コンクリート工学年次論文報告集, Vol.16, No.2, 1994

論 文

[2191] Experimental Study on Bond Property of Various FRP Rods as Reinforced Concrete Member

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1. INTRODUCTION

Many extensive researches have been carried out for the practical usage of Fiber Reinforced Plastics (FRP) rods in the fields of concrete structure construction. Since FRP rods are produce commercially a few years ago, there are still many unknown factors that must be made clear so that these materials can be used with safety and reliability.

The authors have conducted an experimental study on bond property of various FRP rods. Although no standard testing method for the FRP rods have been established, we referred to that of the provisional testing procedures of The Japan Society of Civil Engineers (JSCE).

Twelve kinds of FRP rods having different types of materials, matrix and diameters were used in this study. Some relationship between slippage and bond stress of different diameters and materials were investigated.

2. OUTLINE OF EXPERIMENT

2.1 Materials

Twelve kinds of FRP rods are used in this experiment. The outline of FRP rods are shown in table 2.2. There are 7 kinds of carbon FRP, 4 kinds of aramid FRP and a single kind of Vinylon FRP rod. The matrix material for all the rods are of epoxy except SA type aramid is of vinyl-sterol. The diameter and cross-sectional area are the maker values but the modulus of elasticity and tensile strength are determined by the authors. The concrete mix-design used in the experiment is shown in table 2.1.

Table 2.1 Concrete Mix-design

W (kg)	C (kg)	W/C	S (kg)	G(L)kg	G(S)kg	Slump
198	330	60	849	378	568	13.3cm

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Table 2.2 Outline of FRP rods.

Type	Code	Φ mm	Area, cm^2	Matrix matl.	ME,x10^6 kgf/cm^2	Ten.str kgf	Surface Condition
Carbon	LC1	5	0.196	Epoxy	1.60	17316	Twirl
"	LC2	10	0.502	"	1.60	13628	"
"	TC1	5	0.101	"	1.29	19555	Strand
"	TC2	7.5	0.304	"	1.31	21218	"
"	TC3	12.5	0.760	"	1.42	16700	"
"	KC1	6	0.283	"	1.37	19275	Spiral
"	KC2	8	0.502	"	1.37	18154	"
Aramid	SA2	8	0.502	V.S**	0.50	18701	"
"	MA1	6	0.250	Epoxy	0.64	12900	Braid
"	MA2	8	0.500	"	0.61	15498	"
"	MA3	12	1.000	"	0.68	13400	"
Vinylon	KRV2	8	0.502	"	0.26	7604	Spiral

Note; V.S**: Vinyl-ester. ME: Modulus of elasticity.

2.2 Test specimen fabrication

The FRP rods are cut into 90 cm length. The 10 cm cube steel formworks having an opening at the center are used for concreting. The center hole is made so that the FRP rod can protrude about 5 mm into the rubber cork capped on the opening. Figure 2.1 shows the outline of the specimen. The FRP rod in the concrete have 60mm of bonded and 40 mm of unbonded portion. The unbonding is made by wrapping the rubber tape on it. Also a rigid frame is made to hold the rod in vertical position.

The other end of the FRP rods are anchored in steel sleeve by using highly expansive agent. First the FRP rods are placed at the center of the steel sleeve and a slurry of mixture of highly expansive agent and water was poured into the small opening between the steel sleeve and the FRP rod. The 2 mm strain gauges are used to measure the longitudinal and tangential strains on the steel sleeves for the expansive pressure of the agent. From the strain readings the expansive pressure was calculated. Normally, the expansive pressure reached about 400 kgf/cm^2 within 48 hours. The concrete specimens are cured in water for 28 days before the pull-out test in the curing room. The compressive strength of concrete is ranged in 300 kgf/cm^2.

2.3 Test procedures

The pull-out test for bond property was carried out using the provisional testing procedures of JSCE [1]. The assemblage is shown in figure 2.2. A universal testing machine was used for the pull-out test. The concrete block was laid on the steel frame with steel plate and rubber packing. An electrical transducer of 1/1000 mm sensitivity is fixed on the top of the concrete block and the pointer is placed on the protruding portion of the FRP rod. The steel sleeve is fixed firmly by the jaw chuck at the bottom. The machine frame was raised slowly and uniformly. The load and slippage was recorded simultaneously by personal computer and data logger.

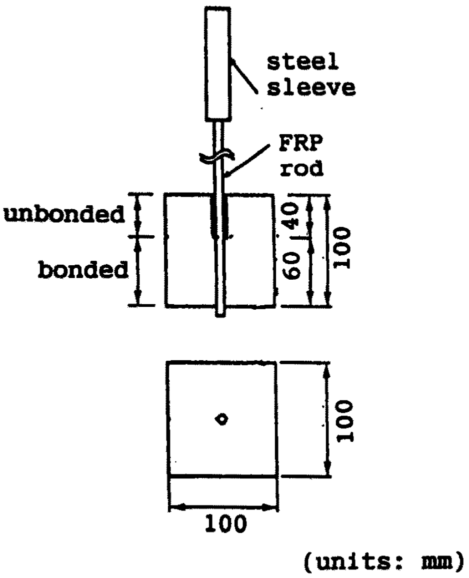


Fig. 2.1 Outline of specimen

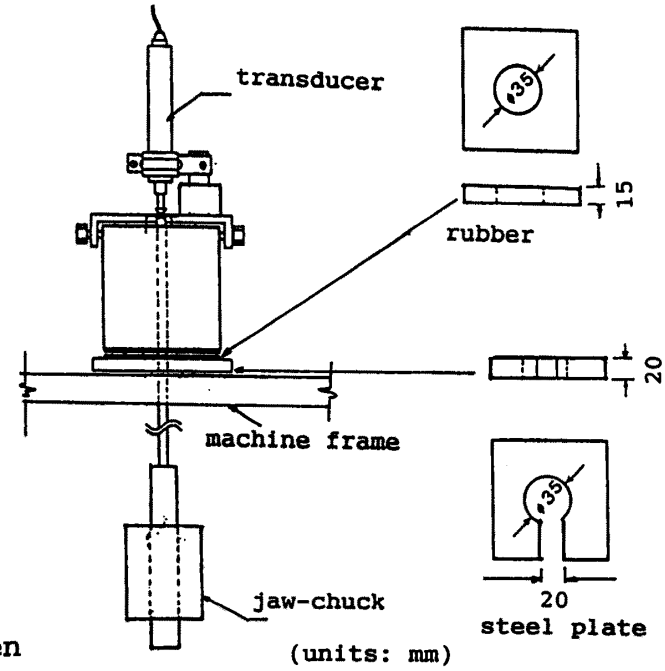


Fig. 2.2 Test assembly

3. RESULTS AND CONSIDERATIONS

The bond stress "τ" is calculated using conventional method. The typical bond stress versus slippage of FRP rods are shown in figure 3 (a)~(f). Three specimens are tested for every FRP rod. The average bond stresses at three levels of slippage and maximum bond stress are shown in table 3.1. From the bond stress versus slippage graphs of FRP rods, three types of bond-slip relationship were found.

The first group has the gradually increasing nature of bond-slip relationship (MA & LC). The initial bond stress at 0.1mm slippage is about 50% to 60% of the maximum bond strength. The second group of FRP rods consisting of TC, SA and KRV showed a sudden change of slipping at 70% to 90% of its maximum bond stress levels, after that sudden change only followed by small increments. The third group with KC type showed an intermediate nature between the first and the second group. The initial bond stress in this case is about 50% of the maximum bond stress level.

(a) First group (LC, MA type)

The rods consisting in the first group are LC rod having large spiral with wide pitch and MA rods with braided surface.

On the LC rod's surface, the pitch of spirals are about five times that of the other spirals types (KRV,SA,KC). In this case it is considered that the first stage of slipping of rods are outstanding than the other spiral-type rods. At maximum level of slippage, the large spirals of LC rod created wedge-action and it was followed by fracture.

Table 3.1 Bond strength of FRP rods

Symbol	Types	Φ mm	Area cm^2	Average "τ" kgf/cm^2 at slip			
				0.05mm	0.1mm	0.25mm	Max.
LC1	carbon	5	0.196	41.9	58.1	88.7	156.4
LC2	"	10	0.502	79.2	90.4	97.9	123.1
TC1	"	5	0.101	41.2	43.7	43.8	44.7
TC2	"	7.5	0.304	50.5	52.6	53.6	54.4
TC3	"	12.5	0.760	84.2	88.2	87.1	94.2
KC1	"	6	0.283	55.6	60.6	65.3	136.7
KC2	"	8	0.502	73.4	79.9	84.8	142.2
SA2	aramid	8	0.502	61.3	80.2	92.5	118.0
MA1	"	6	0.250	22.5	32.8	51.2	78.0
MA2	"	8	0.500	67.0	79.1	99.8	128.9
MA3	"	12.0	1.000	13.7	20.3	37.2	87.2
KRV2	vinylon	8	0.502	85.4	89.3	92.3	93.4

The surface of braided-type have mild deformations(photo 1). The slippage in initial stage was also comparatively steady. However, at the maximum level of slippage, the cracking of concrete was observed on all the MA type specimens. This consideration is supported by the findings at the open-cut observations. Some abrasions were found on the MA type rod (photo 2) and also traces of fibers on the concrete. This is considered that wedge-action took place by the high poisson ratio of MA rods. The expansion of MA rods due to the poisson-effect increased with the diameter. And also the deformation on surface becomes larger with the diameter. Therefore, the bond strength of MA rods have peak value related to the diameter.

(b) Second group (TC,SA,KRV type)

In the second group of FRP rods, the initial bond stress was increasing with little or no slippage. However, at one level of bond stress, the FRP rods of this group slipped and failed. No cracks were found and the sinking of free end of the rod into the concrete was clearly observed on all the specimens of this group.

In the TC type in this group(photo 2), a clear grooves indented by the rod were found on the concrete at the open-cut observation. This showed that the TC strands slide along the grooves at the maximum load. The roughness of the surface of TC rods increased with its diameter, so also the bond strength with its diameter. Therefore, the bond strength of TC strands depend on the adhesion of the fibers to the concrete.

As for the other type of FRP rod of SA and KRV in this group, the rods slipped through the concrete, regardless of the mechanical friction of the spirals. In the open-cut observations for these rods, it was found that the spirals peeled-off from the rods with some broken spirals. Therefore, it is considered that FRP rods slipped through the spirals at the maximum load. In this case it can be concluded that the bond strength of SA and KRV type rods depend on the adhesion of the spirals to the rods and the strength of spiral itself.

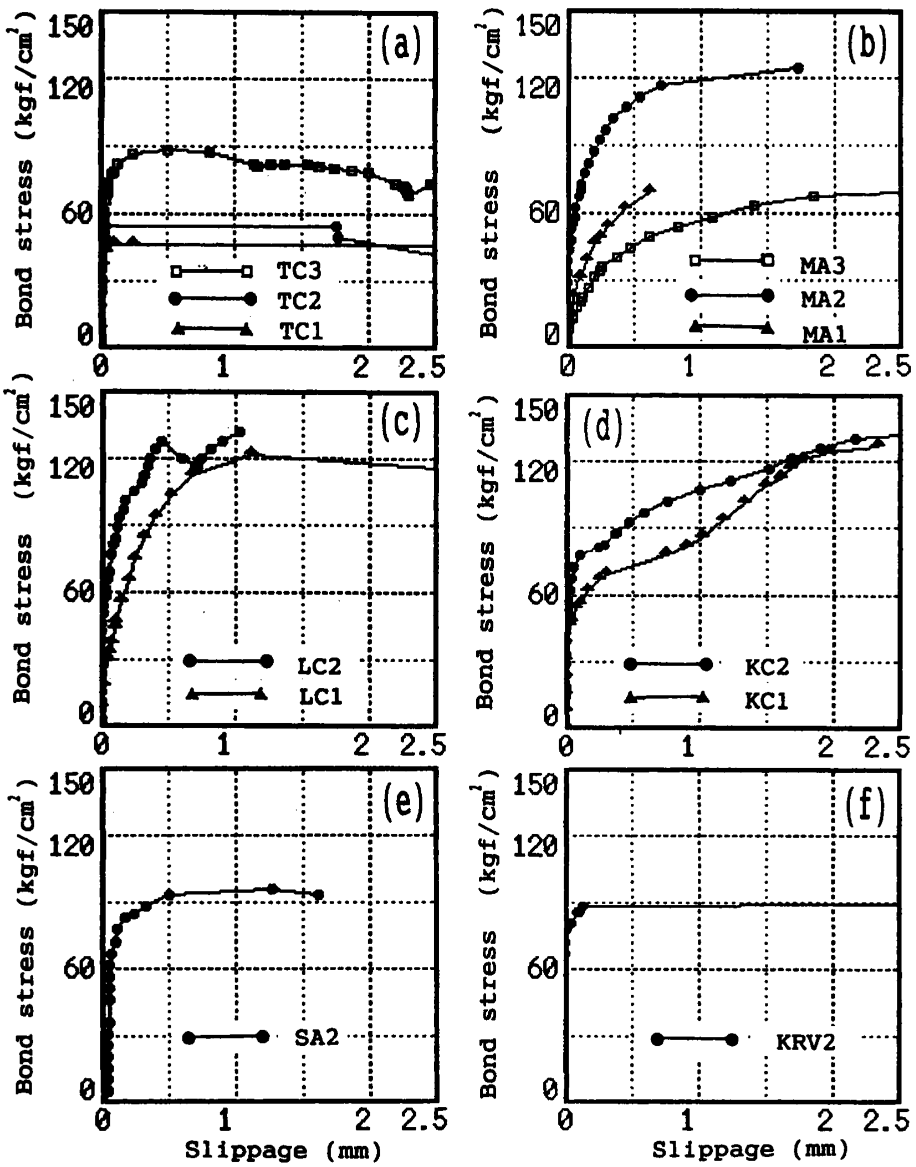


Fig. 3. (a)~(f) Bond stress versus Slippage of FRP rods

(c) Third group (KC type)

The third group consists of only KC type that is also having spirals. At the initial stage, the bond-slip curve was more like second group. But at a level, where the bond stress became around 50% of the maximum level, the curves changed to first group type, with gradually increasing bond-slip relationship. The condition at the failure was also the same as those of SA and KRV. In the open-cut observations, the peeled-off spirals from the rod was found. So, it is considered that the bond property at initial stage of the rod depends on the adhesion of the spirals to the rod. After the adhesion loss, the bond strength was held by the interlocking-effect occurred between rod and peeled spirals. At that time the bond-slip curves were gradually decreasing because these rods were made with highly-tight spirals. Therefore, the maximum strength will be depending on the fiber strength of the spirals and the tightness of spirals to the rods in the production.

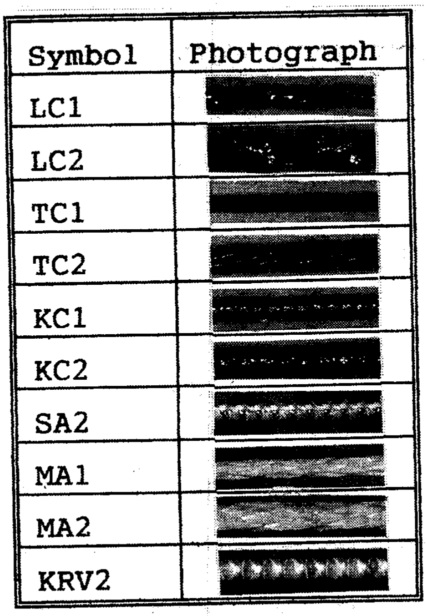
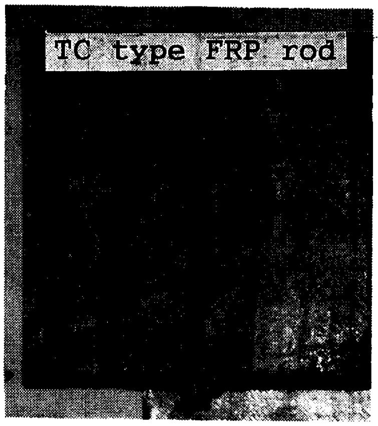
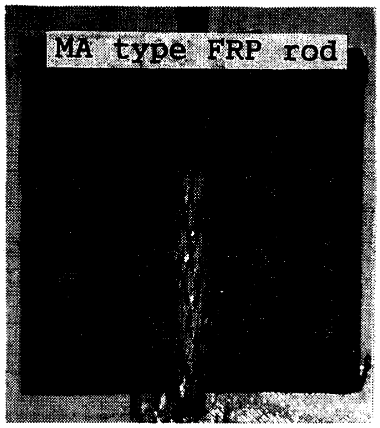


Photo 1. Surface condition of FRP rods





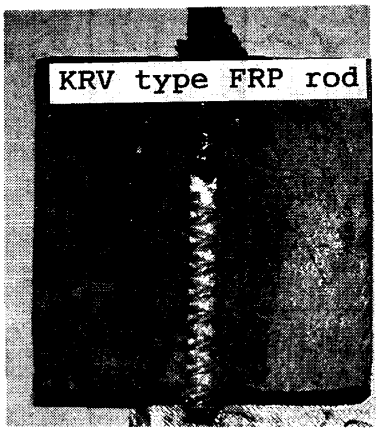


Photo 2. Open-cut observations on FRP rods.

4. CONCLUSIONS

1. The bond strength of FRP rods in cement-concrete depend not only on the surface condition but also on fiber types, fiber strength, spiral-rod adhesion and spiral strength in spiral type FRP rods.

2. The bond-slip characteristics of all the FRP rods used in this experiment can be categorized in three groups. They are, a group with gradual-increasing bond-slip relationship, a group of sudden change of slip at a level and a group of sudden-change followed by gradual increment of bond with respect to slippage.

Acknowledgement.

The authors were deeply grateful to the CCC Research Group for their kind and generous supply of FRP rods. Special thanks to Mr F. Arima (Research Associate), Mr M.Maemura (Technician) and Mr K. Watanabe (student) for helping us to carry out this experiment.

References:

1)Concrete library, No.72. Practical usage of CFRP on concrete structures (in Japanese) 1992. April. JSCE.