FUNDAMAENTAL CHARACTERISTICS OF NEW CFRP RODS WITH U-END ANCHOR FOR APPLICATION TO PRESTRESSED CONCRETE STRUCTURES

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I. Objectives

The objective of this study is to investigate the bond strength and the tensile capacity of both rods and U-anchors of CFRP manufactured by the UCAS robot of Kyushu University. A secondary objective is to analyze load-deflection behavior of two deferent scales of concrete beams containing CFRP as reinforcement, and to develop the behavior of CFRP for possible use in prestressed concrete members.

II. Contents

1. Introduction

Due to the corrosion problem and the necessity for materials to have a long-term durability, there is an increasing need to introduce new materials that can be also used to repair damaged reinforced concrete structures and to construct new structures that are able to resist corrosion. For these reasons, Carbon Fiber Reinforced Plastics materials (CFRP) have been introduced. These materials are light, quite strong, easy to apply, and more durable than other materials. However, the use of CFRP materials can be costly and engineers must also deal with the problems of low modulus of elasticity and anchoraging. In order to investigate the properties of CFRP, the authors have been developing a research program called Uni-Directional Carbon-Fibers Assembly System (UCAS) at Kyushu University, to develop CFRP composite bars as reinforcement for concrete structures and to reduce their disadvantages.

2. UCAS method

The UCAS method is a construction method by which Carbon Fibers CF are fabricated under constant tensile force by an automatic arrangement robot. This automatic arrangement robot was developed by researchers at Kyushu University. UCAS program has introduced two types of robots which produce CFRP rod. The properties of these two types are presented in Table 1.The making UCAS rods consists of three steps as shown in Figure 1:

Step 1: The carbon fiber supplying portion is moved in a parallel direction, and as the fibers are impregnated with epoxy, "axial fibers" are wrapped around the anchor, at this time; a constant tensile stress is applied to the carbon fibers.

Step 2: After the prescribed rotations are completed, the carbon fiber supplier moves in a parallel direction and the anchors on both ends are rotated simultaneously. This time also a constant tensile stress is applied to the carbon fibers.

Step 3: An electrical heat curing equipments are attached to anchors on both ends. An electrical current is circulated through the carbon fibers and the fibers are heated to 70 degrees, which makes the epoxy plastic is hard in approximately 1.5~2 hours.

Table 1.Differences between Robot 1 and 2

Characteristics	Robot 1	Robot 2
speed	300 mm/s	1200 mm/s
lengths of CFRP	0.8 m, 1.5 m	Up to 10 m
Versatility	Horizontal reinforcement	–

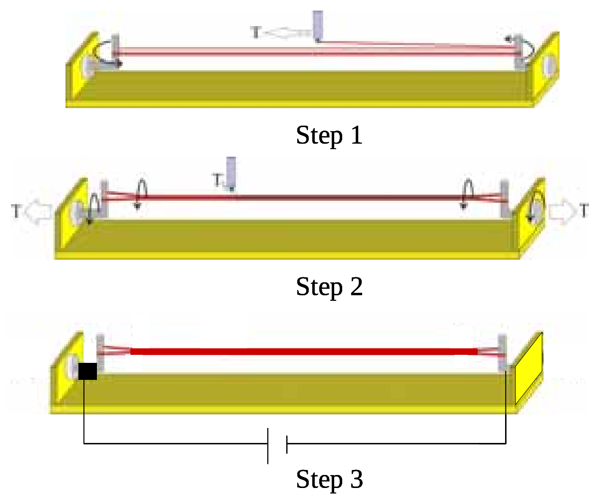


Figure 1.Making UCAS rod

3. Mechanical properties of CFRP

The tensile properties of CFRP materials and their bond behavior to concrete are of the main aspects to be considered in designing reinforced bars for concrete structures, and an understanding of CFRP tensile performance is necessary for their application. Finally, an understanding of bonds is important for stress transfer from the concrete to the CFRP rods. In order to classify the material properties of CFRPs three kinds of experiments were carried out:

- Tensile test of CFRP rods.
- Tensile test of U-anchors.
- Pull out bond test of CFRP rods.

Table 2.The material brands of CFRP

CFRP type	Carbon Fiber	Epoxy
80S*	T700SC	TS プライマー(S)
80S	T700SC	エピコート 801P エピキュア EMI 24
250S*	T700SC	TS プライマー(S)
250S	T700SC	エピコート 801P エピキュア EMI 24

The CFRP tested were manufactured at Kyushu University, 80 and 250 strands of carbon Torayca T-700-12K were used in this study, Two brands of epoxy were used to fabric them .Table 2.shows the material brands of CFRP.

- **Tensile test of CFRP rods**

The conventional method to run a tensile test for a steel specimen is to grip the specimen directly with the steel jaws of the test machine. However, this method does not apply for CFRP bar tensile testing. The reason for this is that the CFRP bars are sensitive to compressive forces in the transverse direction. To run these experiments two soft metal sleeves (see Figure 2) were installed at each end of 1300mm and 2300mm long CFRP leadline rod. Ex gripper mortar type-A was used as a grout. The load was applied using hydraulic jack equipped at a rate of 8 kN per minute, which in terms of stress was 130 MPa per minute for CFRP 80 strands, and 30 kN per minute, which in terms of stress was 144 MPa per minute for CFRP 250 strands. The behaviors of all specimens were linearly elastic way up to failure no matter what the failure mode was. The curves of stress-strain relationship are shown in Figure 3**,** and the experimental results are presented in Table 2.

- **Tensile test of U-anchors**

Many investigations have been carried out to solve the anchoraging problem, the joint between two CFRP rods, and the application of CFRP rod as prestressed tendon were the main raisons for using U-anchor as the end of CFRP rod. The U-anchor is shown in Figure 4. Table 3 summarizes the experimental results of CFRP U-anchor. CFRP U-anchors revealed an elastic behavior, and increasing the number of strands did an increase the tensile capacity of U-anchor. The tensile capacity of U-anchor was Type A (83% of the tensile capacity of rod 80S*) Type B (74% of the tensile capacity of rod 80S) Type C (55% of the tensile capacity of rod 250S) and Type D (57% of the tensile capacity of rod 250S).

- **Pull out bond test of the CFRP rods**

The bond between CFRP and concrete is one of the keys to the success of resistant mechanisms of reinforced concrete furthermore; bond characteristics are responsible for transferring the load from concrete to reinforcement and for developing the required stress in the reinforcement for equilibrium. In order to test the bond strength of CFRP rods, five types of CFRP rods were used for pull out bond tests, Each test specimen used in this study was composed of a concrete block;(see Figure 5), the experiments results indicate that the bond strength of CFRP is approximately close to the bond capacity of the conventional deformed steel, Table 4 summarizes the bond test results.

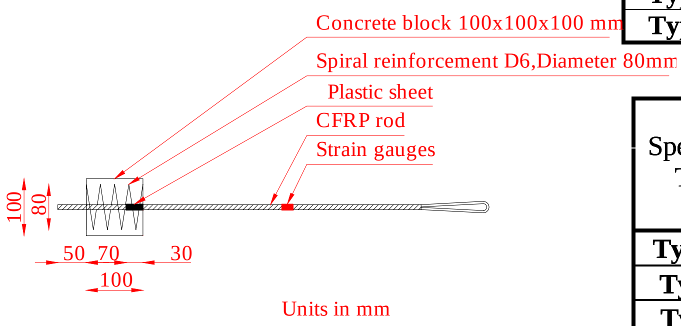


Figure 5.Specimen details

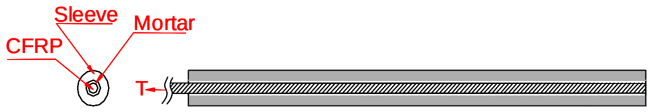


Figure 2. The sleeve

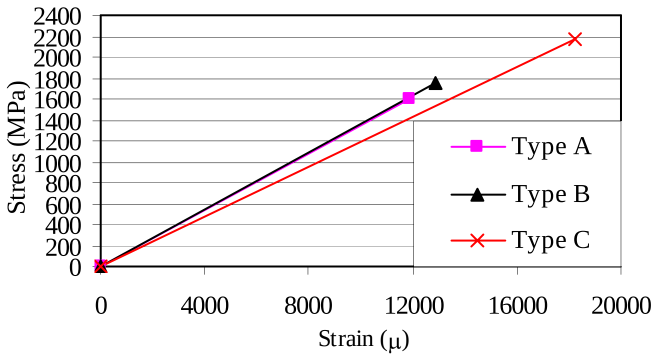


Figure 3. Stress-Strain relationship of CFRP rod

Table 2. The main mechanical properties of CFRP rod

Specimen Type	CFRP Type	Diameter (mm)	Tensile Strength (Mpa)	Modulus of elasticity (GPa)
Type A	80S*	9.15	1606	135
Type B	80S	8.91	1828	136
Type C	250S	16.25	2167	119

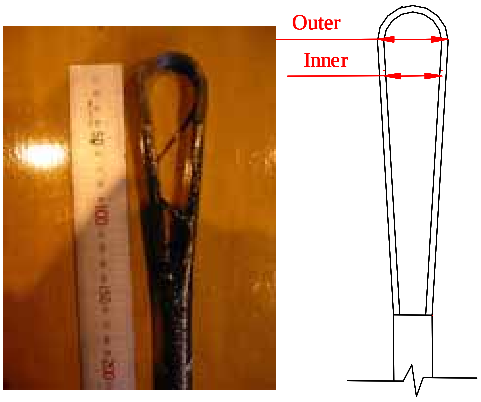


Figure 4. The U-anchor

Table 3. The properties of CFRP U-anchor

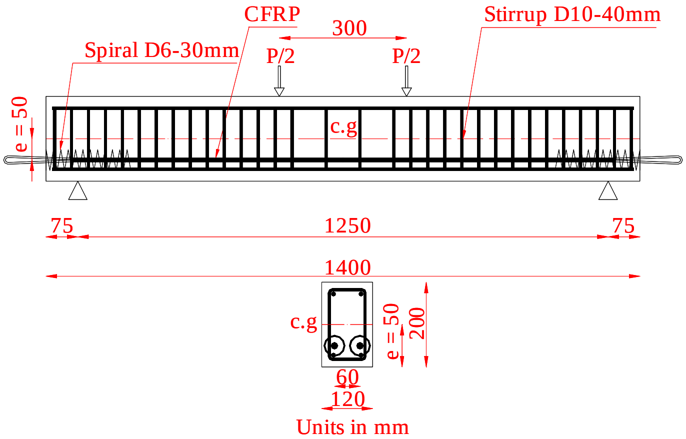
Specimen Type	CFRP Type	U-anchor Diameter (mm)		U-anchor Thickness (mm)	Ultimate Load (kN)
		Inner	Outer		
Type A	80S*	20	24.04	4.04	87
Type B	80S	20	23.83	3.83	83
Type C	250S	35	43.07	8.07	248
Type D	250S	35	43.03	8.03	254

Table 4. The summary of pull out bond test

Specimen Type	CFRP Type	Rod Diameter (mm)	Maximum Pull Out Load (kN)	Bond Strength (MPa)
Type A*	80S*	8.69	15	8.00
Type A	80S*	9.15	26	12.77
Type B	80S	8.91	11	6.36
Type C*	250S*	16.25	43	12.17
Type C	250S	16.25	33	9.17

4. Flexural behavior of beams reinforced by CFRP

In order to apply the CFRP with U- anchor to the real scale, and to clarify the span effect on the behavior of the structures stressed with CFRP, two-point bending flexural tests were conducted on beams reinforced by carbon fiber reinforced polymer.



- **Beams with span of 1250 mm**

Two prestressed concrete beams and one non-prestressed beam reinforced by CFRP with a U-anchor were constructed, each beam was 1400 mm in length and the dimension of their cross-sections were 120 mm × 200 mm. Two rods of CFRP with U-anchor were installed as prestressing tendon with eccentricity (e) of 50 mm, The details of the specimen are shown in Figure 6. Each prestressing tendon was pulled to an average load of 62.5 kN. This increased the stress of the rod to 1016 MPa (44% of the tensile strength of CFRP). The tension forces were released after 5days of casting the concrete. After releasing the tension forces, the loss of strain near the ends of the U-anchors, due to the slip of tendons, was about 66% of the initial value before releasing. The effective development length was about 275 mm, which was approximately 30 times that of the CFRP rod diameter. At the inner part of the tendon and, due to elastic deformation, the loss of strain was about 3.5% of the initial value before releasing. Figure 7 shows the strain distribution along CFRP rods after releasing.

The test results in Figure 8 shows that the prestressed concrete beams give rise to a nearly triangular normal strain distribution in the tension and compression chord, with close agreement between the predicted value and test results.

While waiting for the testing, the concrete strain was also measured for 15 days simultaneously. The loss due to the creep during these days was about 2.3%.The total losses of strain until testing day were 6%.

The beams were un-cracked before loading. Afterwards small cracks began developing vertically at midspan of the RC beam when the load was reached at 15 kN, while the first crack on PC 1 started when the load was reached at 61 kN and for PC 2 at 63 kN, all cracks continued to grow in both width and length. The damaged beams continued to resist the applied load until the concrete at the top of the beams began to collapse. On the RC beam, the maximum load when concrete crushed reached 117 kN, whereas, on the PC 1, the maximum load when concrete crushed reached 130 kN and for PC 2 at 139 kN. Figure 9 shows the load-deflection relationship of prestressed beams and non-prestressed beam.

- **Beams with span of 3200 mm**

Each specimen was 3200 mm long, with section area 250 mm × 400 mm, one beam was prestressed by two rods of CFRP and the second one was prestressed by three rods of CFRP to increase the tension forces, the eccentricity (e) was 100 mm. The details of each specimen are shown in Figure 10.

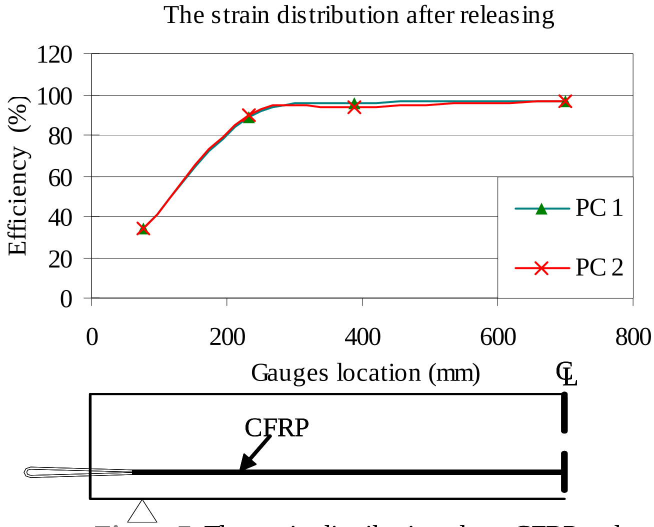


Figure 7. The strain distribution along CFRP rods

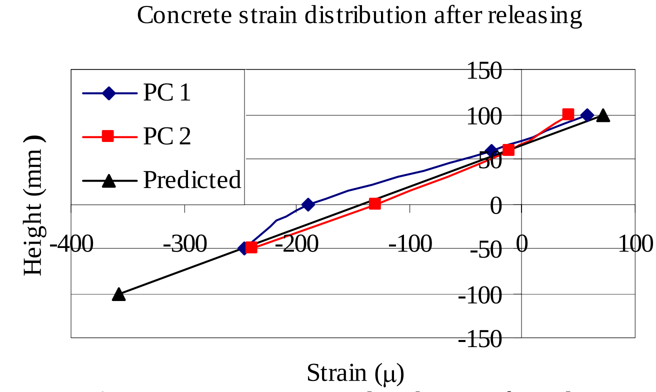


Figure 8. Concrete strain distribution after releasing

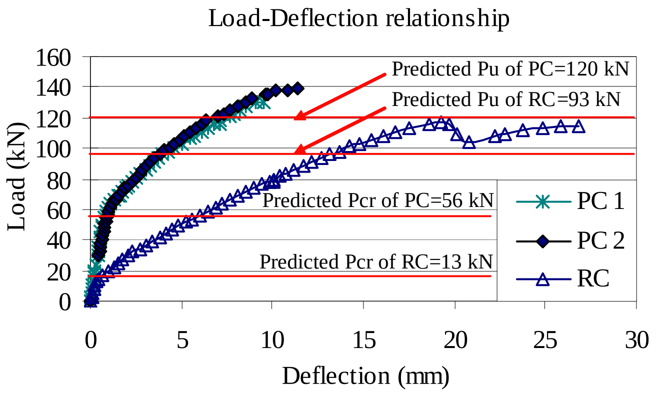


Figure 9. Load-Deflection relationship

The prestressing tendons were tensioned to 150 kN, and after 5 days tension forces were released, The loss of strain after releasing near the ends of U-anchors due to the slip of tendons was about 62.8 % of initial value before releasing in PC 3, and 14.2 % of initial value before releasing in PC 4. The effective development length was about 450 mm, which was also approximately 30 times that of the CFRP rod diameter, at the inner part of the tendon and, due to elastic deformation, the loss of strain was about 3.1% of the initial value before releasing in PC 3, and 4.2 % of the initial value before releasing in PC 4. Figure 11 shows the strain distribution along CFRP rods after releasing. Figure 12 shows that the strain distribution of concrete after releasing was a nearly triangular, with an agreement between the predicted value and test results. The loss due to the creep during 15 days was 2.8 % in PC 3 and 5.6 % in PC 4. The total losses of strain until testing day were 5.9 % in PC 3 and 9.8 % in PC 4.
Before loading the beams had no cracks, the first flexural crack started at the midspan of the PC 3 beam when the load climbed to 118 kN, and the first crack on PC 4 beam appeared when the load climbed to 147 kN .Cracking sounds were heard which an indication of the CFRP were debonding from the concrete. The maximum load when the concrete was crushed reached 342 kN, on the PC 3, whereas, on the PC 4, the maximum load reached 429 kN. Figure 13 shows the load-deflection relationship of prestressed beams. The flexural behavior for two series of beams was similar, and comparing to the predicted results, the experimental results were higher in range of 10 % to 20 %.

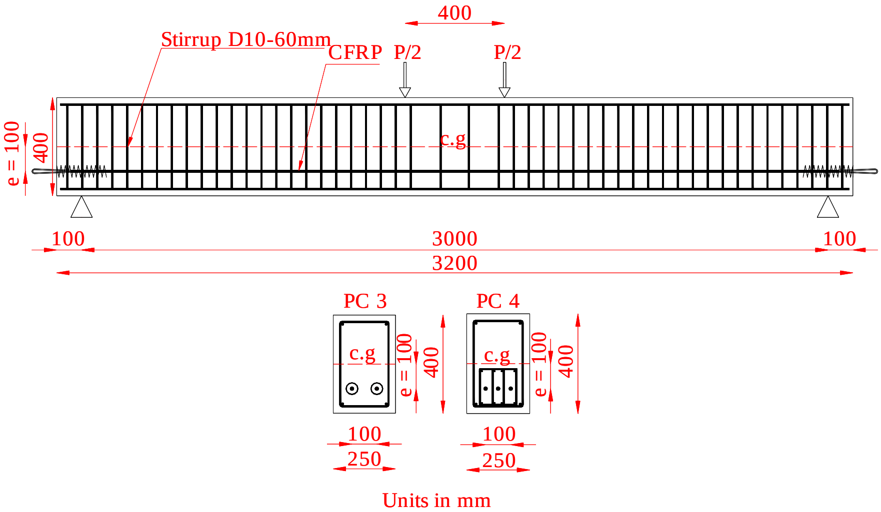


Figure 10. The details of the beam

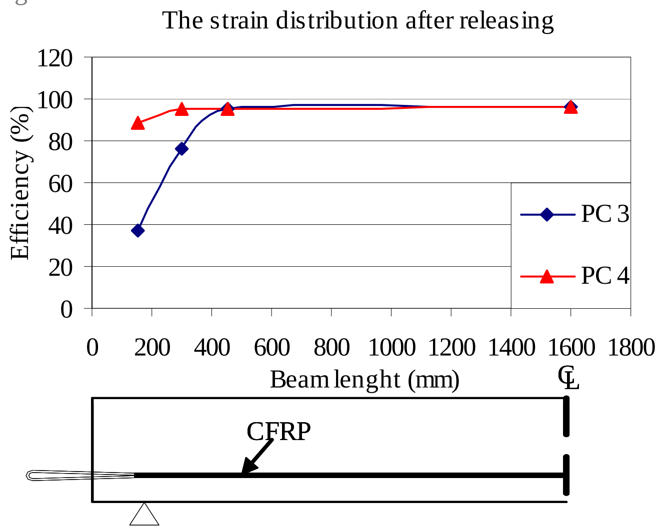


Figure 11. The strain distribution along CFRP rods

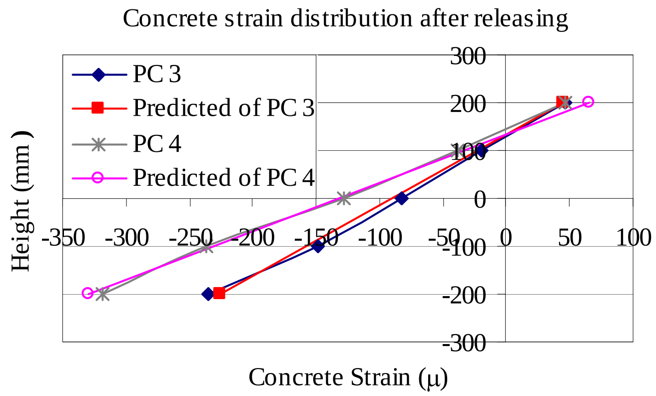


Figure 12. Concrete strain distribution after releasing

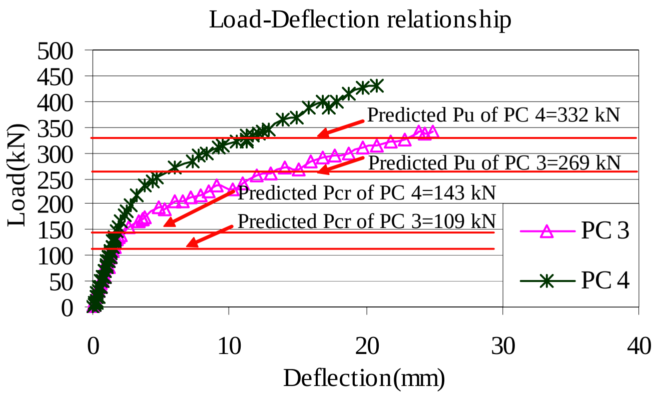


Figure 13. Load-Deflection relationship

5. Conclusions

- The stress-strain relationship was linear at all stress levels, and the ultimate tensile strength increased by making the rod diameter larger. On the other hand, the elasticity decreased by increasing the rod diameter.
- The beams appeared to display a linear behavior to the cracking load, and the CFRP rods also appeared to display a linear behavior to the cracking load.
- The initial strain could be transferred to the concrete with a total loss in range of 6 % to 10% within 15 days.
- The effective development length was approximately 30 times larger than the length of the diameter of the CFRP rod.
- Based on this study ordinary design theory of PC and RC could be used to design prestressed and non-prestressed beams reinforced by the proposed CFRP with U-anchor.
- This study also has shown that CFRP rod is a type of reinforcement that can be used as an alternative to steel for concrete beams.