コンクリート工学年次論文報告集, Vol.16, No.2, 1994

論 文

# [2037] Local Bond Stress-Slip Relationship of Braided Aramid Fiber Bar Obtained from Pretensioned Bond Test

Hiroshi SHIMA[*1] and Tetsuji SUGA[*2]

## 1. INTRODUCTION

Continuous fiber reinforcing materials such as braided aramid fiber bar and carbon fiber strand are going to be applied to concrete structures. A design concept of concrete structures reinforced or prestressed with continuous fiber reinforcing materials has already been reported by JSCE committee[1]. However, bond characteristics between the reinforcing materials and concrete have not been clarified yet and research work is necessary to determine anchorage length or to estimate deformations of the structures.

In the bond characteristics, a local bond stress-slip relationship is the most basic law for representing interaction between the reinforcing materials and concrete. Although many pullout bond tests of continuous fiber reinforcing materials with short embedded length have been carried out[2], the local bond stress-slip relationship of these reinforcing materials obtained from bond tests with long embedment may be different from that obtained in the short embedment bond tests, as is the case for deformed steel bars[3]. Furthermore, for prestressing steel strands, it was reported that the bond stress in an anchorage zone of pretensioned prestressed concrete members was larger than that obtained from a pull bond test[4,5]

Local bond stress-slip relationships of braided aramid fiber bars and carbon fiber strand obtained from pull bond tests with long embedment were reported by the authors[6]. With regard to the bond behavior of continuous fiber reinforcing materials in the anchorage zone of pretensioned prestressed members, Nanni et al.[7] reported the stress transfer length of braided aramid fiber bars. However, the local bond stress-slip relationship of the pretensioned continuous fiber reinforcing material is not known.

In this research, pretensioned bond test with long embedment of braided aramid fiber bar was carried out. From the measurement of strain distribution along the bar during release of the pretension force, the local bond stress-slip relationships were determined. Differences between the local bond stress-slip relationship obtained from the pull test with long embedment and those obtained from the short embedment test or obtained from the pretensioned bond test are discussed.

*1 Department of Civil Engineering, The University of Tokushima, DR, Member of JCI
*2 Tokyo Branch Office, Taisei Corporation, ME, Member of JCI

## 2. EXPERIMENTS

### 2.1 EXPERIMENTAL CONDITIONS

The experimental conditions are given in Table 1. The experimental variable was concrete strength. Pretension force was 60% of ultimate strength of the bar and the embedded length was made large enough to transfer the pretension force to concrete completely.

Table 1 Experimental conditions

| Condition No. | Material | Nominal bar diameter (mm) | Concrete strength $f'_c$ (MPa) | $l_e$ / $D$ | Cross section of concrete (mm) | Pretension force of bar [Stress] [Strain] |
|---|---|---|---|---|---|---|
| 1 | Braided aramid fiber bar | 14.0 | 35 | 56.25 | 300×300 | $0.6P_u$ [752MPa] [0.011] |
| 2 | | | 67 | 56.25 | | |

$l_e$ : Embedded length, $D$ : Nominal bar diameter, $P_u$ : Ultimate strength of bar

### 2.2 MATERIALS

(1) Reinforcing materials

A braided aramid fiber bar having 14.0mm nominal diameter was used. The shape of the bar is shown in Fig.1 and its properties are given in Table 2.

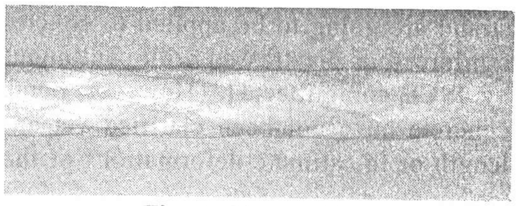

Fig. 1 Shape of bar

Table 2 Properties of braided aramid fiber bar

| Nominal diameter (mm) | Nominal area (mm$^2$) | Young's modulus (GPa) | Ultimate strength (GPa) |
|---|---|---|---|
| 14.0 | 150.0 | 68 (65*) | 1.25 |

* : Catalog value

(2) Concrete

The concrete compressive strength at testing was 35MPa in one half of the specimen and 67MPa in the other half. In order to avoid the influence of bleeding on bond properties, the concrete was made not to produce any bleeding by using an additive for non-bleeding and a high range water reducing admixture. The maximum aggregate size was 25mm.

### 2.3 SPECIMEN

The shape and dimensions of the specimen are shown in Fig.2. The bar was arranged horizontally in the center of a rectangular concrete block. Size of cross section of the concrete block was 300mm×300mm. This cross sectional size was determined to be large enough to avoid splitting cracks and to make stress in concrete small, because the bond behavior would be

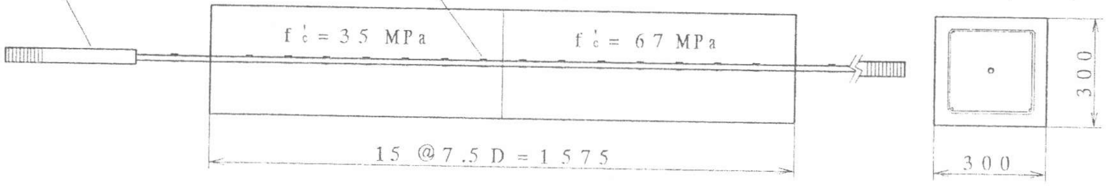


Fig. 2 Specimen

more complicated if the cross sectional size was small and concrete deformed in the radial direction. The compressive stress in concrete at the center of specimen was 1.25MPa when the tension force was released completely.

### 2.4 TESTING METHOD

*Attaching strain gages*: Foil resistance strain gages having gage length of 2mm were attached on opposite faces of the bar, located at intervals of 7.5 times of bar diameter, to measure the strain distribution along the embedded bar.

*Pretensioning*: A gripping steel pipe was fixed at both ends of the bar by the method proposed by Harada et al.[8], using an highly expansive material. The pretension force was applied to the bar before casting of concrete.

*Casting concrete*: Concrete was cast in the direction normal to the bar. The concrete was cured for three days while maintaining the pretension force constant.

*Measuring*: The strains along the bar were measured by a digital strain meter while the pretension force was being released. The releasing rate was about 100μ strain per minute at the end of specimen.

### 2.5 CALCULATION METHOD OF LOCAL BOND STRESS–SLIP RELATIONSHIP

The strain at a measuring point was derived from the average value of two gages attached there. The strain distribution curve along the bar at a certain released force level was determined by connecting every three neighboring points with 2nd degree polynomial functions.

The local bond stress, $\tau$, at a given location can be obtained from the slope of the strain distribution curve, $d\varepsilon/dx$, at that location as follows.

$$\tau = \frac{EA}{u}\frac{d\varepsilon}{dx} \tag{1}$$

where $E$ is Young's modulus, $A$ is the area and $u$ is the perimeter of bar.

The local slip, $S$, was determined by integrating the difference between bar strain, $\varepsilon_b$, and concrete strain, $\varepsilon_c$, from the center of specimen to the point concerned, $x$, as follows.

$$S = \int_0^x (\varepsilon_b - \varepsilon_c)dx \tag{2}$$

The strain of concrete was calculated from the external tension force and the bar strain with Young's modulus of concrete which was 29GPa and 40GPa for concrete of strength 35MPa and 67MPa respectively.

## 3. RESULTS AND DISCUSSIONS

### 3.1 STRAIN DISTRIBUTION

The strain distributions along the bar at several force levels while the initial pretension stress of 752MPa (strain of 0.011) was being released are shown in Fig.3. There was little decrease of strain at the center of specimen. This means that the pretension force was transferred to concrete completely in length of the embedment. The slope of strain distribution curve in the part with higher concrete strength was larger than that in the part with lower concrete strength.

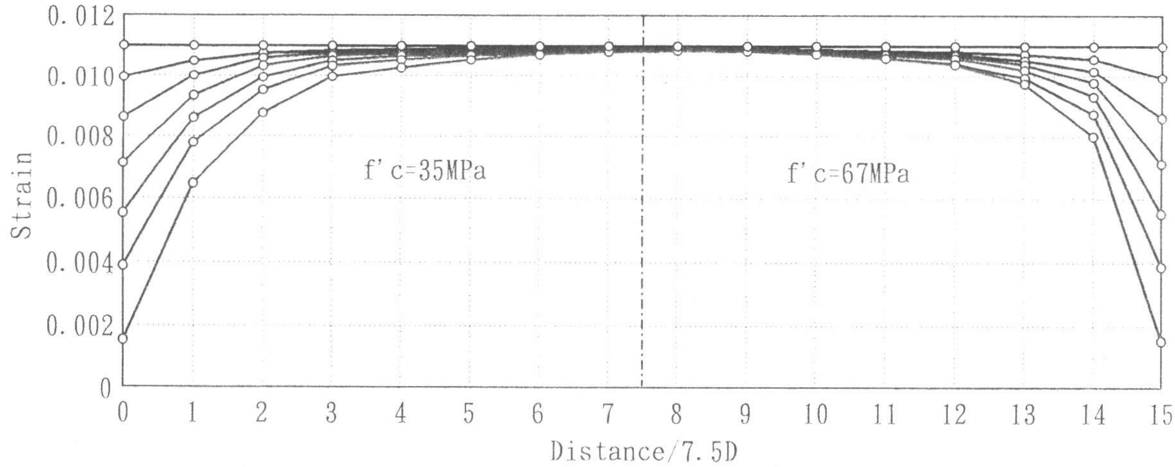

Fig. 3 Strain distribution along bar

## 3.2 LOCAL BOND STRESS–SLIP RELATIONSHIP

### (1) Non–dimensional slip

Since the slip was proportional to the bar diameter in the braided aramid fiber bar[6], it may be preferable to use the non–dimensional slip in which the slip is divided by the bar diameter.

### (2) Shape of curve

The local bond stress–slip relationships of the bar at the both ends of the specimen and those at the location of 7.5*D* from the end are shown in Fig.4. In the range of slip in this experiment, the bond stress increases with slip up to the maximum slip. The maximum bond stress which may exist at larger slip could not be obtained.

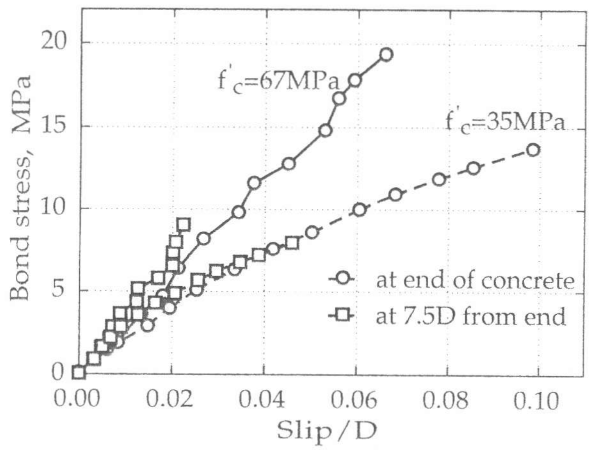

Fig. 4 Local bond stress–slip relationship obtained from pretensioned bond test

### (3) Effect of location

Although the bond stress–slip relationships at the end of specimen and 7.5*D* from the end for each concrete strength are not so different, the effect of location along the bar on bond stress–slip relationship is not clear in this experiment.

## 3.3 COMPARISON WITH OTHER TEST METHODS

### (1) Shape of curves

The comparison of the bond stress–slip relationship of the bar obtained from the pretensioned bond test with those of the same braided aramid fiber bar obtained from the pull bond test with long embedment by the authors[6] and a pullout bond test with short embedment by Okamoto et al.[9] is shown in Fig.5. In the pull bond test with long embedment, concrete was cast with no stress in the bar and the bar was pulled in one direction after concrete was hardened as shown in Fig.6. The diameter of the bar and the dimensions of concrete cross section are the same as in this pre-tensioned test. In the pullout bond test with short embedment, the bar having 10mm diameter was arranged in the center of well confined concrete cube (150×150×150mm) with embedment length of $6D$ and unbonded region of 90mm. The bond stress and the slip in the short embedment test are not the local bond stress and the local slip but the average bond stress in the embedded length and the free end slip. However, the average bond stress-free end slip relationship in short embedment length test is close to the local bond stress-slip relationship with small bar strain.

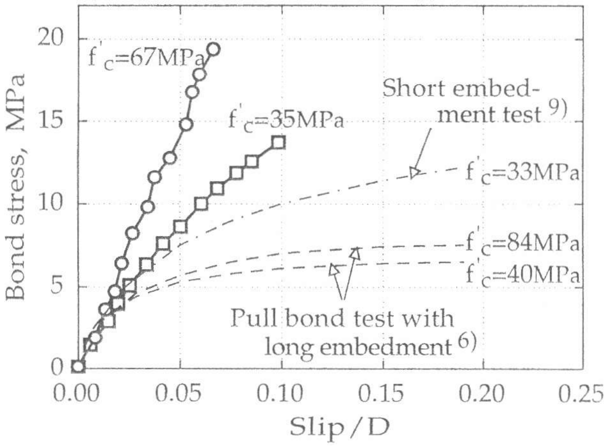


Fig. 5 Comparison of bond stress-slip relationship with that obtained by other testing methods

The bond stress obtained from the pretensioned bond test is much larger than that obtained from the pull bond test with long embedment. The bond stress obtained from the pullout test with short embedment is intermediate between these bond stresses. For seven-wire prestressing steel strands, Burnett and Marefat[4] and Uijl[5] explained that reduction of the strand diameter due to Poisson effect produced lower bond stress when initially untensioned strand was pulled out, and increase of the strand diameter produced larger bond stress when pretensioned strand was released into concrete as related to Hoyer effect of prestressing wire[10]. There should be the same situation for the braided aramid fiber bar. In the short embedment test, there is less Poisson effect because change of bar strain is small in spite of large slip.

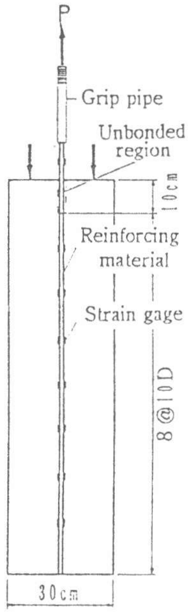


Fig. 6 Pull bond test[6]

(2) Effect of concrete strength

The relationships between the bond stress and concrete compressive strength obtained from this test, a short embedment test by Okamoto et al.[9] and the pull test with long embedment by the authors[6] are shown in Fig.7. Exactly the same bar as used in this test ($D$=14.0mm) was used in the short embedment test and the pull test with long embedment. For pretensioned bond test, the bond stress at Slip/$D$ equals to 0.05 is shown because maximum bond stress did not appear in the test.

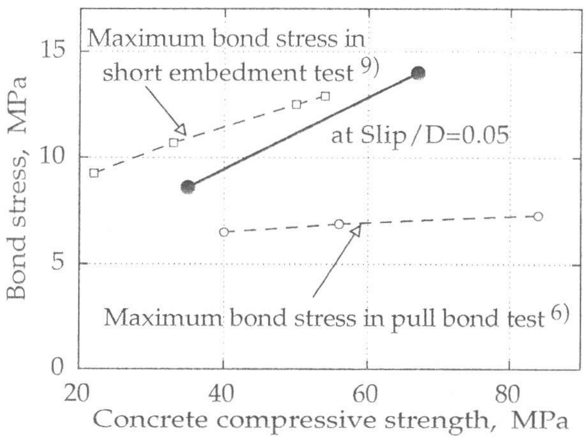


Fig. 7 Effect of concrete strength on bond stress

The effect of concrete strength on the bond stress-slip relationship differs between these tests. Although the maximum bond stress obtained by the pull bond test increases very slightly with concrete strength, the bond stress obtained by the pretensioned test increases with concrete strength remarkably.

The degree of the effect of concrete strength in the short embedment test is intermediate between the pretensioned bond test and the pull bond test with long embedment.

The difference in the effect of concrete strength is thought to result from difference in restriction against the bar from surround concrete. The effect of concrete strength on the restriction against the bar should be large when the bar attempts to become thicker in the pretensioned test, but this effect should be small when the bar becomes thinner in the pull test with long embedment.

## 4. CONCLUSIONS

(1) The local bond stress-slip relationship of braided aramid fiber bar varies with test method such as a pretensioned bond test, a pull bond test with long embedment and a pullout test with short embedment. The bond stress obtained from the pretensioned bond test is much larger than that obtained from the pull bond test with long embedment. The bond stress obtained from the pullout test with short embedment is intermediate between these bond stresses.

(2) The effect of concrete strength on the local bond stress-slip relationship of braided aramid fiber bar differs with test method. The bond stress at a certain slip increases with concrete strength remarkably in the pretensioned bond test although the effect of concrete strength on the bond stress is little in the pull bond test with long embedment.


## ACKNOWLEDGEMENTS

The authors would like to express their gratitude to Grant-in-Aid for scientific research (No.04302040, Organized by Prof. Yoshio Kakuta, Hokkaido University) of the Ministry of Education for providing financial support, to Mitsui Construction Co. for providing the braided aramid fiber bars, to Prof. Peter Marti at Swiss Federal Institute of Technology for giving a chance to stay and finish this paper.


## REFERENCES


(1) Application of Continuous Fiber Reinforcing Materials to Concrete Structures, Concrete Library International, No.19, June 1992, Japan Society of Civil Engineers, pp.89-130.

(2) State of the Art Report on Continuous Fiber Reinforcing Materials, Concrete Engineering Series, No.3, Japan Society of Civil Engineers, July 1993.

(3) Shima, H., Chou, L. and Okamura, H., "Bond-Slip-Strain Relationship of Deformed Bars Embedded in Massive Concrete," Concrete Library International, No.10, Japan Society of Civil Engineers, Dec. 1987, pp.79-94.

(4) Burnett, E. and Marefat, M., "Anchorage Bond for Seven-Wire Strand," Proc. of CEB Conference on Bond in Concrete, Vol.1, Riga, Oct. 1992, pp.68-78.

(5) Uijl, J., "Bond and Splitting Action of Prestressing Strand," Proc. of CEB Conference on Bond in Concrete, Vol.1, Riga, Oct. 1992, pp.79-88.

(6) Shima, H., Suga, T. and Honma, M., "Local Bond Stress-Slip Relationship of Continuous Fiber Reinforcing Materials obtained by Pull Bond Tests with Long Embedment," Transactions of the Japan Concrete Institute, Vol.15, 1993, pp.297-304.

(7) Nanni, A., et al., "Transfer Length of Braided Aramid Fiber Tendons," Transactions of the Japan Concrete Institute, Vol.13, 1991, pp.259-264.

(8) Harada, T., et al., "New FRP Tendon Anchorage System Using Highly Expansive Material for Anchoring," Proc. of FIP Symposium '93, Kyoto, Oct.1993, pp.711-718.

(9) Okamoto, T., et al., "Study on Braided Aramid Fiber Rods (Part 3 - Bond Characteristics I)," Proc. of Annual Meeting of AIJ, Oct. 1988, pp.829-830.

(10) Hoyer, E., "Der Stahlsaitenbeton," Otto Elsner Verlag, Berlin, 1939, pp.55-62.