Evaluation of Applicability of FRTP to Rebar in Concrete

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Received 9 June 2021, accepted 4 March 2022  doi:10.3151/jact.20.188

Abstract

Though the thermosetting FRP (FRTS) is commonly used, its cost is very high and has not been widely used in actual structures. On the other hand, thermoplastic FRP (FRTP) can be mass-produced and the cost can be reduced. However, few studies have focused on the use of composites with concrete. This study clarifies the applicability of FRTP made of carbon fiber or glass fiber to reinforcing bars in concrete. In the case of the FRTP rod alone, the tensile strength and elastic modulus before and after exposure to water at room temperature and before and after immersion in a highly alkaline aqueous solution were evaluated. In the case of FRTP rods and concrete complexes, the variations in the pull-out test were evaluated. Based on these results, we summarize the applicability of FRTP rods to concrete reinforcements. Finally, the bending strength of concrete beams with embedded FRTP rods was evaluated experimentally and theoretically.

1. Introduction

Fiber-reinforced plastic (FRP) rods with high corrosion resistance are attracting attention for use as reinforcing bars in concrete. ISO10406-1 describes the test method, and several studies have clarified its tensile strength. The FRP used in these studies is thermosetting and has been socially implemented to date (Bradberry 2001; Nagajothi and Elavenil 2020). Unfortunately, its cost is so high that it has not been widely used in actual structures. On the other hand, fiber reinforced thermosetting plastics (FRTP) has a higher molding speed than thermosetting fiber-reinforced plastics (FRTS). Therefore, it is expected that the cost can be reduced because FRTS can be mass-produced. However, few studies have focused on the application of composites with concrete. For example, EI-Tahan et al. (2013) studied carbon fiber reinforced thermo plastics (CFRTP), and Sayed-Ahmed et al. (2017) studied glass fiber reinforced thermo plastics (GFRTP). However, only the physical properties of FRTP itself were evaluated, and it was not embedded in concrete.

To withstand the external force as a composite member, it is important that the concrete and reinforcing bars are integrated. Therefore, the adhesiveness of various reinforcing bars has been investigated. For example, the adhesive strength was evaluated when reinforcing bars of D16 to D57 were used as reinforcing bars, and the effects of the inclination angle of the side of the poutch, the spacing between the poutch, and the diameter of the rebar were investigated (Murata and Kawai 1984). In particular, in D32, it was confirmed that the variation in the measured values of the bond strength when the type of cement and the non-bond section were changed was extremely small. Furthermore, the bond strength between FRTS or FRTP rods and concrete immediately after casting was evaluated, and the effect of rib processing on the surface and coating processing with glass fiber was clarified (Imai et al. 2005; Sakuraba et al. 2019). However, although the bond strength immediately after the preparation of the specimen has been measured, the bond strength between the FRTP rod and concrete after exposure to a predetermined environment has not been investigated.

Figure 1 and Table 1 show examples of meteorological data for 2020 in Japan (JMA 2020). It can be seen that temperature and humidity differ depending on the seasons in Japan. Inland areas such as Kumagaya and Gifu have large daily temperature differences. Therefore, when FRTP rod is embedded in concrete and used in construction, it is assumed that it will be affected by temperature fluctuations. At the same time, there is concern that FRP, including FRTP, will hydrolyze, so it is necessary to consider the effects of water in the evaluation (JSCE 2018). Furthermore, to apply FRTP to concrete members, it is necessary to evaluate it in consideration of alkali resistance (Emparanza et al. 2020).

Based on the above background, this study clarifies the applicability of FRTP made of carbon fiber or glass fiber to reinforcing bars in concrete. The research flowchart is shown in Fig. 2. Section 2 evaluates the tensile strength and elastic modulus of the FRTP rod. Based on the above background, the subject was exposed to an environment in which water absorption was taken into consideration. In addition, assuming that the rod will be embedded in concrete, it was exposed to an alkaline environment. Next, Section 3 evaluates the variation in the FRTP rod pull-out test. Section 4 clarifies the bond strength between the FRTP rod and the concrete. In ad-
dition to the presence or absence of water absorption, the subject was exposed to an environment in considera-
tion of temperature fluctuations based on the above background. In Section 5, Sections 2 and 4 are summa-
rized to evaluate the applicability of FRTP rods to con-
crete reinforcements. Finally, Section 6 experimentally
and theoretically evaluates the bending strength of con-
crete beams with embedded FRTP rods.

2. Influence of water and alkaline aqueous
solution on tensile strength and elastic
modulus of FRP rod

2.1 Experimental procedure

Two types of FRTP developed in the authors et al. pro-
ject (ICC n.d.) and two types of FRTS on the market
were used as listed in Table 2. In particular, CFRTP
adheres glass fibers to make irregularities on the surface.
Also the environmental conditions are listed in Table 3.
That is, the samples were immersed in water of 20°C for
one year. In addition, according to JSCE-E 538, they
were immersed in an alkaline aqueous solution with a
pH of 13.0, using sodium hydroxide with a purity of
97% or more, for one month. After these exposures, the
tensile strength and elastic modulus were measured ac-
cording to JIS A 1192. Here, regarding the grip part of
the FRP rod, the fixing method developed by Harada et
al. (1999) was referred to. As shown in Fig. 3, a thread
was provided inside the steel pipe sleeve with a length
of 200 mm and an inner diameter of 18 mm, which was
used as a fixing tool. In addition, according to Yamada
et al. (1999), the FRP rod was fixed using the static
crushing agent shown in Table 4, and the FRP rod was
cured by standing in air for 7 days before the test. Five
test samples were used in each case.

Fig. 2 Research flowchart.
2.2 Experimental results

Figure 4 shows the experimental results before exposure to CFRTP as a measurement example of the tensile test. According to this figure, it was confirmed that the variation in the tensile strength-strain of the five test materials was small. In addition, in all the experimental results, it was confirmed that the variation was within 20% of the average tensile strength. Table 5 shows the Maximum value, minimum value and average value of tensile strength.

Figure 5 shows the relationship between the tensile strength before and after immersion in water. Figure 6 shows the relationship between the elastic modulus be-

| Type | Appearance | Materials (Fiber / Resin) | Diameter (mm) | Sectional area (mm²) | Surface shape | Fiber Tensile strength (N/mm²) | Modulus of elasticity (kN/mm²) | Vf (%) |
|------|------------|--------------------------|--------------|---------------------|--------------|-------------------------------|-------------------------------|--------|
| CFRTP |  | Carbon / Thermoplastic epoxy | 9.0 | 49.7 | Strand (7 wires) | 4900 | 230 | 70 |
| GFRT |  | E-Glass / Polypropylene | 4.4 | 15.2 | Strand (1 wire) | 1500 | 74 | 25 |
| CFRTS |  | Carbon / Epoxy | 8.0 | 50.3 | Deformed | 5000 | 230-240 | 58 |
| GFRTS |  | Glass / Polyester | 9.0 | 63.6 | Nondisclosure by maker |  |  | 75 |

Table 3 Exposure environmental condition in Section 2.

| Immersion condition | Temperature | Exposure period |
|---------------------|-------------|-----------------|
| Tap water           | 20°C        | 1year           |
| High alkaline aqueous solution | 60°C | 1month |

(a) Before fix  
(b) After fix.

Fig. 3 Jig part.
fore and after immersion in water. From these results, it was confirmed that the tensile strength and elastic modulus before and after exposure were similar for all types of reinforcing bars.

Figure 7 shows the relationship between the tensile strength before and after immersion in an alkaline aqueous solution. Figure 8 shows the relationship between the elastic modulus before and after immersion. From these results, it was confirmed that the tensile strength and elastic modulus before and after immersion were approximately the same for all reinforcing bar types. Since the standard concentration is very severe, it is considered that the alkali resistance in general concrete could be verified. However, further exposure period experiments may be required for long life structures.

3. Evaluation of variation in bond strength between CFRTP rod and concrete

3.1 Experimental procedure

Table 6 shows the types and characteristic values of the materials used for the concrete, and Table 7 lists the composition. The slump was 8.5 cm, and the air content was 3.1%. Forty-eight hours after the concrete was poured, the mold was removed, and underwater curing was performed. The compressive strength at 14 days of age was 31.7 N/mm².

Figure 9 shows an outline of the specimen. In accor-

| Type     | Before exposure | after immersion in tap water | after immersion in high alkaline aqueous solution |
|----------|-----------------|-----------------------------|-----------------------------------------------|
| CFRTP    | 1344.1          | 1338.0                      | 1340.0                                       |
| GFRTS    | 1217.3          | 1285.1                      | 1372.4                                       |
| CFRTS    | 2128.7          | 1974.3                      | 1766.6                                       |
| GFRTS    | 2098.9          | 2009.9                      | 1974.3                                       |
| GFRTS    | 1174.2          | 1126.7                      | 1195.6                                       |
| GFRTS    | 1057.1          | 1127.1                      | 1171.1                                       |

Tensile strength is listed in the order of maximum value, minimum value, and average value.
dance with JSCE-E 539, bond with a length four times its diameter was provided on the free end side. Table 8 lists the types of materials used as reinforcing bars. In other words, two types of reinforcing bars and FRTP using carbon fibers whose surface did not have any roughness were used. A pull-out test of 17 specimens was performed for each reinforcing bar, and the adhesive strength with concrete was measured. In order to confirm bond, the attachment part of the specimen was cut after the pull-out test and the length was measured. The bond strength was calculated from Eq. (1).

$$\tau = \frac{P}{\pi D l}$$  \hspace{1cm} (1)

where $$\tau$$: Bond strength (N/mm²); $$P$$: Pull-out load (N); $$D$$: Diameter (mm); $$l$$: Bond length (mm).

### 3.2 Experimental result

Table 9 shows all the measurement results. Based on this table, Fig. 10 shows the relative frequency distribution and normal distribution in the bond strength between the reinforcing bar and concrete. Here, the normality was verified by the Shapiro-Wilk test shown in Table 10. According to this table, since the P value in both cases is higher than the significance level of 0.05, it can be confirmed that the distribution follows a normal distribution (Nakagawa 2019). Next, Table 11 shows the mean, standard deviation and coefficient of variation. According to this table, it can be seen that the coefficient of variation is about the same regardless of the type of reinforcing bar. Therefore, in the next section,
it was determined that the evaluation can be performed using the average value.

In addition, the adhesive strength of the reinforcing bar to the concrete was higher than that of CFRTP. Here, since the materials of CFRTP and reinforcing bars are different, the surface shape is focused. That is, it has been reported that the more complicated the surface shape, the higher the bond strength (Sakuraba et al. 2019), so in CFRTP with less surface irregularities, it is considered that the bond strength has become relatively small.

### 4. Influence of water and temperature fluctuation on bond strength between FRP rod and concrete

#### 4.1 Experimental procedure

The materials and formulations used for the concrete were the same as those used in Section 3. The types of rods are listed in Table 12. The same types were used as in Section 2, namely all four types of FRP. However, because GFRT P has a small diameter and a large de-
flection, it was tied with a band and combined in a bundle of 7 so that the rod material would not be deformed or damaged in the process from casting to the pull-out test.

Table 13 lists the environmental conditions. That is, in the case of a stable environment, the rods were exposed to water at 20°C for one year. On the other hand, for an unstable environment, 12 h was regarded as one cycle of temperature fluctuation, and the rods were exposed to water or air for 200 cycles. To measure the strain of the rod during temperature fluctuation, a strain gauge was attached to the surface of the rods. Here, the twist angle of the CFRTP was 5° with respect to the axial direction. Therefore, the amount of strain in the axial direction was calculated by multiplying the measured strain value of the gauge attached to the strand by 1.004. In addition, a temperature sensor was embedded in the concrete. In calculating the strain, the influence of temperature was corrected using the formula (2).

\[
\varepsilon' = \varepsilon - (\alpha_G - \alpha_{FRP}) \times t
\]

where \(\varepsilon'\): strain after temperature correction (μ); \(\varepsilon\): strain before temperature correction (μ); \(\alpha_G\): coefficient of thermal expansion of strain gauge (×10⁻⁶/°C); \(\alpha_{FRP}\): thermal expansion coefficient of FRP (×10⁻⁶/°C); \(t\): fluctuation temperature (°C).

The pull-out test complied with JSCE-E 539. Three specimens were used in each case. The bond strength of specimen attached the strain gauge was slightly lower, so if the test result as significantly affected, it was excluded from the measured values.

### 4.2 Experimental result

Figure 11 shows a comparison of the bond strength before and after exposure when immersed in water in a stable environment. It was confirmed that the bond strength before and after exposure was the same for all types of rods. From this, it can be judged that there was no time-dependent deterioration of the bond between the concrete and the rod due to the hydrolysis of FRP and the alkaline action of the pore solution of the concrete. This is supported by the high water resistance and alkali resistance of the FRP used as shown in Figs. 5 - 8.

These results can be compared with previous studies that focused on the bond strength. According to Bamonte et al. (2003), the bond strength between concrete and reinforcing bars was reported to be approximately 6.5 to 16.3 N/mm². Therefore, it was confirmed that the bond strength with GFRTP was equivalent to that of the reinforcing bar. In addition, it was confirmed that the bond strength of CFRTP was higher than that of the reinforcing bar.

Figure 12 shows a comparison of the bond strength before and after exposure to an unstable air environment. Similarly, Fig. 13 shows a comparison of the bond strength before and after
exposure in an unstable underwater environment. From these results, it was confirmed that the bond strength before and after exposure was the same for GFRTP and GFRTS regardless of whether they were in air or water. However, with CFRTP and carbon fiber reinforced thermosetting plastics (CFRTS), it was confirmed that the bond strength after exposure decreased. This is considered based on the coefficient of thermal expansion. The coefficient of thermal expansion of concrete is \(10 \times 10^{-6}/^\circ\text{C}\) (JSCE 2017). As shown in Table 11, the coefficients of thermal expansion of GFRTP and glass fiber reinforced thermosetting plastics (GFRTS) are equivalent to those of concrete. On the other hand, because the difference in the coefficient of thermal expansion between concrete and CFRTP and CFRTS is large, it is considered that repeated raising and lowering temperatures reduced the adhesive force.

Figure 14 shows the temperature and rod strain for any two cycles during exposure to an unstable air environment. The theoretical value of concrete strain is also plotted in this figure. According to Fig. 14, it was confirmed that the strains of GFRTP, GFRTS, and concrete were linked to the temperature and had almost the same values. On the other hand, in CFRTS, the values are linked to the high and low temperatures like the strain values of concrete, but the value when the strain is large is different. This is because the coefficient of thermal expansion of CFRTS is smaller than that of concrete, so that there is a difference in elongation between the rod and concrete during a rise in temperature. Therefore, it is probable that because the shape is uneven, as shown in Table 11, the rod and concrete are both stretched owing to the physical meshing effect, but the bond is reduced. Furthermore, as shown in Fig. 15, in CFRTP which has a large difference in thermal expansion coefficient from that of concrete, the above-mentioned deformation phenomenon becomes excessive, resulting in a decrease in the bond. Moreover, because the shape is a stranded wire, the physical meshing effect is small, so CFRTP could not follow the elongation of the concrete, and the strain did not exceed approximately 250 μ.

5. Applicability of FRTP to rebar in concrete

In Sections 2-4, elemental tests were conducted to clarify the applicability of FRTP to concrete reinforcements. In Section 2, the tensile strength and elastic modulus of the rod itself after exposure to water or an alkaline aqueous solution were evaluated. In Section 4, the presence or absence of water and the bond strength between the rod and concrete after exposure to temperature fluctuations were evaluated. Based on these results, Table

![Fig. 12 Comparison of bond strength between before and after exposure in air under nonstationary condition.](image1)

![Fig. 13 Comparison of bond strength between before and after exposure in water under nonstationary condition.](image2)

![Fig. 14 Strain of rod and temperature under nonstationary condition.](image3)
summarizes the environments that are difficult to apply to concrete reinforcements. That is, GFRTP and GFRTS are applicable in the environments evaluated in this study. According to Fig. 14, the strains of concrete and rod are the same in all FRPs when the room temperature is in the temperature range of 0°C to 30°C. Therefore, at approximately room temperature, CFRTP and CFRTS are also considered to be applicable as reinforcing bars for concrete.

### Table 14 Environment that is difficult to apply to rebar in concrete.

| Type   | Tensile strength of rod alone | Bond strength between concrete and rod | Difficult environment to apply |
|--------|-------------------------------|----------------------------------------|--------------------------------|
| CFRTP  | No effect of water            | No effect of water                     | Temperature fluctuation of 30°C or more in a short time |
| CFRTS  | No effect of water and high alkaline | Decreased in a temperature fluctuation environment | |
| GFRTS  | No temperature fluctuation, no effect of water | Not applicable in this research | |
| GFRTS  | No effect of water and high alkaline | | |

### Table 15 Mixture proportion of concrete for bending test.

| W/C (%) | s/a (%) | W  | C  | S  | G  | Air entraining and high-range water reducing agent | Air entraining agent (kg/m³) |
|---------|---------|----|----|----|----|-----------------------------------------------|-----------------------------|
| 33.0    | 40.0    | 175| 530| 636| 961| 2.65                                         | 0.0265                      |

14 summarizes the environments that are difficult to apply to concrete reinforcements. That is, GFRTP and GFRTS are applicable in the environments evaluated in this study. According to Fig. 14, the strains of concrete and rod are the same in all FRPs when the room temperature is in the temperature range of 0°C to 30°C. Therefore, at approximately room temperature, CFRTP and CFRTS are also considered to be applicable as reinforcing bars for concrete.

### 6. Bending strength of concrete beam with FRTP rod

#### 6.1 Experimental procedure and theoretical calculation procedure

The materials used for concrete were the same as those used in Sections 3 and 4. Table 15 lists the concrete compositions. The slump was 18.0 cm, and the air content was 4.0%. Twenty-four hours after the concrete was poured, the mold was removed and exposed to moist air (RH 90%) at 20°C for 14 days. Figure 16 shows the

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![Image diagram in which concrete and CFRTP are displaced due to temperature fluctuations.](image1)

Factors that reduce bond strength
- Coefficient of thermal expansion of CFRTP is small
- Shape is a stranded wire

The meshing effect is small, so CFRTP can not follow the elongation of concrete.

![Bending test specimen and loading situation.](image2)
outline of the specimen and the loading test. Four types of FRP rods and reinforcing bars (diameter 9.5 mm, SD345) as used in Section 2 were used as reinforcing bars, and one of each was embedded in concrete. During the bending load test, a displacement meter was installed at the center of the specimen. 14 stirrups made of carbon steel with a diameter of 6 mm were buried between the loading point and the fulcrum to prevent shear fracture and to precede bending fracture. A bamboo stick was used to assemble the reinforcement.

To calculate the theoretical value, the bending strength is given by Eq. (3), and the bending fracture load is given by Eq. (4).

\[
M_u = A_t \times f_y \times \left( d - \frac{A_t \times f_y}{2 \times 0.85 \times f'_c \times b} \right) \tag{3}
\]

\[
P_a = \frac{2 \times M_u}{a} \tag{4}
\]

where \(M_u\): bending strength (kN mm); \(A_t\): cross-sectional area of reinforcing bar (mm²); \(f_y\): tensile strength of reinforcing bar (N/mm²); \(d\): effective height of beam (mm); \(f'_c\): compressive strength of concrete (N/mm²); \(b\): width of cross section (mm); \(P_a\): bending fracture load (kN); \(a\): distance between loading point and fulcrum (mm).

### 6.2 Experimental result

Figure 17 shows the relationship between the load and the span center displacement. Figure 18 shows the bending fracture load obtained from the experiments and theoretical formulae. According to these figures, it was confirmed that CFRTP has a large bending fracture load similar to that of CFRTS, and toughness reaches the end. On the other hand, it was confirmed that GFRTP has a small diameter and low tensile strength at the trial stage, so that the bending fracture load is small and brittleness reaches the end. Here, the tensile rebar ratio and the balanced rebar ratio are shown in Table 16. According to this, the tensile rebar ratio of GFRTP is significantly lower.

Figure 19 shows sketches of the occurrence of cracks and peeling at the maximum load in the experiment.

| Type      | Tensile rebar ratio | Balanced rebar ratio |
|-----------|---------------------|----------------------|
| CFRTP     | 0.7                 |                      |
| GFRTP     | 0.2                 |                      |
| CFRTS     | 0.6                 | 1.2                  |
| GFRTS     | 0.7                 |                      |
| SD345     | 0.8                 |                      |

Fig. 17 Relationship between load and displacement.

Fig. 18 Comparison of maximum load.

Fig. 19 Sketches of crack occurrence situation at maximum load.
Bars. Moreover, the experimental and theoretical values of CFRTS and higher than that of GFRTS and reinforcing which CFRTP is embedded is equivalent to that of CFRTP. Adhering less to concrete in an environment. CFRTP adheres less to concrete in an environment. The measurement results of the pull-out test between the CFRTP and concrete were normal.

In water and aerial environments subject to temperature fluctuations of 0–60°C, the bond strength between GFRTP and concrete is the same before and after exposure. However, the bond strength between the CFRTP and concrete decreases after exposure. This is because the coefficient of thermal expansion of concrete and CFRTP is different, and the interface between the concrete and FRP rod shifts with the temperature rise and fall.

CFRTP and GFRTP are considered to be applicable as reinforcing bars for concrete with or without water in the environment. CFRTP adheres less to concrete in an environment with temperature fluctuations of 30°C or higher.

The bending strength of a concrete beam specimen in which CFRTP is embedded is equivalent to that of CFRTS and higher than that of GFRTS and reinforcing bars. Moreover, the experimental and theoretical values of the bending strength were the same. The GFRTP in the trial production stage has a small diameter, low tensile strength, and low bond strength to concrete; thus, the bending strength is small.

7. Conclusion

This study evaluated the applicability of FRTP rods to use in concrete reinforcements. The conclusions are as follows.

For the CFRTP and GFRTP rods, the tensile strength and elastic modulus before and after exposure to water at room temperature for one year and before and after immersion in a highly alkaline aqueous solution for one month are the same.

The bending strength of a concrete beam specimen in which CFRTP and concrete were normal.

In water and aerial environments subject to temperature fluctuations of 0–60°C, the bond strength between GFRTP and concrete is the same before and after exposure. However, the bond strength between the CFRTP and concrete decreases after exposure. This is because the coefficient of thermal expansion of concrete and CFRTP is different, and the interface between the concrete and FRP rod shifts with the temperature rise and fall.

Acknowledgements

This research was carried out by the COI program “Construction of next-generation infrastructure system using innovative materials” (JPMJCE1315) by the Ministry of Education, Culture, Sports, Science and Technology and the Japan Science and Technology Agency. Former students Mr. Satoshi Terada, Mr. Ibuki Akai, and Mr. Takumi Goto supported the experiment. In addition, Associate Professor Hidetaka Yamaoka provided support for statistical analysis. We are deeply grateful to you for this paper.

References

Bamonte, P., Coronelli, D. and Gambarova, P. G., (2003). “Smooth anchored bars in NSC and HPC: A study on size effect.” Journal of Advanced Concrete Technology, 1(1), 42-53.

Bradberry, T. E., (2001). “Concrete bridge decks reinforced with fiber-reinforced polymer bars.” Transportation Research Record, 1770(1), 94-104.

Ei-Tahan, M., Galal, K. and Hoa, V. S., (2013). “New thermoplastic CFRP bendable rebars for reinforcing structural concrete elements.” Composites Part B, 45(1), 1207-1215.

Empananza, A. R., Morales, C. N., Palacios, J. M., De Caso, F. and Nanni, A., (2020). “Durability assessment of GFRP rebars exposed to high pH-seawater.” In: Proc. of 15th International Conference on Durability of Building Materials and Components, 1-8.

Harada, T., Idemitsu, T., Khin, M., Soeda, K. and Watanabe, A. (1999). “A study on anchorage method for continuous fiber reinforcing materials (FRP) using highly expansive material.” Journal of JSCE, 62(44), 77-90. (in Japanese)

ICC, (n.d.). “Organization for Advancement of COI Research.” Kanazawa Institute of Technology, Available from: <https://www.icc-kit.jp/coi/en/index.html> [Accessed 21 May 2021].

Imai, F., Shimozaki, T., Kiku, S. and Nakazawa, T., (2005). “Study on sleeve anchoring of CFRP rods and bond performance of the rods to mortar.” Proceedings of the Japan Concrete Institute, 27(2), 727-732. (in Japanese)

JMA, (2020). “Climate in Japan.” Tokyo: Japan Meteorological Agency. Available from: <https://www.data.jma.go.jp/tcc/tcc/products/japan/index.html> [Accessed 15 February 2021].

JSCE, (2017). “Standard specifications for concrete structures - 2017: Design.” Tokyo: Japan Society of Civil Engineers, 44. (in Japanese)

JSCE, (2018). “Report on research subcommittee for structural use of fiber reinforced concrete (Second stage) (Concrete technology series 119).” Tokyo: Japan Society of Civil Engineers. (in Japanese)

Murata, J. and Kawai, T., (1984). “Study on bond strength of deformed bars by pull-out tests.” Journal of JSCE, 348, 113-122. (in Japanese)

Nagajothy, S. and Elavenil, S., (2020). “Shear Prediction of geopolymer concrete beams using basalt/Glass FRP bars.” Journal of Advanced Concrete Technology, 19(3), 216-225.

Nakagawa, S., (2019). “Testing for normality.” Tokyo: Kyoritsu Shuppan, 39-41. (in Japanese)

Sakuraba, H., Kawashima, Y. and Nishizaki, I., (2019). “Tests for bond, tension and alkaline resistance of CFRTP tendon.” In: Proceedings of the 13th Symposium Research and Application of Hybrid and Composite Structures, 313-319. (in Japanese)

Sayed-Ahmed, M. S., Hajimiragha, B., Hajimiragha, B., Mohamed, K. and Bennokrane, B., (2017). “World’s first thermoplastic GFRP mfx-bars subjected to creep effects.” In: Proceedings of Fifth International
Conference on Durability of FRP Composites for Construction and Rehabilitation of Structures, Sherbrook Canada 19-21 July 2017, 1-8.
Yamada, K., Harada, T., Idemitsu, T., Soeda, K. and Khin, M., (1999). “Experimental study on the durability of highly expansive material for anchorage in high pressure conditions.” Journal of JSCE, 634(V-45), 145-156. (in Japanese)