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STUDIES ON LOW-COST CONSTRUCTION SYSTEM FOR CONCRETE STRUCTURES BY USING UCAS METHOD

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ABSTRACT

UCAS is an abbreviation of Unresin Carbon fibers Assembly Systems. UCAS is a new construction system suited IT in applying of unresin carbon fibers cable (CF cable) or partially resin ones as reinforcement on concrete structures. These cables can be produced cheaply by using automatic arrangement reinforcement robot where preimpregnated and thermosetting processes are eliminated. And the cost of usual preimpregnated one is very expensive in comparison with their of steel bars. These defects are improved by using UCAS.

The primary objective of the research reported in this paper is to study the mechanical performance of an unresin CF reinforcing system produced by UCAS for concrete structures. The following tests are conducted: tensile test of CF cables and bending test of full-scale precast concrete slab. It was found that the unresin CF cables possessed a higher ultimate tensile strength than steel bars, and its tensile strength about 30 to 35% of tensile strength of CF strand provided by manufacturer. And the developed grid system to overcome the bonding weakness of CF cables showed good performance in order to develop a mechanical bond between CF cables and concrete. The bending behavior of the slab reinforced by unresin CF cables indicated that it may be a good alternative for steel reinforcement.

KEYWORDS

Unresin Carbon Fibers, UCAS Method, Automatic Arrangement Reinforcement Robot, Concrete Slab

1. INTRODUCTION

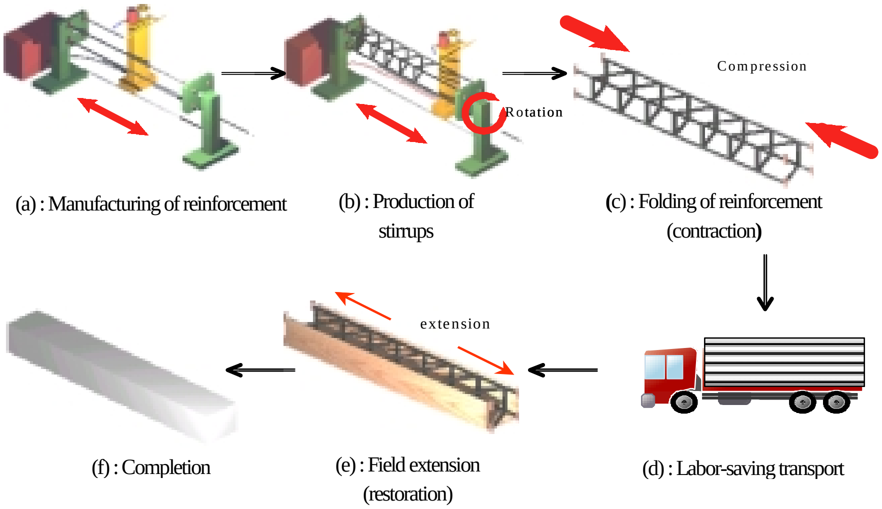
Information technology (IT), of which the Internet is a typical example, has been rapidly changing social and economic systems worldwide, and shaking the foundation of public values. The keywords representing the concepts defining the society in the 21st century are undoubtedly (1) IT society, (2) environmental conservation and circulatory society and (3) safe and secure society. Future construction technologies need to provide efficiency in different phases such as design, construction, maintenance, dismantling and recycling. They also must be socially accountable since life cycle assessment, especially total evaluation of energy and cost, is emphasized. The construction industry sticks to labor-intensive construction systems while acquiring heavy structural materials such as steel and concrete, and heavy equipment including cranes, they must accept their position as a low-profit industry unfit for IT.

This paper first points out problems involved in the construction industry as a member of IT society, and refers to the enhancement of the competitiveness of the industry, especially to the importance of the ability to develop unique technologies. Then, discussions focus on concrete structures as a major player in the construction field. Ideal concrete structures compatible with the super ordinate concepts identified and the technology supporting such structures are presented.

Herewith, the new method in constructing the reinforcement using CF cables for concrete structure is introduced. UCAS is developed for construction society in IT era, and it was developed based on the keywords as follows: digitalization, weight reduction, automation, size reduction, fast distribution, labor saving, corrosion resistance, recycling and mechanical properties. The basic concept of constructing system of reinforcement in UCAS was based on the consideration that to efficiently utilize of CF strength, they must be arranged in uniform initial tensile strength. Based on this consideration, an automatic arrangement reinforcement robot have been developed to assemble the unresin CF cables to be a reinforcement. The reinforcement is assembled by turning the CF cables between two end anchor under certain constant tensile force for unresin reinforcing system.
This paper introduces a study on application of unresin CF cables reinforcement system produced by UCAS to concrete structures. Some experimental clarification has been done in order to study the performance and the behaviors of unresin CF cables as reinforcing materials. The mechanical properties of CF cables and bending test of full-scale precast concrete slab are presented. It should be noticed here that the slab will be applied on one building in Kyushu University campus. This slab test is aimed to clarify the slab performance at design load level, safety factor include the maximum capacity.

2. NEW CONSTRUCTION SYSTEM FOR CONCRETE STRUCTURES

CF is a strand of 12000 to 70000 continuous filaments, each of which has a diameter of approximately seven microns. The strand has a tensile strength from 10 to 20% of the nominal tensile strength that generally ranges from $3.5\text{x}10^3$ to $4.8\ \text{x}10^3\ \text{N/mm}^2$, due to initial loosening. CF strand is, therefore, usually preimpregnated (unhardened resin is soaked), and is subjected to thermosetting at a temperature of 120 to 150 degree to obtain a strength slightly over 70% of the nominal strength. The process makes hardened CF more than about 5 times costlier than unhardened CF, and prevents general use of the hardened type for construction. Even if a decrease of tensile strength is considered, unhardened CF is much superior to hardened type in cost. A diagram of a new IT-based construction system using unhardened CF is shown in Figure 1.



(a) : Manufacturing of reinforcement

(b) : Production of stirrups

(c) : Folding of reinforcement (contraction)

(f) : Completion

(e) : Field extension (restoration)

(d) : Labor-saving transport

Figure 1: New IT-based construction system using UCAS

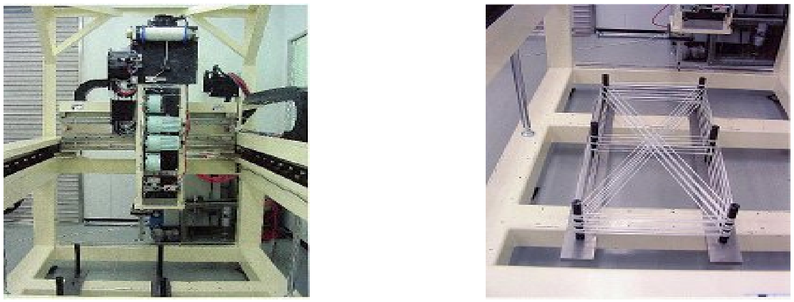


Photo 1 : Automatic arrangement reinforcement robot

A reinforcement system is built as designed using an automatic arrangement reinforcement robot based on digitized design drawings as shown in Figure 1 (a) and (b). Photo 1 shows the automatic arrangement reinforcement robot the author is developing jointly with Professor Onikura of Kyushu University. The reinforcement is bonded spot-wise at intersections and ends of anchorage. The reinforcement can be compressed into a compact shape as shown in Figure 1 (c) since it originally has a flexible structure. The lightweight compact product with design information added can be delivered anywhere via the Internet just in time and along the optimum route (Figure 1 (d)). Then the reinforcement is extended in the formwork (Figure 1 (e)), and concrete with high flow ability is placed (Figure 1 (f)). The process considerably saves skilled field workers engaged in such work as reinforcement arrangement, gas pressure welding and splicing. The lightweight of the reinforcement enables saving of heavy equipment including cranes, and increases the safety and efficiency of construction work.

3. TENSILE PROPERTIES OF UNRESIN CF CABLE

3.1 Specimen and Test Procedure

Table 1 and 2 show material properties of CF filaments stated by maker and specimen detail. At Table 2, Type A, B and C are constructed respectively 40, 80 and 120 CF strands. To investigate the variation of tensile strength of cables, 20 specimens were constructed for each type. Specimen detail and loading system are presented in Figure 2 and 3. Based on the condition of tensile test devices, two anchorages system were used in this test. Transversal anchor system was used for specimen Type A and the sleeve anchor system with expandable mortar was used for specimen Type B and C. To avoid the effect of anchoring system to the tensile strength of cable in testing, the cable around anchor was hardened by epoxy resin.

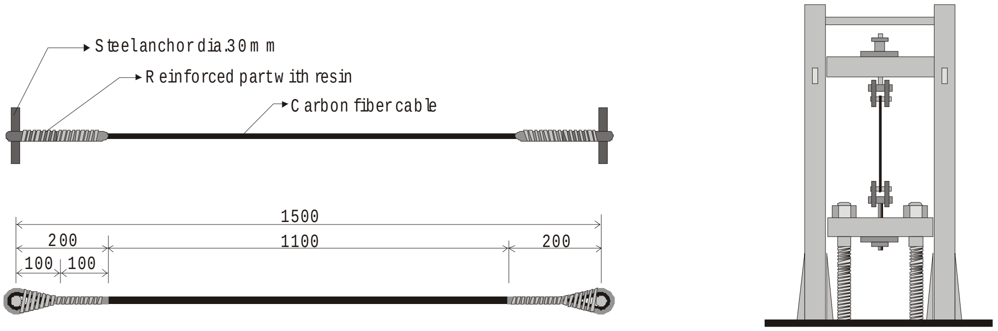
Table 1 : Material properties of the carbon fibers stated by maker

Maker	Designation	Tensile strength [N/mm^2]	Elastic modulus [N/mm^2]	Ultimate strain [%]	Weight density [g/cm^3]	Cross section area [mm^2/strand]*
Toray	TORAYCA T700S (12K)	4800	2.3×10^5	2.1	1.76	0.46

* 1strand = 12K = 12000 filamens

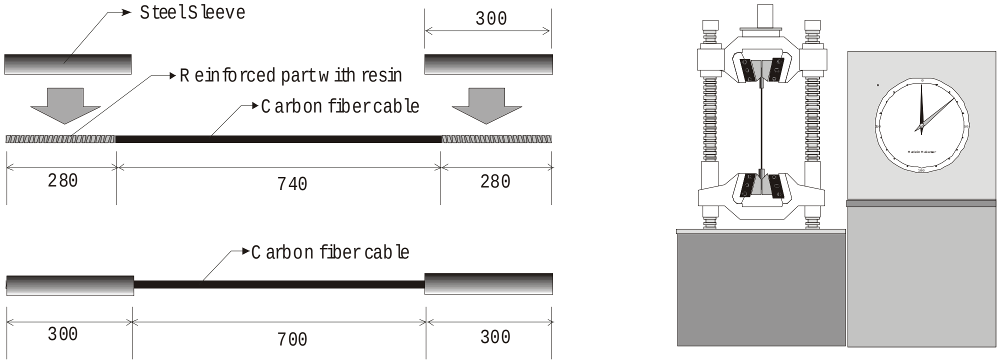
Table 2 : Specimen detail

Type	Number of strand	Cross section area [mm^2]	Specimen length [mm]	Unresin part length [mm]
A	40	18.4	1500	1100
B	80	36.8	1300	700
C	120	55.2	1300	700
D	120	55.2	4000	3500



(a): Specimen detail **(b): Loading system**

Figure 2: Specimen And Loading System Of Specimen Type A



(a): Specimen detail **(b): Loading system**

Figure 3 : Specimen And Loading System Of Specimen Type B And C

The load was applied in 1kN increments until cable failure. The recorded applied load, deformation as well as the strain on cable were recorded for later processing.

3.2 Test Result

Figure 4 shows the typical tensile stress-strain response of all types. These experimental tensile stress of cables were calculated by dividing the experimental maximum load with the cable's cross section area. The strains shown in this graph are the strain measured by strain gauges. These results showed that the tensile stress-strain response of CF cables were almost linear. Specimen Type B and C showed little nonlinear response at low applied load because of initial loosing. Response from about 30% up to close maximum level was almost linear. Just before failure, the stress-strain curves showed a decreasing of cable stiffness.

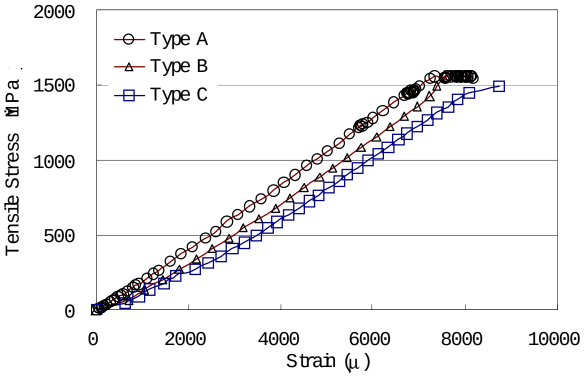


Figure 4 : Stress-Strain Curve

Table 3 : Average of results

Type	Maximum load [kN]	Maximum tensile strength [N/mm^2]	Garantee tensile strength [N/mm^2]	Elastic modulus [N/mm^2]
A	30.9	1676 (34.9%)	1295 (27.0%)	2.03x10^5 (88.3%)
B	58.3	1583 (32.9%)	1381 (28.8%)	2.16x10^5 (93.9%)
C	81.9	1480 (30.9%)	1261 (26.3%)	2.08x10^5 (90.4%)
D	73.0	1323 (27.6%)	---	2.06x10^5 (89.5%)

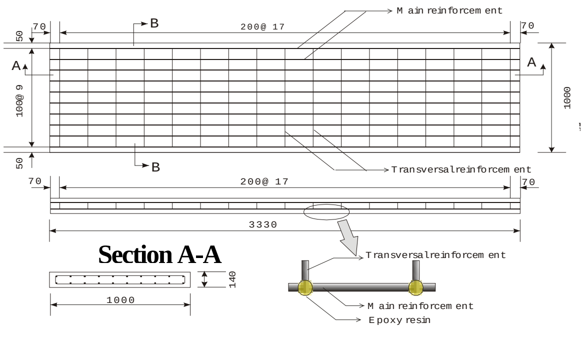
Table 3 shows the value of material properties of all data for each type. It's shown high-level tensile strength that the maximum tensile strength (Type A) is 34.9%, the guarantee tensile strength is 27.0%, and the experimental elastic modulus is close to one stated by maker. Based on the safety consideration reason, the guarantee strength was taken as averages value minus 3 times of standard deviation value. And the co efficiency of variation for specimens was very little; Type A is 7.4%, Type B is 4.2%, Type C is 5.2%.

4. BENDING TEST OF FULL-SCALE PRECAST CONCRETE SLAB

Based on the previous experimental study it was found that the CF cable had very weak bond capacity. Based on the fact that for an effective reinforcing action in flexural members of reinforced concrete, it is necessary that the tensile reinforcement bond to concrete. To overcome the bonding weakness of CF cables, a grid system has been developed in UCAS. The grids were constructed by joint the intersection point between longitudinal and transversal reinforcement by epoxy resin. The results indicated that the developed grid system showed good performance in order to develop a mechanical bonding between CF cables and concrete. This performance of grid system has been also clarified in bending test of concrete beam. The results indicated that unresin reinforcing system (with grid system) may be a good alternative for steel reinforcement. As an attempt to clarify the performance of unresin reinforcing system on full-scale concrete structure, an experimental study on full-scale precast concrete slab have been conducted. This study has also aimed to clarify the performance of slab at design load level before applying them to one building in Kyushu University campus.

4.1 Specimen and Test Procedure

To investigate the bending performance of full-scale concrete slab before application to a building in Kyushu University, the slab with length of 3.3m, width of 1.0m and thickness of 14cm as presented in Figure 5 was constructed. Both of main and transversal reinforcement were made of unresin CF cables. The intersection between main and transversal reinforcement were joined with epoxy resin forms a grid. The grids were hoped could develop a mechanical bonding between main reinforcement and concrete. The slab had no end-anchors so that the reinforcing action between reinforcement and concrete was fully carried by the grid.



Section A-A

Section B-B **Grid system**

Figure 5 : Specimen detail

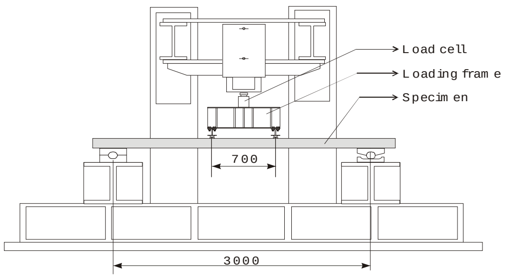


Figure 6 : Loading system

Table 4 : Material properties of concrete

Compressive strength [N/mm^2]	Tensile strength [N/mm^2]	Elastic modulus [N/mm^2]	Poisson ratio
76.9	4.48	3.62×10^4	0.24

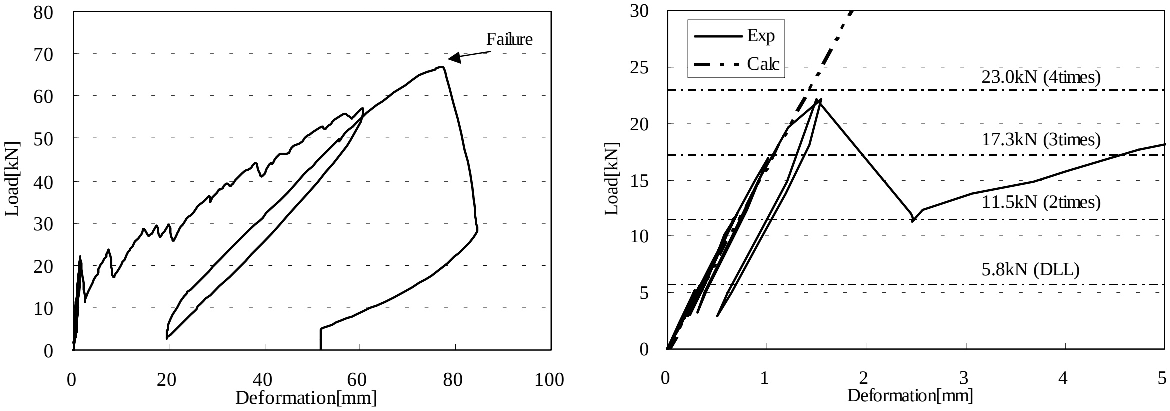
Type D of Table 2 shows the tensile test result of the CF cables that is applied main reinforcement for the slab. The cables were pretensioned under 5.0kN. Two weeks cylinder test result for concrete is presented in Table 4. The loading system is presented in Figure 6. It should be noted here that the slab was designed to carry 3.0 kN/m^2 of service load.

4.2 Test Result

Figure 7 shows the load - deformation relationship at whole response and design load level of the slab. The horizontal thick line on this graph marks the design load level (DLL=5.8kN). As it can be observed that DLL is lower than the crack load (about 22kN). This means that the slab serves the service load under un-crack condition. The behavior at un-crack region is linear. In testing, the re-loading process is done 5 times at this level. When the tensile stress at the bottom of the slab reached the tensile strength of concrete, crack occurs. This graph (b) shows that the load drops to about 11.5kN. In further load, the load was increased again. This phenomenon occurred till the slab reached its ultimate capacity at about 66kN. It was considered that this unstable response was caused by the grid pitch in which the grid pitch was too big. This cause the bond capacity becomes small and not enough to develop effective bending action.

Figure 8 and Photo 2 show crack distribution of the slab and photo of specimen under testing, respectively. The vertical straight line marks the transversal reinforcement position. The cracks grew almost instantaneously to a height of approximately 30 mm above of the base of the slab. Average crack spacing was roughly 200 mm. This was close to grid pitch.

The slab failed under compressive failure of concrete. It was observed that the crack widened and grew instantaneously. This caused the increasing at compressive strength of concrete and then the slab failed under compressive failure.



(a) : Ultimate level **(b) : Design level**

Figure 7 : Load - deformation relationship

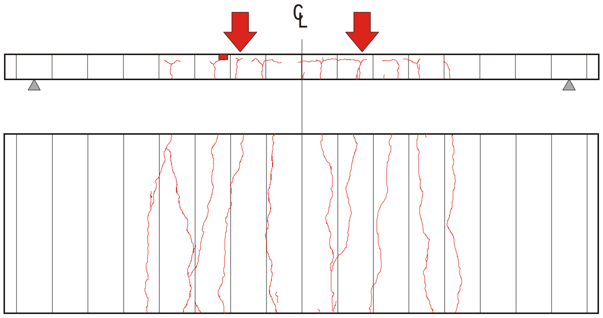


Figure 8 : Crack distribution

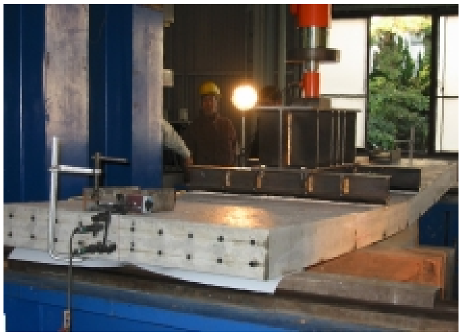


Photo 2 : Slab under testing

5. CONCLUSIONS

The results of this experimental study are summarized as follows.

1. The tensile strength of CF cable is much lower than the tensile strength of CF strand provided by manufacturer, and its ranges from 30% for cable made of 120 strands to 35% for cable made of 40 strands.
2. The slab has enough capacity to carry the service load where the service load level occurred much lower than crack load. The design load level of the slab is about one-forth of crack load. Compare to the ultimate load, the service load level is about one-tenth. In this study, it was considered that the big grid pitch caused the unstable post crack response. The distance between grids should be made closer to prevent this problem.

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