>
<tr><td>Affiliation</td><td colspan="4">Zhengzhou University (China)
Email: chenqun9958@163.com</td></tr>
<tr><td>Research Field</td><td colspan="4">Concrete Structure</td></tr>
<tr><td>Period of Internship</td><td colspan="4">December 21, 2022 to January 20, 2023 (Online only)</td></tr>
<tr><td>Host Professor</td><td>Gaochuang CAI</td><td>Title</td><td colspan="2">Associate Professor</td></tr>
<tr><td>Affiliation</td><td colspan="4">IROAST
Email: cai@kumamoto-u.ac.jp</td></tr>
</table>

1. Details of activities

The IROAST research internship program provided me with a great chance to gain more experience in researching the **effects of steel fiber volume fraction and repeated loading on the flexural behavior of ultra-high-performance concrete beams reinforced with CFRP bars.**

1.1. Background

The corrosion of steel reinforcements has always been one of the stubborn problems faced by global engineering consultants, which has seriously shortened the life cycle of public and civil buildings. Recently, offshore structures such as drilling platforms, ports, and wharves were easily damaged by seawater, which made the structures unable to meet the design requirements. To alleviate the steel corrosion problem, the technology of using fiber-reinforced polymer (FRP) bars instead of steel reinforcements in ordinary concrete (OC) structures has been adopted by some scholars. Fiber-reinforced polymer (FRP) bars have the advantages of lightweight, high strength, corrosion resistance, low creep, and stable chemical properties. Although FRP bars possess excellent mechanical properties, the FRP bars reinforced ordinary concrete structures do not exhibit good ductility due to their linear elastic brittle behavior. And the deformation and crack of FRP bars reinforced ordinary concrete structures were usually large.

Ultra-high performance concrete (UHPC) was a new cement-based composite material with high durability, high workability and high strength. Therefore, the combination of FRP bars and ultra-high performance concrete (UHPC) can effectively solve the above problems. The design of a cross-section with holes of FRP bars reinforced UHPC beams can not only improve the strength utilization rates of FRP bars but also take full advantage of good ductility and high toughness of UHPC, meanwhile, it also can reduce the weight of the structures and cost of the engineering project.

Based on the above views, five carbon fiber reinforced polymer (CFRP) bars reinforced UHPC beams were subjected to a four-point bending test under repeated loading (Fig.1). During the IROAST online research internship, I completed the analysis of failure mode, load-deflection curves, stiffness degradation, strength degradation and DIC of experiment results, and proposed the formula for calculating the ultimate bearing capacity of the UHPC beams reinforced with CFRP bars under the guidance of Professor Cai. The results of the research project are described in the following sections.

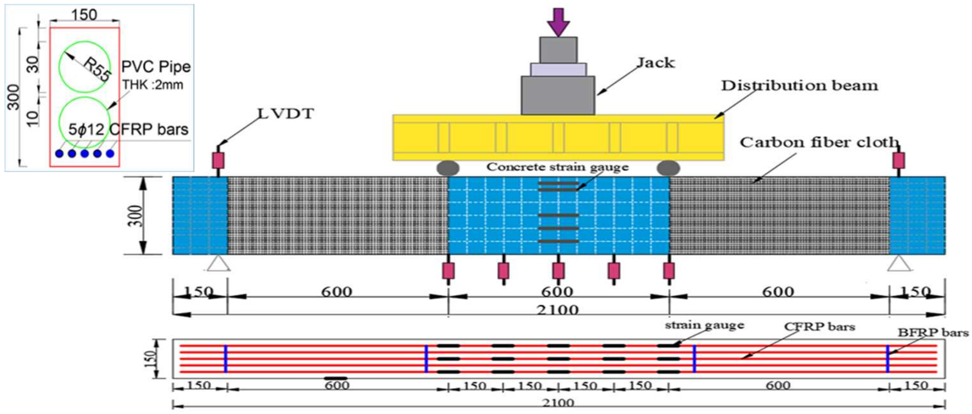
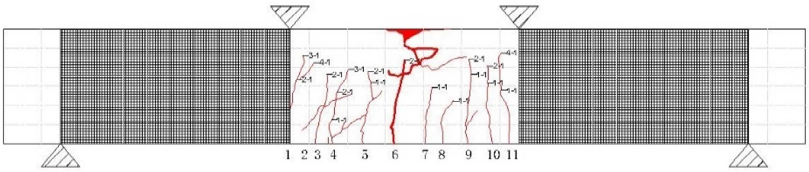
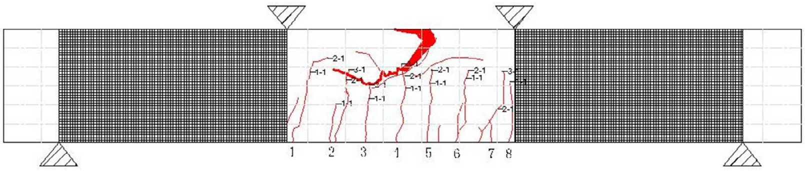


Fig. 1 Cross-section and test method

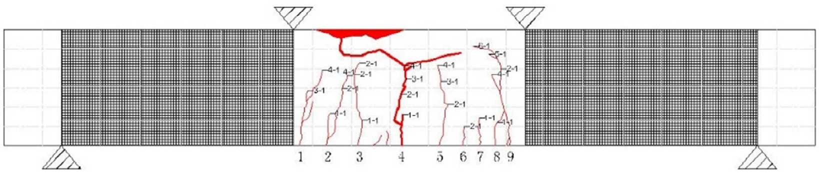
1.2 Failure mode



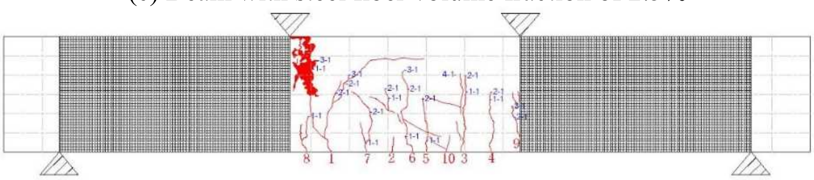
(a) Beam with steel fiber volume fraction of 1.5%



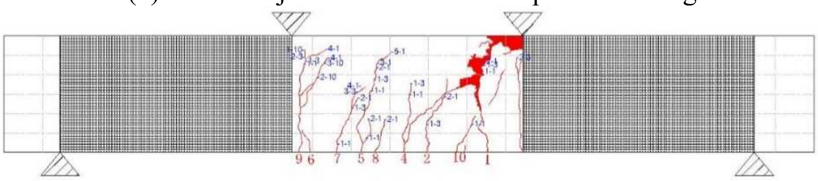
(b) Beam with steel fiber volume fraction of 2.0%



(c) Beam with steel fiber volume fraction of 2.5%



(d) Beam subjected to three times repeated loading



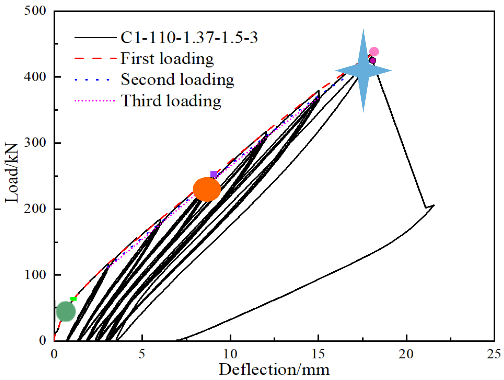
(e) Beam subjected to ten times repeated loading

Fig.2 Crack distribution of beams at failure

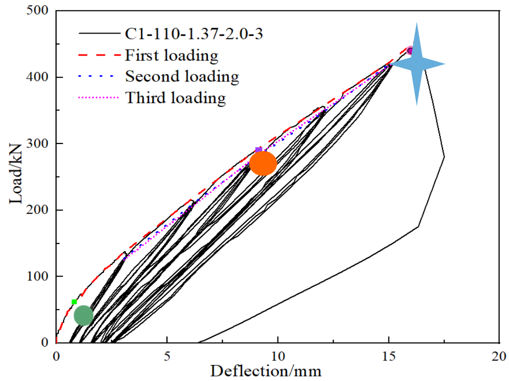
"a-b" represents the b time loading of the 3a mm's repeated loading

It can be seen from Fig.2 that the failure mode of CFRP-reinforced UHPC beams was concrete crushing failure, which is the same as the design failure mode. The section opening saves the cost of concrete production but reduces the cross-sectional area of UHPC in the compression zone. Under the condition of ensuring the normal use of the building, the amount of UHPC can be appropriately reduced by changing the section design.

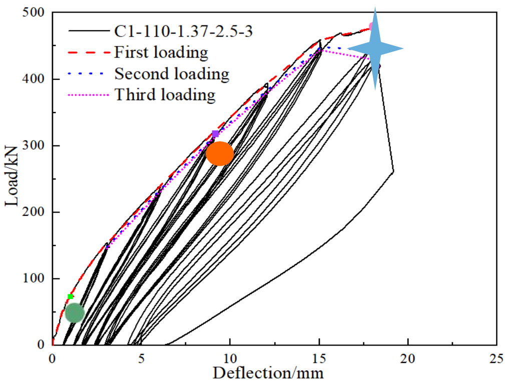
1.3 Load deflection curves



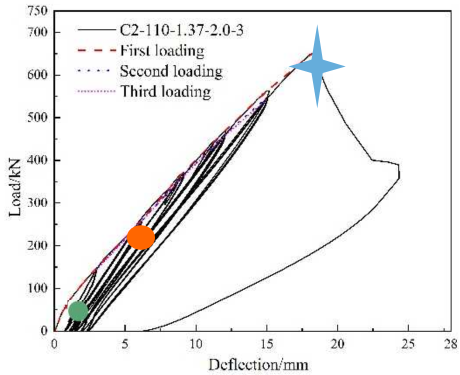
(a) Beam with steel fiber volume fraction of 1.5%



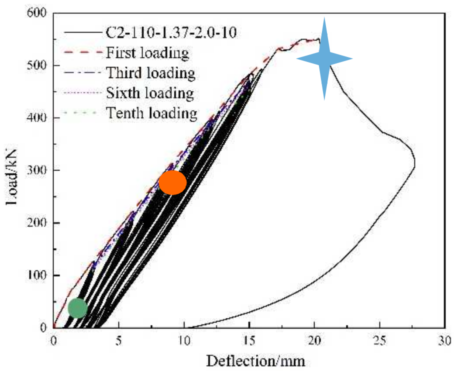
(b) Beam with steel fiber volume fraction of 2.0%



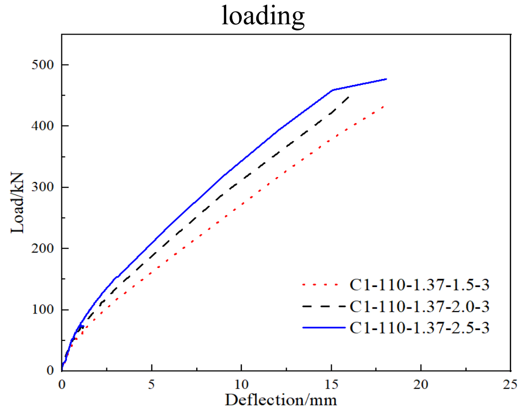
(c) Beam with steel fiber volume fraction of 2.5%



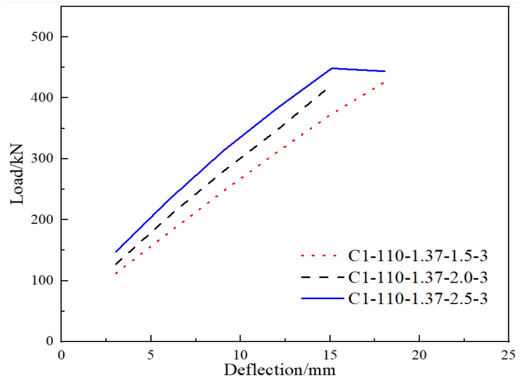
(d) Beam subjected to three times repeated loading



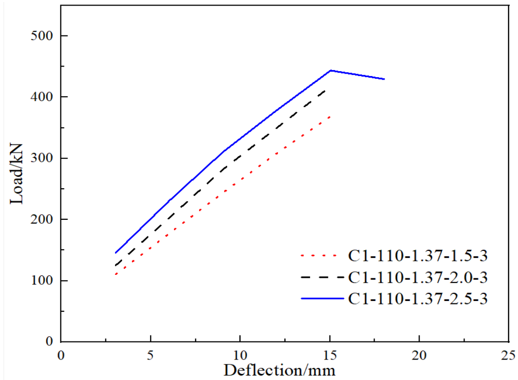
(e) Beam subjected to ten times repeated loading



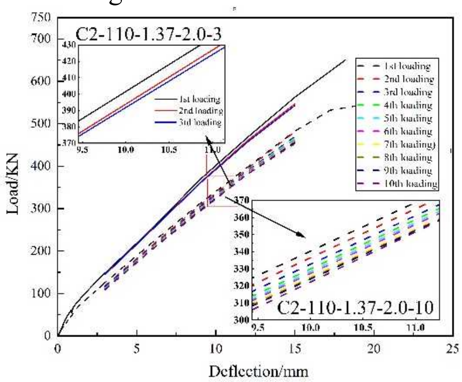
(f) Comparing the effect of steel fiber volume fraction under the first loading



(g) Comparing the effect of steel fiber volume fraction under second loading



(h) Comparing the effect of steel fiber volume fraction under third loading



(i) Comparing the effect of loading regime

Fig.3 Load-Deflection curve of beams

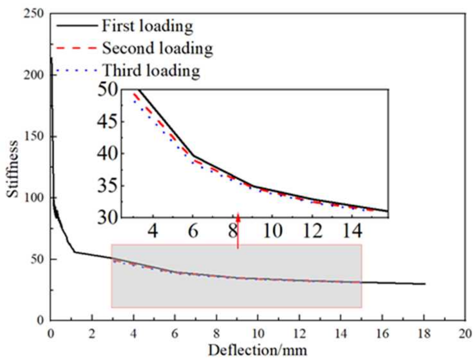
crack load stable load ultimate load

It can be seen from Fig.3 that the load-deflection curves of CFRP bars reinforced UHPC were bilinear. With the increase in loading times, the load decreased under the same deflection. With the increase of steel fiber volume fraction, the slope of the curve increases, and the cracking moment, stable moment and ultimate moment of CFRP-reinforced UHPC beams increased. Fig.(i) showed that as the number of repeated loadings increased from 3 to 10, the slope of the curve, stable moment and ultimate moment of CFRP-reinforced UHPC beams reduced significantly.

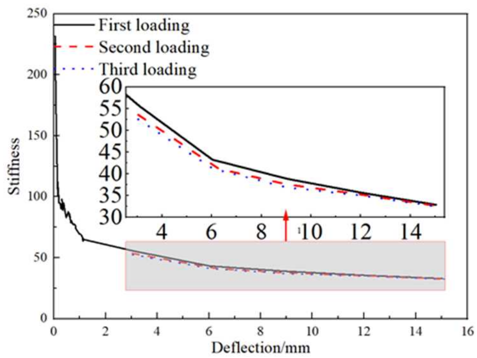
1.4 Stiffness degradation

The stiffness can be calculated according to the load-deflection curve of the beams, and the calculation of the stiffness is shown as follows:

$$K = \frac{p}{\Delta} \tag{1}$$

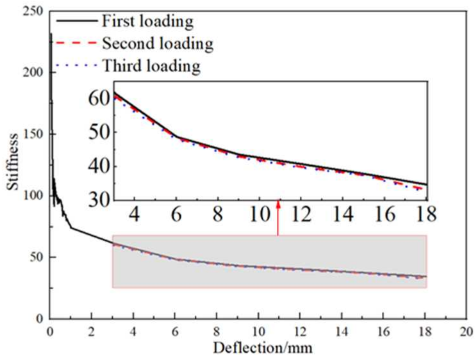


(a) Beam with steel fiber volume fraction of

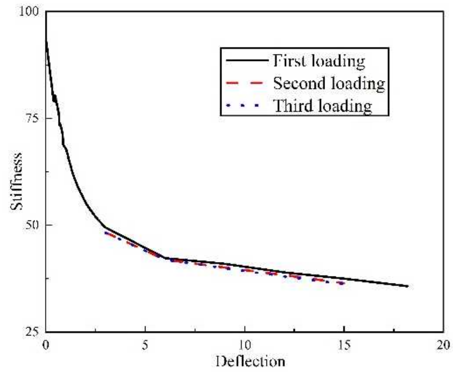


(b) Beam with steel fiber volume fraction of

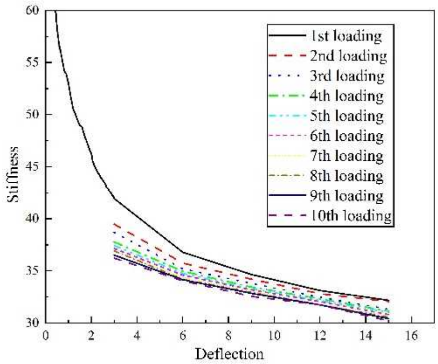
1.5% 2.0%



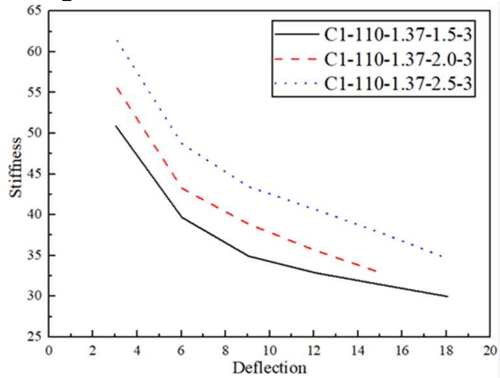
(c) Beam with steel fiber volume fraction of 2.5%



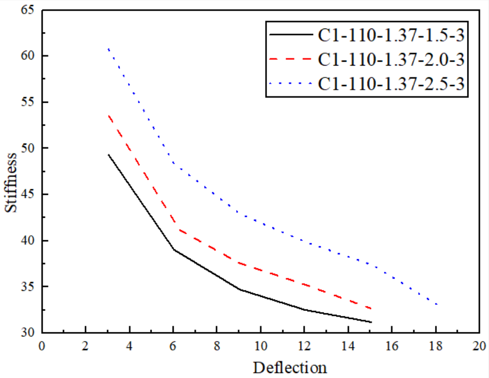
(d) Beam subjected to three times repeated loading



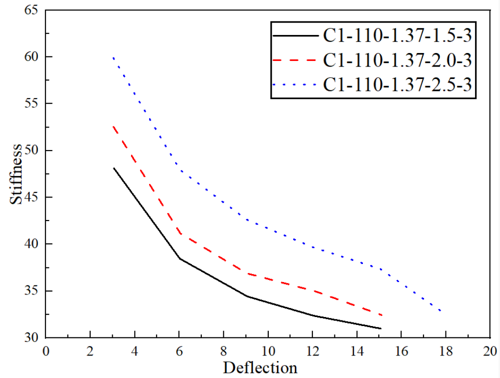
(e) Beam subjected to ten times repeated loading



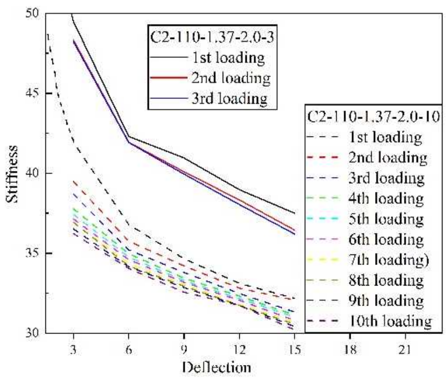
(f) Comparing the effect of steel fiber volume fraction under the first loading



(g) Comparing the effect of steel fiber volume fraction under second loading



(h) Comparing the effect of steel fiber volume fraction under third loading



(i) Comparing the effect of loading regime

Fig.4 Stiffness of beams

It can be seen from Fig.4 that with the increase in loading times, the stiffness decreased gradually under the same deflection. And with the increase of steel fiber volume fraction, the stiffness of the beams improved under the same deflection. Comparing the stiffness of CFRP-UHPC beams subjected to different loading regime, it is shown that ten times repeated loading had a worse effect on the stiffness, and with the increase of deflection, the stiffness difference between three times repeated loading and ten times repeated loading was increasing.

1.5 Strength degradation

The strength degradation of the beam is described by a strength degradation coefficient, the calculation formula is as follows:

$$\lambda_i = \frac{p_i}{p_1} \tag{2}$$

By calculating the strength degradation coefficient, it is shown that the stiffness degradation coefficient is in the range of 0.85 to 1 within ten cycles of loading. The maximum value of λ_i is 0.9966, and the minimum is 0.86356, the average of λ_i under the deflection of 3, 6, 9, 12, and 15 mm are 0.9195,0.9573, 0.9669, 0.9721 and 0.9654, respectively.

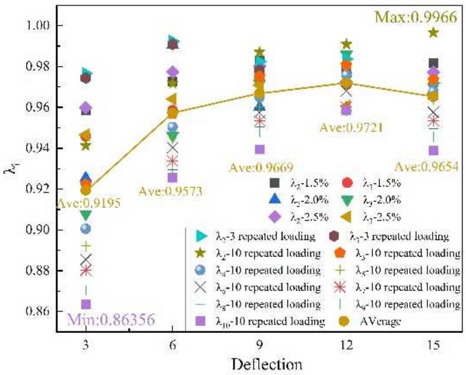
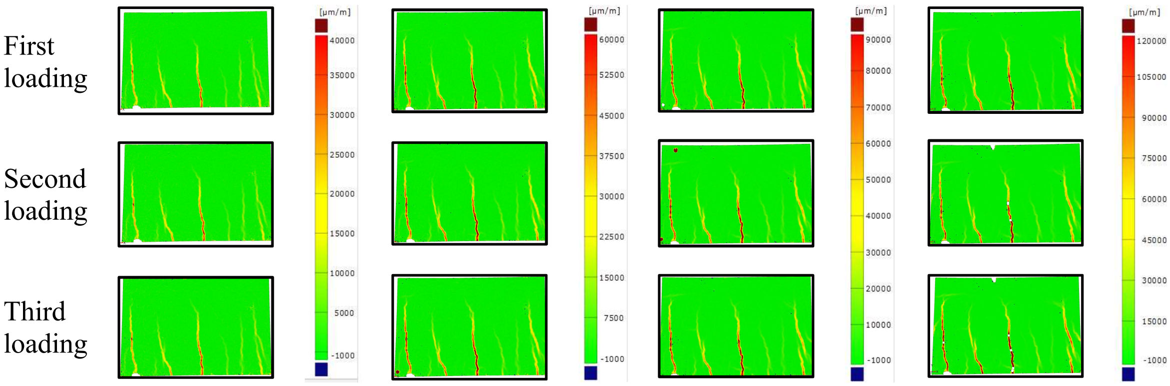
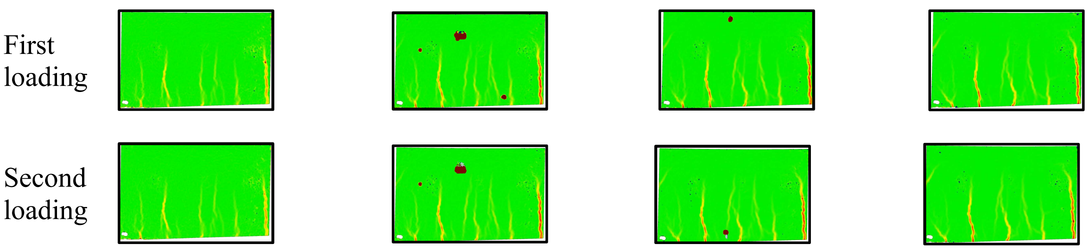


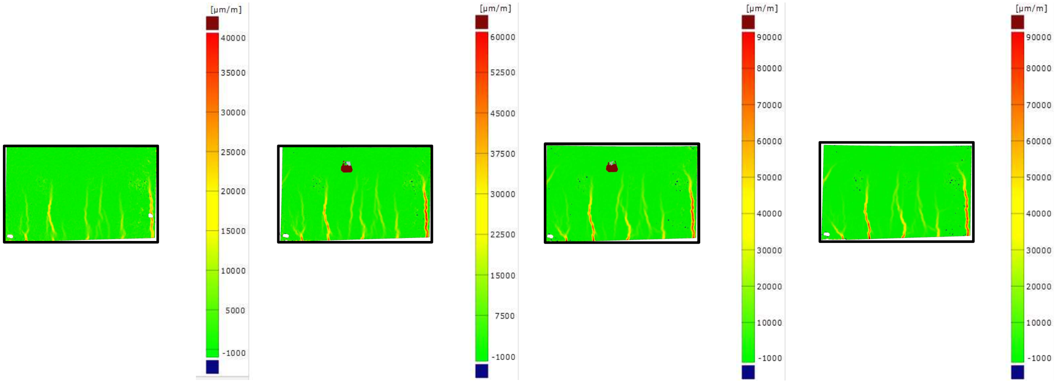
Fig.5 The result of λ_i

1.6 DIC result

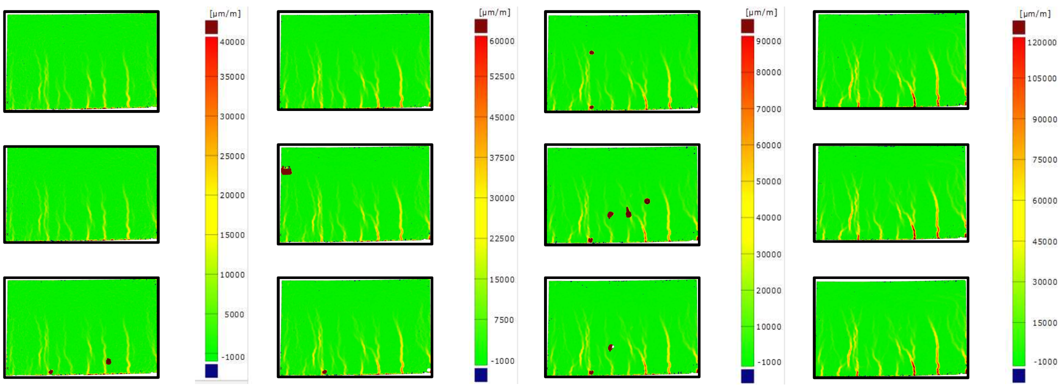


C110-1.37-1.5%-3





C110-1.37-2.0%-3



C110-1.37-2.5%-3

Fig.6 DIC photos

Fig.6 shows that the strain of CFRP-UHPC beams increased with the increase of deflection, but the strain did not change much under the same deflection. Therefore, the strain of beams with different steel fiber volume fractions under different deflections during the first loading was compared. With the increase of steel fiber volume fraction, the strain under the same deflection decreased, and the crack width of beams decreased, indicating that steel fiber has an inhibitory effect on the generation and development of cracks.

1.7 Calculation formula of ultimate bearing capacity

Calculation assumptions:

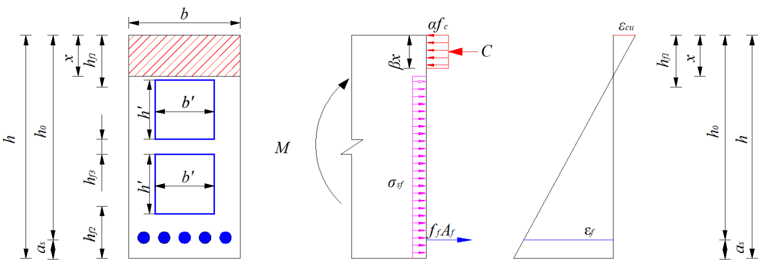
(1) The concrete strain should conform to the flat section assumption.

(2) After cracking, UHPC can still provide residual tensile stress

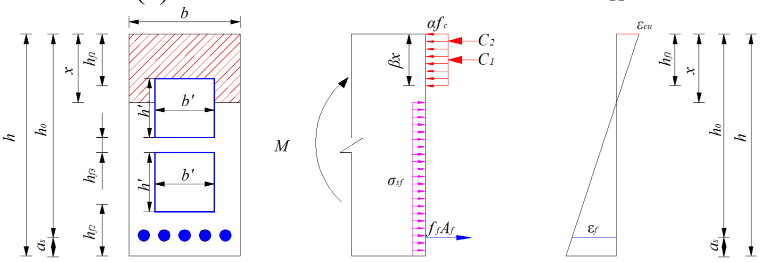
(3) For the constitutive model of concrete under repeated loading, the constitutive model under static load can still be used.

(4) The stress-strain relationship of FRP bars increases linearly, and FRP stress f_f can be calculated by the following formula.

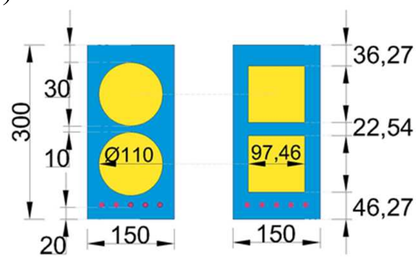
$$f_f = E_f \varepsilon_f \tag{3}$$



(a) Stress-strain distribution x<h_{f1}



(b) Stress-strain distribution x >h_{f1}



(c) Simplified concrete cross-section

Fig.7 Calculating of ultimate bearing capacity

Based on the above calculation assumptions that UHPC can still provide residual tensile stress after cracking and consider the effect of steel fiber, proposed a formula for calculating the ultimate bearing capacity of UHPC beams reinforced with CFRP bars. And the calculation formula is as follows:

$$M_t=\alpha f_c \beta bx\left(h_0-\frac{\beta}{2}x\right)-\sigma_{sf}\left[\frac{1}{2}b(h-x)^2-b'h'(h-x-h_{f2}-\frac{1}{2}h')\right] \quad x<h_{f1} \quad (3)$$

$$\begin{aligned}M_t=&\alpha f_c \beta x(b-b')\left(h_0-\frac{\beta}{2}x\right)+\alpha f_c \beta h_{f1} b'\left(h_0-\frac{h_{f1}}{2}\right)\\&-\sigma_{sf}\left[\frac{1}{2}b(h-x)^2-b'h'((h-x-h_{f2}-\frac{h'}{2})+\frac{1}{2}b'(h'+h_{f1}-x)^2)\right]\end{aligned} \quad x>h_{f1} \quad (4)$$

2. Future research plans

At present, the data processing of the UHPC beams is completed. Next, I intend to write an academic paper based on the test results. If I have the honor to pass the doctoral application at Kumamoto University, I will continue to research concrete structures.

3. Achievement

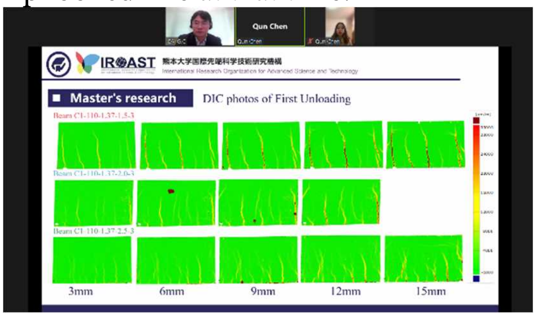
Based on the above research work, **an academic paper** on the flexural behavior of UHPC beams reinforced with CFRP bars will be submitted to the international journal of Construction and Building Materials under the host professor’s supervision.

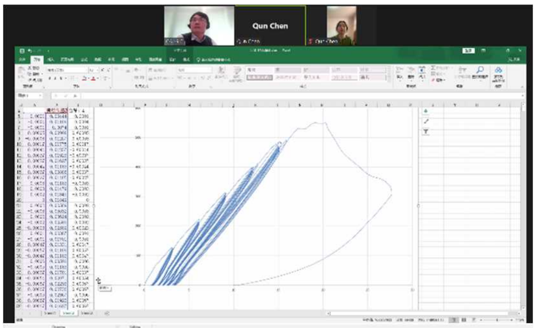
4. Acknowledgement

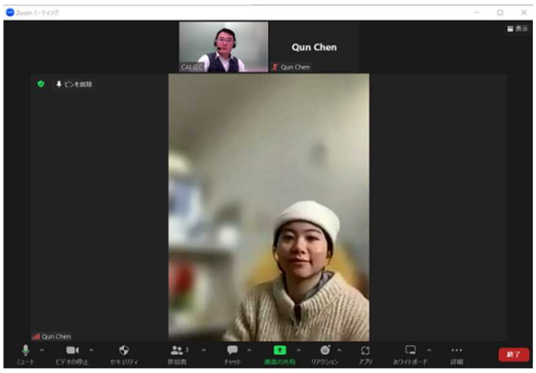
I am very grateful to Kumamoto University for its full support of this project. It is a great honor and an unforgettable experience to participate in the IROAST research internship project at Kumamoto University. Finally, I am particularly grateful to Professor Cai for helping me complete this study. Without his guidance, none of this can be achieved.

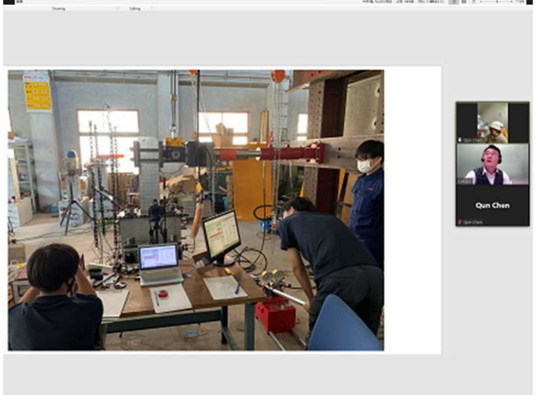
Appendix

The following photos show what the internship looked like at that time.









No.6-2	Flow-based photodecomposition system for radioactive metal purification		
Name	Rahmat HIDAYAT	Title	Lecturer
Affiliation	Politeknik Negeri Lampung (Indonasia) Email:rahmathidayat@polinela.ac.id		
Research Field	Environment-friendly technology / Advanced materials		
Period of Internship	November 25, 2022-January 31, 2023 (Onsite: December 5, 2022- January 25, 2023)		
Host Professor	Shin-Ichi OHIRA	Title	Professor
Affiliation	Faculty of Advanced Science and Technology（FAST）/IROAST Email: ohira@kumamoto-u.ac.jp		

Details of Activity

1. Evaluation of the decomposition product or by-product from radioactive metal purification

There are two major components of EDTA derivatization that are carboxylic and amine [1]. Moreover, after synthesis of TiO_2, the determination of decomposition product was done using liquid chromatography (HPLC). Fig. 1(a) shows the separation of carboxylic acid molecules which is possible contained in the product. There are two dominant peaks, first peak at retention time of 4.9 min is confirmed as NO_3^- (nitrate) intensity and the other is belong to glycolic acid at around 8.3 min. The nitrate appears from the solvent that is used as an ion receptor from electrodialysis process of metal mixture separation. Besides, nitrate can source from decomposition of EDTA. However, the perfect decomposition would result a simple molecule such as CO_2, NH_4^+, and NO_3^-. But nitrate appearance can interfere the appearance of carboxylic peak. The nitrate peak has high intensity because of the wavelength (210 nm) which is absorption range of nitrate. After shifting the wavelength to 235 nm, the intensity extremely decreases.

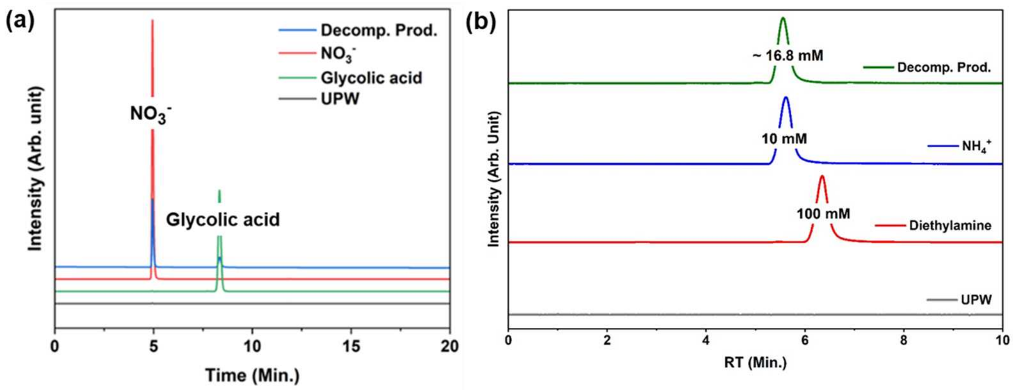


Fig. 1. (a) Qualitative analysis of decomposition product compared to standard and (b) cation chromatogram from standard and decomposition product.

Mechanism pathway shows the appearance of some ionic product which could be detected using ion chromatography. Ion chromatography (Fig. 1b) exhibits peaks of UPW, diethyl amine, ammonium, and decomposition product. Chromatogram pattern of decomposition product indicates single peak of ammonium around 5.8 min and no other peak detected. The ion measurement is only performed under cation observation to get information about ammonium cation. This instruments actually could scan amine-based group, for example diethyl amine peak appear above 6 min. Regardless, single peak of decomposition sample gives a proof that amine functional group on EDTA converted to ammonium through oxidation process. EDTA compound also is not exist in solution because of no identified peak.

There are a lot of knowledge and experiences that I got from this activity. Previously, I think that the radioisotope (RI) metals are a dangerous material or for producing energy only through generator. After joining with Prof. Ohira Lab, I realize that RI metals also have widely useful for biochemistry tracer and medical diagnosing [2], which is so important. I learnt how to obtain RI metal in medical grade through simple and fast method. Besides that, the determination of product or by-product using advanced instrumentation, especially with IC (ion chromatography) that I never use before for sample analysis, add new knowledge and science.

2. **Decomposition of EDTA-complex using a catalyst**

A new decomposition reactor was developed for comparing the faster method between with and without TiO_2. There are two type of reactor, Type I, coating on outside of inner tube, and type II reactor, coating on inside of outer tube, both are investigated the performance of EDTA decomposition. Glycolic acid always appears on each of analysis, but not for the other carboxylic. Oxalic, formic, and acetic acid are occasionally observable on chromatogram. This phenomenon is affected by difficulty of intermediate study from decomposition activity. Different time would result dissimilar mechanism therefore triggering the product or by-product disparately even catalyst is not already used. After TiO_2 utilizing on type I reactor, glycolic peak becomes smaller than without catalyst existing. Coating on the outside of inner tube covers the irradiation of UV lamp so the photon much interacts with TiO_2 not the sample molecules. Oxidative reaction is inhibited by catalyst with this design. Hence, the reactor structure is designed as type II which is coating on the inside of outer tube.

3. **Determining the faster method of decomposition EDTA-complex**

Catalyst could enhance glycolic acid intensity that means increasing decomposition activity. TiO_2 has ability to accelerate oxidative reaction by generating radical ions although as not strong as peroxide. Catalytic-based decomposition depends on irradiation time because the finite of radical molecule. Intensity in each of peaks is increasing due to raising time. Therefore, results indicate that TiO_2 improves the decomposition activity of EDTA even though has not completely replaced of peroxide.

Here, I learnt how to improve the decomposition activity with some modification on the reactor. Presence of catalyst on the reactor caused degeneration of radical molecules, therefore the efficiency is higher. Other experience also I could get from this through how to set up the reactor and modify the reactor. These experiences will be meaningful for me because I never do that in my previous work.

Conclusion & Future Work

Along research internship period, we studied decomposition EDTA-complex for improving previous work on Ga recovery from its complex. From evaluating product or by-product, decomposition solution contains glycolic acid, nitrate, and NH_4^+. TiO_2 has big chance for replacing the oxidative molecule so the decomposition works more environmentally friendly. The effectivity of Ga recovery has not been studied yet. But, based on the increasement of glycolic acid after EDTA decomposition with TiO_2, the probability of Ga recovery improving is still high.

Next work, the amount of Ga needs to be evaluated therefore the increasing of efficiency could be known exactly. The decomposition of Ga-EDTA might be different with EDTA only but separation of metal-complex seems more easier than decomposition of stable molecule (EDTA). The recovered Ga from metal mixture would be in little amount which needs extra work carefully. In the future, after completing the study, Ga for medical will be produced via automated process without intervention of human hand so it works safely and efficiently. With this report, firstly I would like to thank you to IROAST Kumamoto University that organizes and financial supports this beneficial internship. Secondly, to Prof. Shin-Ichi Ohira as host professor providing and guiding me, and also for Prof. Kei Toda, thank you for the guiding.

Reference

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Some Pictures of Internship Activity


Left: Optimizing the HPLC & **Right**: Setting up the decomposition reactor

No.6-3	Application of silk fibroin as medical materials シルクフィブロインの医療応用に関する研究			
Name	Hsiu-Chin HUANG	Title	Ph.D. course student	
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Research Field	Biotechnology & healthcare technology			
Period of Internship	November 29, 2022-January 27, 2023 (Onsite: January 5, 2023- January 18, 2023)			
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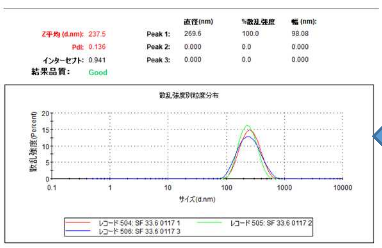
In this mission, I extracted silk fibroin from cocoons, after obtaining the appropriate molecular weight protein by degumming, preparation of silk fibroin aqueous solution, and dialysis process, silk fibroin nanoparticles were prepared and observed to enter HeLa cells.
The study of replacing synthetic polymers with natural polymers for medical materials and improving biocompatibility is a valuable development.



Kumamoto University has a strong research group in the school of pharmacy, faculty of science, and faculty of engineering, and has sufficient analytical instruments.
I am very grateful to IROAST and Professor Niidome for giving me this opportunity to study.

I hope to return to Kumamoto University for doctoral studies in the future, and learn about medical material development, cancer treatment drug delivery system development research, and natural medicine active ingredient research.