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DEVELOPMENT OF CARBON FIBER REINFORCED THERMOPLASTIC STRAND ROD

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ABSTRACT: The purpose of the main research is to develop a more linear shape structural member using Carbon Fiber Reinforced Thermoplastic composite material. This paper will discuss the production stage begin with the instrumentation and machinery used in manufacturing, material selection for manufacturing the three-layer basic structure, and some improvement especially in material strength such as the tensile strength. In the process, fiber content and cavity ratio test, tensile strength test, alkali resistance test, temperature dependency test, weather resistance test, etc. is performed. Products that satisfy the expected performance were applied to the actual construction project. However, Carbon fiber composite materials are not included in designated building materials in the Japanese building standard. Therefore, it is difficult to apply the carbon fiber composite material in building construction in the present. An example case on a real project, carbon fiber composite materials used in structural member into the earthquake (horizontal) force resistant members.

Keywords: CFRTP, thermoplastic, structural performance, seismic reinforcement

1. INTRODUCTION

Carbon fiber reinforced thermoplastic resin (CFRTP) strand rod is known as a lightweight and sturdy material and when it is used as construction material, it will give benefits such as in cost and construction period reduction because of it does not need heavy equipment in the installation process. However, there are also disadvantages such as the high material cost of carbon fiber and low fire resistance. It is also not been recognized yet by Japanese Standards as a construction material, therefore its utilization in construction practices is limited.

Measurement tests on the basic performance of materials in the development process are conducted in this research, with the purpose to understand the structural performance required for CFRTP. The observed structural performance is used in the actual project, using CFRTP as material for seismic reinforcement. Carbon fiber (CFRTP) material used in this research is carbon fiber composite material Torayca®□T700SC shown by Figure 1.

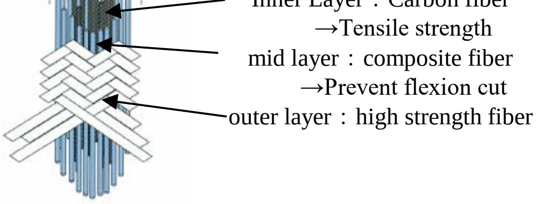

Fig.1 Structure of Carbon Fiber

2. VERIFICATION OF MATERIAL PERFORMANCE

2.1 Fiber Volume Content (VF)

Volume content (V_f) is measured by performing combustion process shown by Figure 2. Tests were conducted based on the fiber content and cavity ratio test method of carbon fiber reinforced plastic as recommended by JIS K 7075. The volume content can be calculated by:

$$V_f = W_f \cdot \frac{p_c}{p_f} \qquad (1a)$$

Fig.2 Volume content measurement

$V_f = W_f \times \rho_c / \rho_f = 82.62 \times 1.33 / 1.8 = 61.1$ (%)
Specimen density $\rho_c = 1.33$ (g) Carbon fiber density $\rho_f = 1.8$ (g)
Volume content of carbon fiber in the CFRTP used in this study was 61.1%, therefore, the ratio of the resin contained in CFRTP was 38.9%.

2.2 Tensile Strength Test

Tensile strength test was performed to understand the performance of CFRTP based on its tensile strength, standard deviation, and rigidity. The

Specimen used in the test listed in Table 1 and the test results for each specimen shown by Figure. 3 to Figure. 6 (each Figure shows a maximum load on the top left, a histogram of rigidity on the top right, and stress-strain relation on bottom).

a) Experiment Result of Specimen No. 1

The average of the maximum load P_{max} is 62.19 kN, with standard deviation σ_p of 3.74, and the average of the stiffness k is 75.1 kN / mm, with a standard deviation σ_k of 11.9. The number of carbon fibers is 4.8×10^5 pieces, and the cross-sectional area of the carbon fiber is 18.33 mm^2.

Standard deviation obtained from this specimen is the largest compared to others and it probably caused by the shape of CFRTP. Bundled carbon fiber material was manually cut and introduced into the resin, and the tip was processed into tea whisker shape.

b) Experiment Result of Specimen No. 2

The average of the maximum load P_{max} is 40.39 kN, with standard deviation σ_p of 3.28, and the average of the stiffness k is 5.93 kN / mm, with a standard deviation σ_k of 0.22. The number of carbon fibers is 2.4×10^5 pieces, and the cross-sectional area of the carbon fiber is 9.17 mm^2.

The Standard deviation for both of the maximum load and the rigidity resulted is smaller than that resulted in the specimen No. 1. This is may be caused by the manufacturing process of specimen no. 2. Unlike specimen no. 1, specimen no. 2 was manufactured using machinery.

c) Experiment Result of Specimen No. 3

The average of the maximum load P_{max} is 56.33 kN, with standard deviation σ_p of 1.71, and the average of the stiffness k is 4.20 kN / mm, with a standard deviation σ_k of 0.16. The number of carbon fibers is 2.4×10^5 pieces, and the cross-sectional area of the carbon fiber is 9.17 mm^2.

Standard deviation resulted was the smallest among specimens no. 1, no. 2 and no. 3 (all of three specimens are straight shaped carbon fibers). Small standard deviation resulted in this specimen might be caused by the improvement of accuracy in the manufacturing process. The outer layer of carbon fibers was made from PET fiber to glass fiber.

d) Experiment Result of Specimen No. 4

The average of the maximum load P_{max} is 87.22

Table 1 Specimen used in tensile strength test and results

No.	Production	Configuration	Outer layer	Edge	Amount for test	Ply/ twist
1	Manual	20 pieces of 24K	PET	No	52	No
2	Manufactured	1 piece of 24K ×10	PET	Yes	57	No
3	Manufactured	1 piece of 24K ×10	Glass	Yes	100	No
4	Manufactured	3 pieces of 24K ×7	Glass	Yes	400	Yes
Carbon fiber: Torayca®T700SC			Jig: Twist cutting steel pipe			

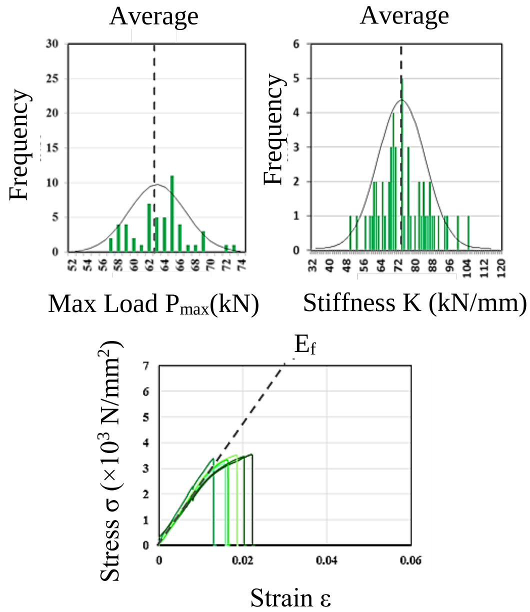

Fig.3 Tensile test result of specimen No. 1

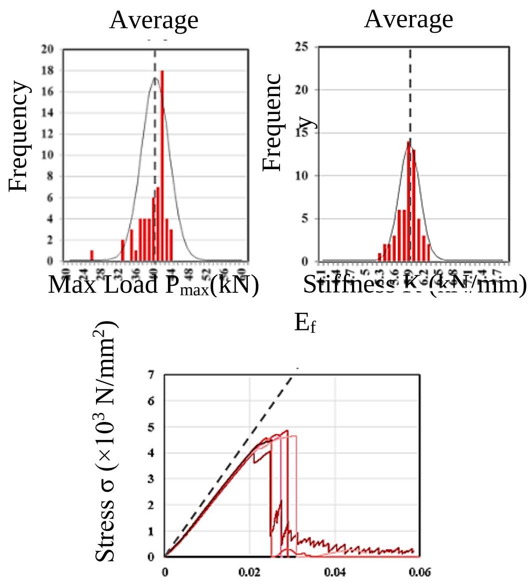

Fig.4 Tensile test result of specimen No. 2

kN, with standard deviation σ_p of 4.25, and the average of the stiffness k is 8.81 kN / mm, with a standard deviation σ_k of 0.82. The number of carbon fibers is 5.04 × 10^5 pieces, and the cross-sectional area of the carbon fiber is 19.25 mm^2.

Standard deviation resulted was bigger than that resulted in specimen no.3. This might be caused by the variation due to the shape of the specimen, which was manufactured in the twisted shape.

e) The evaluation value σ_{cu} of the reinforcing material tensile strength was calculated from the following formula (1 b)

$$\sigma_{cu} = V_f \sigma_f (1 + \frac{1 - V_f}{V_f} \cdot \frac{E_m}{E_f}) \quad (1b)$$

Fiber Volume Content V_f = 0.611
Fiber Tensile Strength σ_{fu} = 4900 N / mm²
Matrix elastic modulus E_m = 2770 N / mm²
Fiber elastic modulus E_f = 23500 N / mm²

f) The average tensile strength avσ_{cu} of only the fibers were calculated from the following formula (1c)

$$A_e = \frac{t_c}{d_c} \cdot n \quad (1c)$$

Fineness t_c = 1650 g / 1000 m
Density d_c = 1.8 g / cm³
n = Number of fibers

g) Design standard strength dσ_{cu} was calculated from the following equation (1 d)

h)

$$d\sigma_{cu} = (av\sigma_{cu}\alpha \cdot \sigma) \cdot \gamma_0 \quad (1d)$$

avσ_{cu} = The calculated average tensile strength
α (coefficient of reduction) = 3.1
σ_p = Standard deviation
γ_b (safety factor) = 0.9

Comparison of the tensile strength test result between CFRTP specimens and steel material is shown in Table 2. The maximum tensile force of specimen no. 4 (7 bundles of 24k 3 pieces) is appeared to be the same for maximum tensile force resulted from tensile strength test of PC steel. The effective strength of the carbon fiber of specimen 1 is 3,393 / 4900 = 0.69 and this strength arises due to the addition of strength from glass fiber.

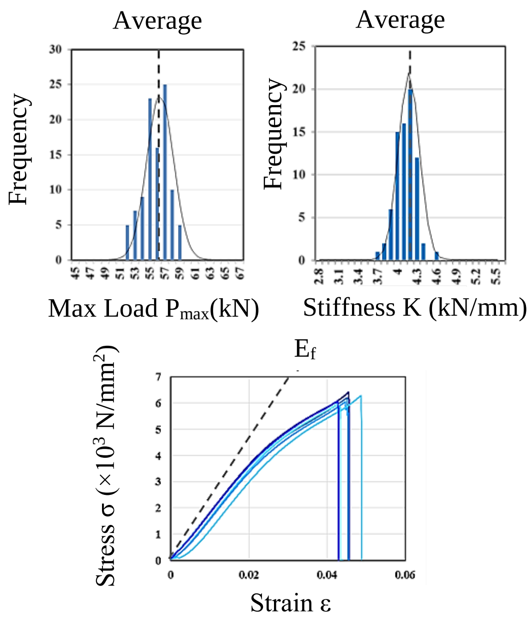

Fig.5 Tensile test result of specimen No. 3

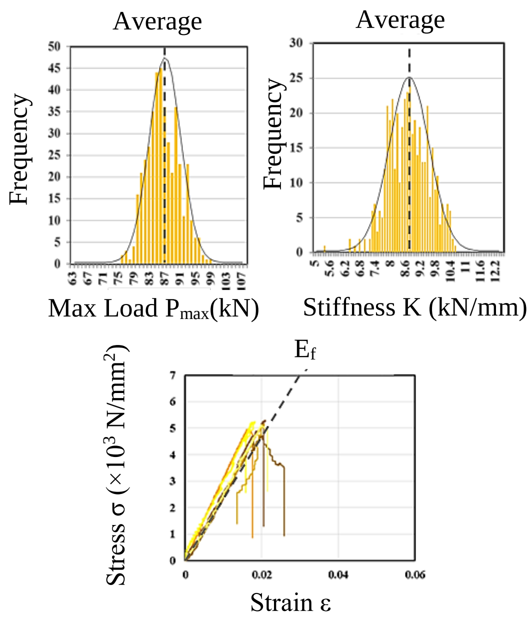

Fig.6 Tensile test result of specimen No. 4

Table 2 Comparison with steel material

Name	Diameter	Area (Carbon fiber)	Max Load	Tensile strength	Design strength
	mm	mm²	kN	N/mm²	N/mm²
No. 1	6.9	18.33	62.19	3,393	3,302
No. 2	9.4	9.17	40.39	4,405	3,987
No. 3	9.4	9.17	56.33	6,143	5,508
No. 4	9	19.25	87.22	4,531	4,048
Seven pieces twisted PC steel wire "	9.3	51.6	88.8	1,720	1,548

2.3 Thermal Expansion Coefficient

Observation of strength and thermal characteristics of CFRTP was conducted in this study using specimens listed in Table 3. Prior to the test, specimens were kept for 24 hours or more at a temperature of 20 ± 2 ° C. and a relative humidity of 65 ± 5% according to Standard temperature state class 2 and standard humidity state class 2 (JIS K 7100), then stored for another 48 hours at the measurement maximum temperature. Measurement conditions for measurement of thermal expansion coefficient are in accordance with the Test method of thermal expansion coefficient by thermomechanical analysis of continuous fiber reinforcement (draft) (JSCE-E 536-1995). From the result of the measurement of the thermal expansion coefficient, contraction starts when temperature exceeding 50 °C. This is considered to be caused by dehydration caused by dehydration and desolvation. Heat treatment is necessary as a pretreatment from this occurrence. Based on the relationship between thermal expansion coefficient measurement and pretreatment time, the specimens pretreated at 70 °C were stable at 1.64 to 1.98 × 10^{-6} / °C. The processing time is considered to be sufficient for 12 hours. The thermal expansion coefficient of the carbon fiber strand rod is less than 2 × 10^{-6} / °C. The thermal stability of CFRTP is higher than that of steel materials and concrete as shown by Table 4.

2.4 Alkali Resistance Test

Alkali resistance test of CFRTP was performed measurement of changes in appearance and maximum tensile load of the specimen after dipping in an aqueous alkaline solution. Alkaline concentration should be pH13 or higher and immersed at 60°C for 28 days. Test conditions conform to Alkali resistance test method for continuous fiber reinforcement (draft) (JSCE-E 538-1995). The test was performed using 5 specimens listed in Table 5. Table 6 shows the results of tensile strength test, and Figure. 7 shows a comparison of strength development. It was confirmed that the tensile strength after immersing in an alkaline solution at a pH of 13 or more was retained to be proof stress of more than 70%. Since the glass fiber used for the outer layer of No. 5 is a general-purpose type, it is very likely that about a 30% reduction in strength was observed. Therefore, alkali-resistant glass is considered to be superior in concrete composite materials.

2.5 Temperature Dependence Test

Temperature dependence of tensile strength is confirmed by measuring tensile strength based on the condition of the specimens. Specimens used in

Table 3 Thermal expansion test and test specimen

Carbon fiber	Carbon fiber 24K, 20 pieces (T700SC-24000)
Outer layer	PET1000d×2 pieces×12 strokes
Impregnation resin	Thermoplastic epoxy resin

Table 4 Thermal expansion coefficient of each material

Material	Thermal expansion coefficient (×10-6/°C)
Epoxy	55~60
Steel	12
Concrete	7~13

Table 5 Alkali resistance test and test specimen

No.	The outer layer of fiber
1	PET fiber 1100dtex 1×1×8 strike
2	Aramid fiber 1670dtex 1×1×8 strike
3	Aramid fiber 1670dtex 1×1×8 strike PET fiber 1100dtex 1×1×8 strike
4	Vinylon fiber 1100dtex 1×1×8 strike
5	Glass fiber75 1/3 3.8S 1×1×16 strike
6	Basalt fiber 4000dtex 1×1×8 strike

Carbon fiber structure: 24K 1 pieces ×10 pieces with a 300mm length

End/tip part (outer layer): exist, fixing resin: UM890-T80

Steel pipe nipple: diameter 14mm/20mm, with the length of 120m

Table 6 Alkali resistance test: tensile strength test result

No	Average value of maximum load	
	Before impregnated	After impregnated
1	34.39	30.45 (88.5%)
2	53	52.72 (99.5%)
3	47.88	45.06 (94.1%)
4	44.16	42.69 (96.7%)
5	56.42	40.34 (71.5%)
6	57.55	42.8 (74.4%)

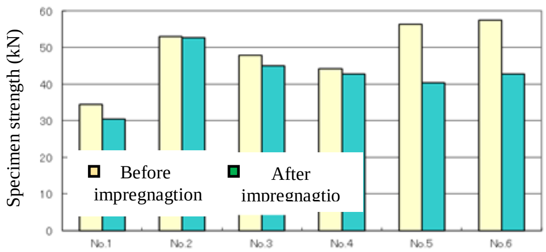

Fig.7 Comparison of strength development

the test is listed in Table 7. The test conditions are based on ASTM D 3090, where the test temperature shall be at -20 °C, 23 °C, 50 °C, or 82 °C. The results of the tensile strength test are shown in Table 8 and the displacement of the maximum load by the ambient temperature is shown in Figure. 8. The maximum load decreases as the ambient temperature rises. It is considered that it might be caused by the effect of temperature on the thermoplastic resin in the CFRTP.

2.6 Weather Resistance Test

Weather resistance performance test is conducted by performing tensile strength test after accelerated exposure test using specimens listed in Table 9. The test conditions are in accordance with Promotional exposure test method for plastic building materials (JIS A 1415) and perform an accelerated exposure test using sunshine weather meter and metering weather meter. Tensile strength test results of the specimens using the sunshine weather meter and metal weather meter are shown by Table 10 and Table 11 respectively. The sunshine weather meter 2000 hours (equivalent to 10 years), Metering ring weather meter 500 hours (equivalent to 50 years). There was almost no decrease in strength in the tensile strength test after exposure.

3. CONSTRUCTION CASE

3.1 Case Study

CFRTP of No. 4 listed in Table 1 is used is an actual seismic retrofit project of a building, which was a three-story office building built in 1968. Figure. 9 and Figure. 10 show the exterior reinforcement and interior seismic reinforcement respectively. The building geometrically regular (no eccentricity) and the structure is a rigid frame structure, with general information as follow.
Project name: Seismic retrofit/ repair work of the K head office building
Total floor area 2777 m^2
Building area 959 m^2
Floor configuration: 0 Basement 3 Floors above ground
Structure type: Reinforced concrete Construction period: From February 12 to November 10, 2015

3.2 Seismic Retrofit

This building was designed in compliance with earthquake resistance standard at the time of construction, however, it was judged to be questionable on seismic resistance on the first and second floors in the X direction and the whole Y

Table 7 Temperature dependent test and test specimen

Structure of carbon fiber	24K 1 pieces ×10 pieces
Outer layer	Glass fiber
Specimen number	3
Fixation resin	UM890-T90 Curing time: 23°C 1h+100°C 1h
Fixation jig	Steel pipe nipple

Table 8 Temperature dependent test and tensile strength test

Temperature	Failure mechanism	Average value of max. load
-20°C in the atmosphere	Base material failure	56.64
23°C in the atmosphere	Base material failure	55.86
50°C in the atmosphere	Base material failure	52.83
82°C in the atmosphere	Base material failure	35.88

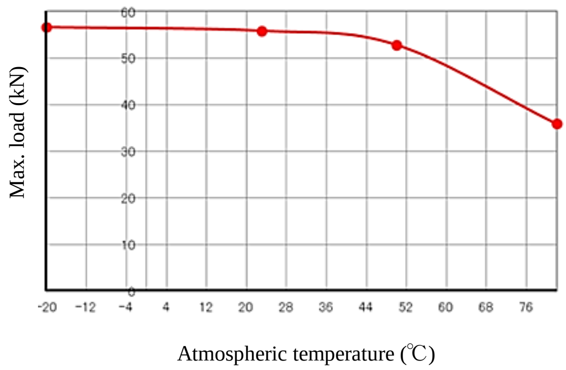

Fig.8 Atmospheric temperature and maximum load

Table 9 Temperature dependent test and test specimen

No.	Outer layer of fiber
1	PET fiber 1100dtex 1×1×8 strike
2	Aramid fiber 1670dtex 1×1×8 strike
3	Aramid fiber 1670dtex 1×1×8 strike PET fiber 1100dtex 1×1×8 strike
4	Vinylon fiber 1100dtex 1×1×8 strike
5	Glass fiber75 1/3 3.8S 1×1×16 strike
Carbon fiber structure: 24K 1 pieces ×10 pieces Fixing resin: UM890-T90 (Curing condition:23°C 1h+100°C 1h) Steel pipe: Threaded steel pipe (φ:14mm/20mm, length 120mm)	

direction after various examination on appearance observation, drawing collation, concrete strength, and concrete neutralization. Therefore, seismic retrofitting is necessary for the first and second floors in the X direction and all floors in the Y direction.

Since CFRTP is a very high-strength material, it has a performance that can be used in seismic retrofit of the entire building. Initially, it was considered to retrofit to building entirely using CFRTP, however, due to authorization limitation, CFRTP is used as an addition to conventional retrofitting to such as structural walls and slit dampers.

4. CONCLUSIONS

In this research, CFRTP with more linear shape has been developed and used as a construction material. Starting with the development of materials manufacturing machinery, it was possible to produce materials with the required performance, focusing on the tensile strength development of the CFRTP material in the three-layer structure. However, the application of CFRTP material is still a challenge because it is yet to be used as construction material due to limitation by Japanese Building Standard. This research is expected will be useful as a pioneering effort to make high-strength fiber composite materials widely used in the future and future research in material improvement such as fire resistance is recommended.

5. ACKNOWLEDGMENTS

This research is the development of a manufacturing apparatus for CFRTP rods, the project to promote the location of innovation in 2012 (an example of the development of facilities such as demonstration and evaluation of enterprises): Ministry of Economy, Trade and Industry 2012/07 - 2014 / 03

6. REFERENCES

[1] Maeda Yutaka: cutting edge technology of carbon fiber "Diffusion Edition", CMC Publishing, April 2013

[2] Izuka Yoshio: Carbon Fiber - Challenge to Complex Era -, Fiber Company, March 2012

[3] Design and Construction Guidelines for Concrete Structures Using Continuous Fiber Reinforcement (draft), Civil Engineering Society, September 1996

[4] Continuous fiber reinforced concrete structural design and construction guidelines, Japan Architectural Institute, April 2002

Table 10 Sunshine weather meter results

No	The outer layer of fiber	Average value of the max load	
		Initial condition	2000 hours
1	PET	34.39	37.42(109%)
2	Aramid	53.17	53.17 (100%)
3	Aramid/PET	46.92	46.92 (100%)
4	Vinylon	44.22	43.12 (97.5%)
5	Glass	56.42	51.68 (91.6%)

Table 11 Metaling weather meter results

	Average value of max. load	Failure mechanism
Initial condition	56.42 (100%)	Base material failure
100 hours	53.59 (95%)	Base material failure
500 hours	55.86 (99%)	Base material failure
Carbon fiber structure: 24K 1 pieces ×10 pieces outer layer: glass		

Fig. 9 Exterior Reinforcement

Fig. 10 Interior Reinforcement

[5] Otani Wataru : Research on product development of carbon fiber composite materials for construction using thermoplastic resin, 2013
[6] Tomita Atsushi: Study on laminated wood incorporating carbon fiber braid (adaptation to beam material), 2014
[7] Hiramatsu Toru: Introduction to carbon fiber composite, pp.10-118
[8] Hiramatsu Toru: Book on carbon fiber, pp.10-96
[9] Epoxy Resin Technology Association: Review Epoxy Resin Volume 4 Application Edition, 2003
[10] Maeda Yutaka: Application and market of carbon fiber, 2008