Crack Width Evaluation of RC Members Reinforced with Braided AFRP Bars
(Part 1: Pullout and Tensile Bond Test of AFRP Bars)

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Crack width Bond stress Slippage
AFRP bars Pullout bond test Tensile bond test

1. Introduction

AFRP bars as an alternative to the steel reinforcements have advantages to no-corrosion, high tensile strength and use in electromagnetic fields. However, AFRP bars with its low elastic modulus and bond stiffness may cause a lager crack width of concrete and it is difficult to grasp the characteristics of crack width due to the AFRP bars with a variety of surface textures such as braided ones.

The purpose of this study is to propose theoretical calculation formulas to predict crack width of RC members reinforced with AFRP bars based on the relationship between reinforcement strain and slip at the loaded end which deduced by previous study[1)]. Pullout bond test and tensile bond test were conducted at the same time to investigate the adaptability of the proposed formulas.

2. Experimental Program

2.1Tested reinforcement and concrete

Fig.1. shows the tested reinforcement with two types of surface. One is normal braided surface and another one is the sand-coated type. Table 2 and Table 3 show the list of reinforcement and the mechanical properties of concrete respectively. Same batch of concrete was used for both two tests.

2.2 Outline of pullout bond test

Pullout bond test was conducted for obtaining the bond stress – slip relationship (bond constitutive law) between AFRP bar and concrete. Specimen details and loading method is shown in Fig. 1. The specimen is a rectangular concrete block with height of 100mm. One rod is arranged in the central position of the block. The bond length is set to 32mm for RA7 and RA7S, or 52mm for RA13 and RA13S. The main parameters are reinforcement type and the sectional area of concrete block which varies as 80mm x 80mm, 100mm x 100mm and 120mm x 120mm. Three same specimens for each parameter were tested. The monotonic pullout load was applied until the slippage reached to 20 mm or concrete failed by splitting. The pullout load and the slippage at the free end were measured.

2.3 Outline of tensile bond test

The purpose of tensile bond test is to obtain measured crack width to compare with calculated value by the proposed formulas. Specimen and loading method is shown in Fig.2. 14

RA7・RA13 (Normal surface) RA7S・RA13S (Sand-coated type)

Fig.1 Tested reinforcement

Table 1 List of reinforcement

ID	Diameter (mm)	Sectional area (mm^2)	Elastic modulus (kN/mm^2)
RA7・RA7S	8.10	51.50	63.7
RA13・RA13S	13.51	143.28	71.2

Table 2 Mechanical properties of concrete

Compressive strength (N/mm^2)	Tensile strength (N/mm^2)	Elastic modulus (kN/mm^2)
37.2	2.67	26.9

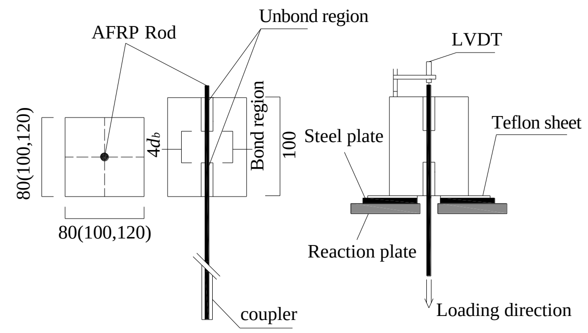

Fig.1. Details and loading method of pullout bond test

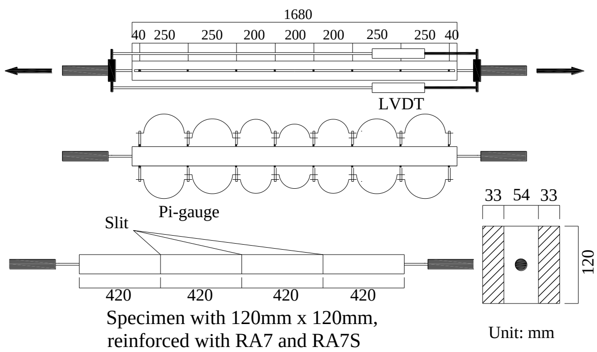

Fig.2. Details and loading method of tensile bond test

Pi-gauges were set on the specimen along axial direction to measure crack width. Specimens are subjected to tensile load until it reaches to a particular value in order to ensure the AFRP bar may not be broken. The main parameters are reinforcement type and the sectional area of concrete as same as ones in the pullout bond test. To make sure crack appears before AFRP bar broken, three slits were conducted in two specimens (120mm x 120mm, reinforced with RA7and RA7S) before loading as shown in Fig.2. The section area at slit is as same as 80mm x 80mm.

3. Test Results

3.1 Test results of pullout bond test

Fig.3 shows two examples of bond stress – slip relationship of pullout bond test and each figure includes three same specimens. Comparing with two figures, it can be found that surface of AFRP bars determines the characteristic of bond constitutive law. Sand-coated type shows higher bond stiffness. Bond stress increased again after the maximum value. It is considered that the lugs as the surface shape of braided bars move toward to loaded end, and cause a mechanical occlusion. Table 3 and Table 4 show the test results of pullout bond test. It can be found that the sectional size of concrete block and the diameter of bar does not have large influence to those values.

3.2 Test results of tensile bond test

Two examples of final crack patterns after loading are shown in Fig. 4. It is remarkable that the higher bond stiffness leads larger numbers of cracks. The whole test results indicate that crack spacing increases as the sectional size becomes larger. Examples of tensile load versus total deformation curves are shown in Fig. 5. The straight lines from the origin indicate the relationship for bare reinforcement. Tension stiffening effect can be found in all the specimens. The effect becomes higher with the concrete sectional size increasing. The curves show several drops of tensile load at which a new crack takes place.

4. Conclusions

A pullout bond test is carried out to obtain the bond constitutive law. From the test results it can be found that surface of AFRP bars determines the characteristic of bond constitutive law. Tensile bond test has also been conducted. It is remarkably that bond phenomenon between concrete and reinforcement determines the characteristic of crack patterns.

Acknowledgement

AFRP bars were provided by Fibex Co., Ltd.

References

1) Kanakubo T., Yamato N., Crack Width Prediction Method for Steel and FRP Reinforcement Based on Bond Theory, Journal of Advanced Concrete Technology, Vol. 12(2014), No. 9, pp. 310-319

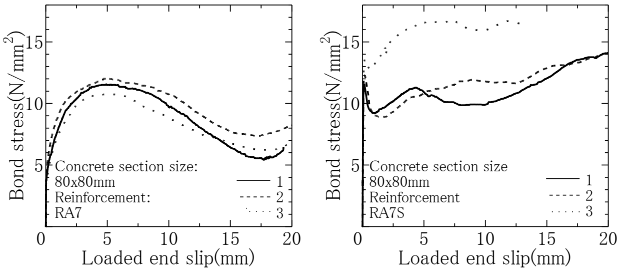

Fig.3. Bond stress – slip relationship of pullout bond test

Table 3 Test results of pullout bond test (RA7 -RA13)

Section size (mm)	AFRP bar	Maximum bond stress (N/mm^2)	Slip at max. bond stress (mm)
80x80	RA7	11.45	5.18
	RA13	—*	—
100x100	RA7	12.28	4.79
	RA13	—	—
120x120	RA7	13.78	4.83
	RA13	—	—

*Did not appear till concrete splitting

Table 4 Test results of pullout bond test (RA7S -RA13S)

Section size (mm)	AFRP bar	Slipping bond stress* (N/mm^2)	Slip at slipping bond stress (mm)
80x80	RA7S	11.91	0.17
	RA13S	10.43	0.17
100x100	RA7S	10.85	0.15
	RA13S	8.83	0.19
120x120	RA7S	10.71	0.21
	RA13S	10.67	0.19

*Definition is explained in part 2

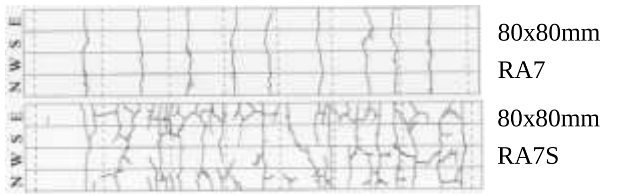

Fig.4. Crack pattern of tensile bond test specimen

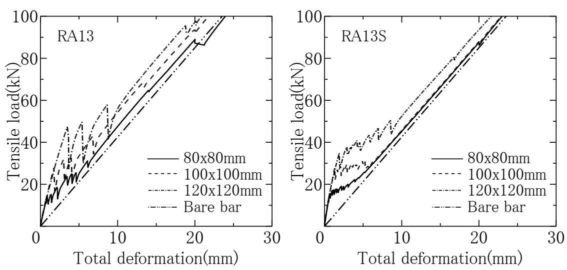

Fig.5. Tensile load – total deformation curve

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