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FRP Award Winning Paper

Pultruded CFRP rods for ground anchor application

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Abstract—Carbon fiber reinforced plastic (CFRP) rods with spiral surface indentations have been developed as tension elements in prestressed concrete and as anchor tendons in place of conventional prestressing steels. The indented type CFRP rods have sufficient bonding strength to concrete without sacrificing the high tensile strength. As a low cost manufacturing process of the advanced composite, the pultrusion processing method was applied to make CFRP rods continuously. New ground anchors using the pultruded CFRP rods were installed for slope stabilization at Fukuchiyama, Kyoto in March this year.

Keywords: CFRP; pultrusion; tension elements; anchor tendon; ground anchor.

1. INTRODUCTION

Comprehensive research and development efforts have been devoted to the use of light weight and highly durable CFRP (carbon fiber reinforced plastics) as well as AFRP (Aramid fiber reinforced plastics) as an alternative material to steel reinforcements in concrete and as tension elements in prestressed concrete. Application of such materials to real structures began recently. Currently, various shapes of FRP tendon materials, such as rod, twisted and braided shapes, are being developed as FRP reinforcing materials alternative to steels. Among these materials, rod-shaped CFRP materials are drawing significant attention as the optimum material for tension elements in prestressed concrete and as tensile materials in ground anchors as their tensile strength is equal to or larger than that of PC steels and research on their durability and fixation methods is underway [1, 2].

Fabricating such CFRP materials using the pultrusion method has the advantage of being able to fabricate high strength unidirectional reinforcing rod at lower cost [3].

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However, the conventional pultrusion process only produces rods with a smooth surface which cannot ensure sufficient bonding forces with concrete or fixation materials. Therefore, it is difficult to meet the requirements of the concrete bonding properties even if a surface groove is made by secondary machining. For this reason, a new method was developed to increase concrete bonding forces by forming appropriate grooves on the rod surface without incurring cutting damage to the reinforcing fibers and while maintaining the strength by improving the pultrusion method [4].

In this paper, the characteristics of CFRP rods (CFRP tension elements) with grooves fabricated by this method are investigated. As CFRP ground anchors using such light weight and corrosion-free CFRP tension materials were certified by the Civil Engineering Research Center [5], this new type of ground anchor was adopted for a slope fire prevention construction ordered by the Kinki Local Construction Bureau of the Ministry of Construction and were completed this past March. The contents of that project are also introduced in this article.

2. CFRP TENSION ELEMENTS

2.1. CFRP rods with indentations

CRFP tension elements were fabricated in different rod shapes by using commercial carbon fibers and epoxy resin with the pultrusion method. Figure 1 shows an example of CFRP tension elements of the double-indentation type and the single-indentation type. The external diameter of the rods is 5–12 mm and the fiber volume fraction is about 65%. The indentations on the rod surfaces were continuously formed without cutting the fibers during the pultrusion process and their shape was determined from the result of examining the relationship among the indentation shape, the tensile strength and bonding strength with concrete [6, 7]. It is also possible to obtain rods with various external diameters and indentation shapes other than those shown here by a similar pultrusion process.

2.2. Characteristics of CFRP tension elements

The physical properties of CFRP tension elements are shown in Table 1 along with the physical properties of PC steel twisted wires (cited from JIS) for comparison.

When comparing both types of material under almost similar tensile loadings, the weight of CFRP tension element is less than 1/6 that of the PC steel wire, which signifies the light weight of the CFRP tension elements. As the relaxation rate of the CFRP tension elements — which is an important factor — is equal to or less than that of the PC wire, there is no problem in degradation of tension forces in actual applications.

The bonding property with concrete was assessed by inserting one end of a CFRP tension element in a $10 \times 10 \times 10\ cm^3$ concrete block whose compressive strength

Figure 1. An example of CFRP tension elements fabricated by the pultrusion method.

Table 1.
Standard physical properties of CFRP tendon and PC steel strand

	CFRP tendon 10 mm ϕ	PC steel strand SWPR7B 12.7 mm ϕ
Tensile force	19 000 kg f	18 700 kg f
Tensile strength	2790 MPa	> 1863 MPa
Young's modulus	147 GPa	196 GPa
Specific gravity	1.6	7.9
Unit weight	118 g/m	774 g/m
Relaxation ratio (at 20 °C)	2–3%	<3%
Thermal expansion	0.7×10^{-6}/°C	10×10^{-6}/°C

is 300 kg f/cm^2 while fixing the other end by a fixation grip and by extracting it with a loaded hydraulic jack following the testing method proposed by the Concrete Committee of the Japan Society of Civil Engineers [8].

Figure 2 shows the result of measuring bonding forces of CFRP tension elements with different indentation shapes by varying the indentation depth and indentation pitch within a range where no tensile strength degradation took place. The bonding force of the straight rod without indentations was less than 0.1 MPa, but by forming indentations on the rod surface, the bonding force with the concrete was increased and it was observed that the deeper the indentation depth, the larger the bonding strength. The bonding strength of the PC steel twisted wire measured by a similar method was about 5 MPa. It is possible to achieve the bonding strength equal to or larger than that of PC steel twisted wires by forming a indentation of about 0.1 mm depth on the rod surface.

2.3. Characteristics of CFRP tension materials

In CFRP tension elements made by the pultrusion (strikethrough: molding) method, fibers are oriented in the axial direction so that the high strength of carbon fibers is fully utilized and the requirements of bonding strength with concrete and fixation materials are fully met. In addition to the high strength, light weight and high corrosion resistance which characterizes CFRP materials, the non-magnetism and its ease of cutting and grinding are also important characteristics when used as a tension element alternative to PC steels. CFRP tension elements can be wound similar to PC steel twisted wires so that they can be transported and deliver in reel rolling, thus contributing to the efficiency of construction.

Table 2 shows the types of CFRP tension elements which are currently manufactured. These rods are marketed as LEADLINE^{TM} (indented type) from Mitsubishi Chemical Inc. along with the fixation system to introduce tension forces.

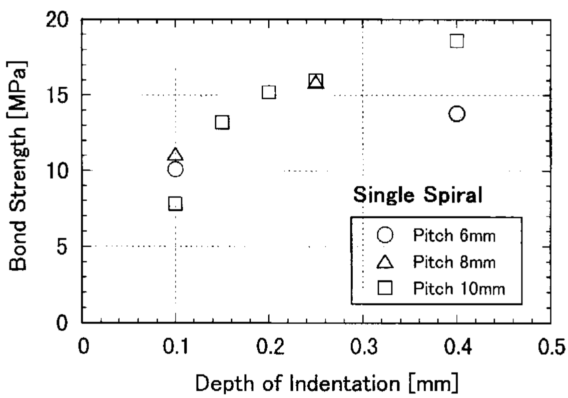

Figure 2. Relationship between the indentation shape and bonding force.

Table 2.
Types of CFRP tendons (indented type)

Diameter (mm) ϕ	5	8	10	12
Tensile force (kN)	46	120	186	282
Gross-section area (mm^2)	17.8	46.1	71.8	108.6
Weight (g/m)	30	77	118	177

3. APPLICATION TO GROUND ANCHOR CONSTRUCTION METHOD

3.1. CFRP ground anchors

Ground anchors are a system to transmit tensile forces to the foundation and are widely used to stabilize slopes or inclinations. PC steels have been used as a tension element but corrosion of PC steels due to rust poses a serious problem from the standpoint of safety and economy. So the development of a new material which can maintain its property semi-permanently has long been sought. CFRP ground anchors are permanent ground anchors that combine multiple lightweight and corrosion-free CFRP rods as tensile materials alternative to the conventional PC steels as tendons.

A CFRP ground anchor consists of the anchor head part, the tendon free length part and the end fixation part as shown in Fig. 3: both ends are fixed by CFRP tension elements and grips by cement-type grout materials. As CFRP tension elements are corrosion free, no grease for anti-corrosion is required on the free length part. Constructions can be carried out similar to the method using conventional PC steels. As CFRP tension elements have higher strength compared with PC steels, fewer rods are required, making it possible to reduce the drilling hole diameter and thus leading to reduction of construction cost. Because of the light weight of the anchors, transportation to inclined grounds and construction in small areas is easy.

3.2. Adoption to slope stabilization construction

The CFRP ground anchors using CFRP tension elements have obtained an examination certificate from the Civil Engineering Research Center, which is an authorized agency of the Ministry of Construction [5]. They were adopted for slope stabilization construction of National Highway Route 9 in Fukuchiyama City of Kyoto Prefecture as a part of special pilot project. The design anchor force was 14.0 tf, the

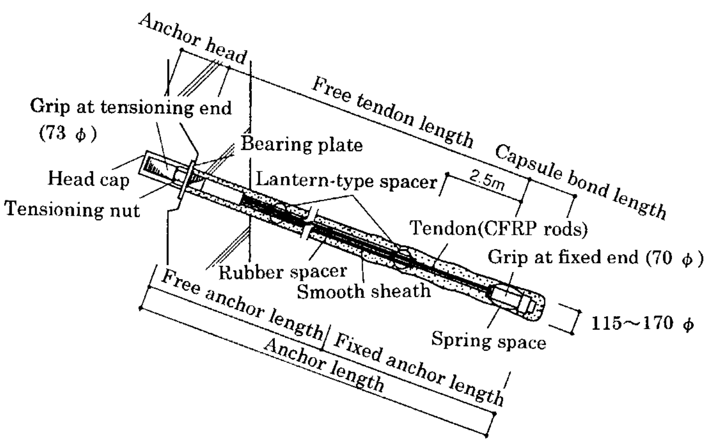

Figure 3. Components of CFRP ground anchors [5].

anchor length was 7.2 –21.2 m and 243 CFRP ground anchors were used. For tensile materials, a combination of two CFRP tension elements of diameters of 8 mm was used and the total amount of 8 mm diameter CFRP was about 6000 m.

4. EPILOGUE

In this article, it was shown that CFRP tension elements made by the pultrusion method demonstrated characteristics that are at least equal if not superior to conventional PC steel wires and they can be used as tensile materials of ground anchors.

Although the anchors in this article were originally developed to prevent small-scale landslides and steep slope falls, large capacity anchors have also been developed using CFRP tension elements that improved the tensile strength and the bonding properties. They can be potentially developed to anchors for temporary facilities. Expansion of the application range of CFRP tension elements is expected, including application of CFRP tension elements to bridge structures in Canada [9] as a fundamental resolution to prevent corrosion of steel materials during the winter season that results from the use of de-icing chemicals.

It is hoped that the use of CFRP tension elements is expanded continuously in the civil and construction fields and the establishment of long-term reliability is being sought.

Acknowledgement

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