COMMENTARY ON THE TEST METHOD FOR BOND STRENGTH OF CONTINUOUS FIBER REINFORCING MATERIALS BY PULL-OUT TESTING (JSCE-E 539-1995)

INTRODUCTION

The test method presented here is based on the JSCE "Proposed Method for Bond Testing of Continuous Fiber Reinforcing Material", published in Vol. 72 of the Concrete Library, April 1992, which was based on the draft "Pull-Out Bond Strength Testing Method" (Concrete Handbook, Japan Concrete Institute, February 1976), referencing also JSCE-G 503-1988 “Bond Strength Testing of Reinforcement and Concrete by Pull-Out (Standard Specification for Design and Construction of Concrete Structures (Standards), August 1991)” and the proposed JIS standard “Bond Strength Testing of Reinforcement and Concrete by Pull-Out”. As the standards quoted above refer to steel reinforcement, adaptations have been made to allow for the difference in materials. Revisions have also been made with reference to the draft “Long Fiber Reinforcing Material Bond Test Method” in the Long Fiber Reinforced Materials Concrete Research Report(Vol.3), March 1993”.

1. SCOPE

The present test is intended for CFRM transmitting loads solely by surface bonding, and therefore excludes grid and mesh materials etc. which have different stress transmission mechanisms. In view of the outstanding processability of CFRM, however, CFRM with no fiber binding material and slab form CFRM with rectangular sections are covered by this test.

There is currently no standardized test for bond performance, and in addition to the pull-out tests quoted above, other forms of test available include push-out testing, double sliding testing, beam testing etc. Each of these has merits and demerits, and so have not been established as standard test methods.

The pull-out test given here has been claimed to be incapable of measuring bond strength accurately owing to the differences in the stress conditions in actual members, but it does have the advantages of being simple, executable with existing test equipment, and using test pieces of convenient size. It should be borne in mind, therefore, that the evaluation of bond performance obtained from this test is a relative evaluation.

2. DEFINITION

The surfaces of CFRM are deformed in various ways to ensure bonding. Implementation of the test involves standard concepts of diameter and circumference of the CFRM, and these are therefore defined here.

Nominal peripheral length refers to the circumferential length when calculated from the nominal diameter, to the circumscribed peripheral length when calculated from the circumscribed circle diameter, and to the sum of the lengths of the sides where the section is rectangular.

3. TEST PIECES

(Comment on 3.1) CFRM may have either circular or rectangular sections, and the surface of the material is frequently subjected to various forms of deformation in order to improve the bonding characteristics. Section diameter therefore refers to the diameter of the equivalent circular section, and to the nominal diameter.

(Comments on 3.2) The standard length of one side of the test piece shall be approximately 6 times the diameter of the CFRM, with a bonded length 3 times the diameter and an unbonded length 2 times the diameter. This provision is to prevent yielding or rupture from occurring before pull-out when the concrete is not reinforced. The outline of the test specimen is shown in Fig. C 1.

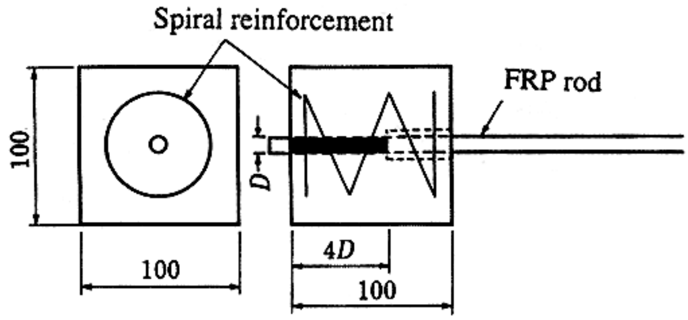

Fig. C 1 Outline of Test Piece

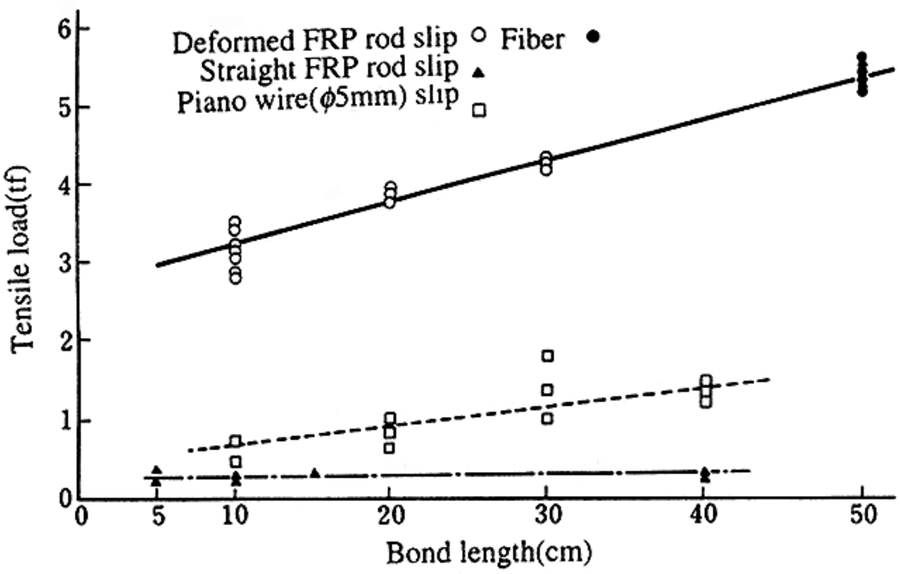

Fig. C 2 Relationship between bond length & pull-out load

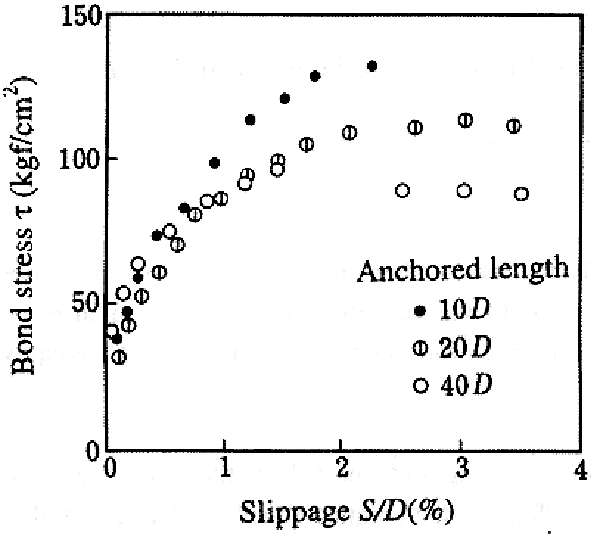

Fig. C 3　Bond characteristics for different anchored lengths

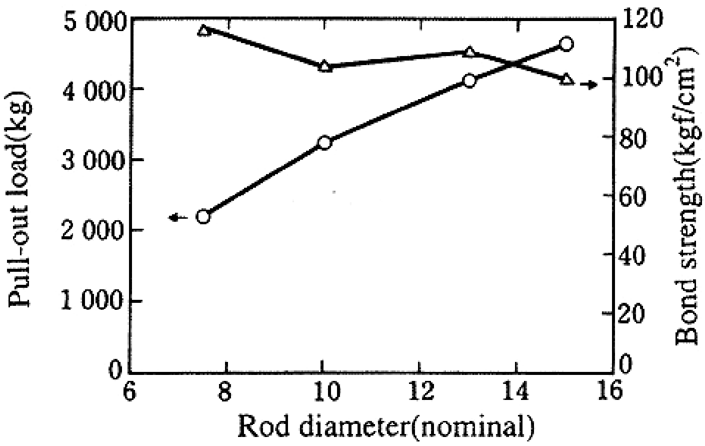

Fig. C 4　Effects of rod diameter on bond strength

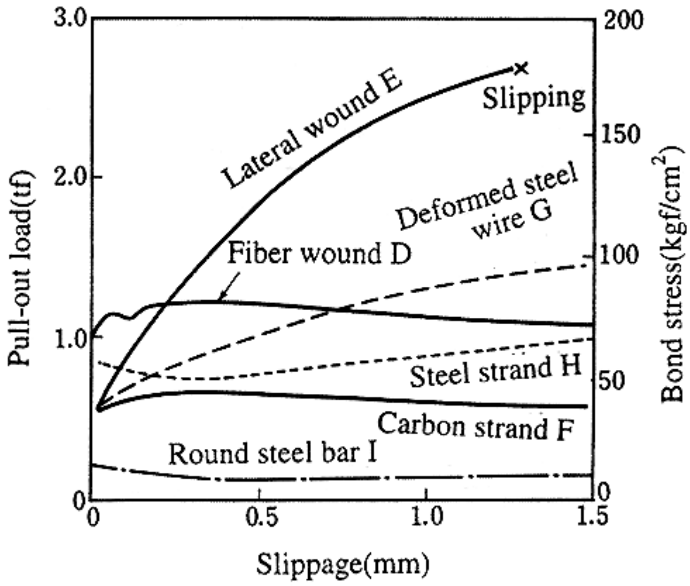

Fig. C 5　Bond behavior characteristics of rod due to differences in deformation treatment

As the length of CFRM anchored in concrete increases, the pull-out load also increases as shown in **Fig. C 2** where a more or less linear relationship is evident, but bond strength conversely tends to fall off as the anchored length increases (**Fig. C 3**). This can be taken to be a general phenomenon whereby the calculated apparent bond strength decreases as the anchored area increases, and this is the case also when the diameter of the CFRM increases (**Fig. C 4**). Consideration has to be made here for the effects of the surface treatment of the CFRM on bond strength. It has been reported, though, as shown in **Fig. C 5**, that especially for stranded materials, the bond strength may be significantly affected if the anchored length is less than one pitch of the strand. In such cases, previous tests have adopted an anchored length of 30~50 cm (10*D*~40*D*).

It has been claimed that bond strength can vary greatly due to stress disturbance within the concrete if the point of introduction of bonding into the concrete is at the end of the test piece. For this reason, the point of introduction of bonding should preferably be inside the test piece, with an unbonded section at the loading end.

(Comment on 3.3) The relationship between slippage displacement and pull-out load (bonding stress) of the CFRM is sometimes required in connection with the bonding characteristics. For this reason, a part of the CFRM has to be left protruding from the concrete, to allow measurement of slippage displacement at the free end.

In pull-out tests of steel reinforcement, the steel can be loaded mechanically by grip Cping. With CFRM, however, the use of a mechanical chuck such as that used on steel would cause a concentration of stress at that point, and could also result in rupture of the CFRM at loads far below the material strength as CFRM are generally weaker in the transverse direction than in the longitudinal direction. A gripping device to transmit loading to the CFRM at the loading end is therefore required. In practice, loading is usually carried out by connecting tie rods to the gripping device, which thus doubles as a coupler for the tie rods.

(Comment on 3.4) The surface bonding strength of an undeformed circular CFRM is considerably lower than that of steel, so the effects of concrete bleeding on bond strength are expected to be correspondingly large. In an admittedly small number of tests where CFRM cast vertically and horizontally in concrete were compared for pull-out strength, the bond strength of the horizontally cast test pieces, which are more subject to bleeding, was found to be slightly lower. In fact, however, CFRM are almost always given deformed surfaces to improve the bonding characteristics, and as **Fig. C 6** shows, bond strength test results are little different from those for deformed steel bars. As the JSCE-G 503-1988 standard also specifies the horizontal position, this has been adopted here also as it gives a conservative evaluation.

(Comment on 3.5) If the concrete undergoes splitting failure during a pull-out test, the bonding is lost instantaneously and a proper evaluation of bonding characteristics cannot be made. It is therefore necessary to reinforce the concrete to prevent splitting failure before pull-out. On the other hand, this reinforcement has to be kept to a minimum, otherwise a constraining effect will appear in the concrete. Some tests of CFRM have been performed with the pitch of the reinforcing bars reduced, or with increased reinforcement, but studies of the constraining effect in these cases are still inadequate, so the original proposal has been retained here. The arrangement of reinforcement also should be gauged accurately, as it has a significant effect on the bond strength.

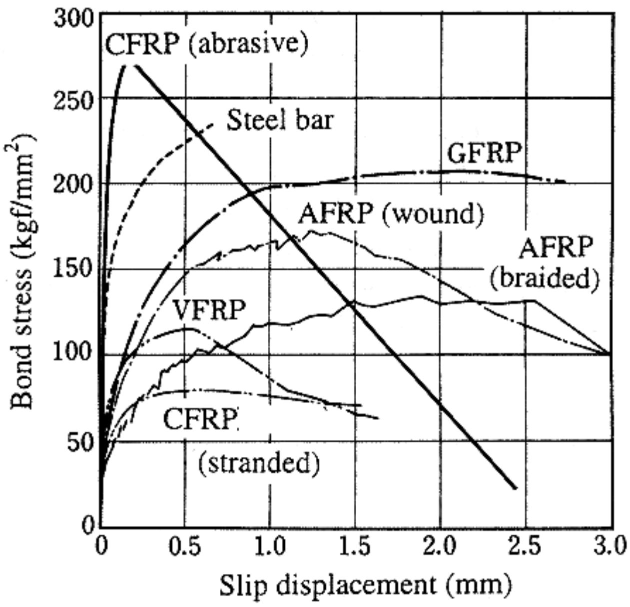

Fig. C 6 Pull-out test results for various reinforcement types

(Comment on 3.6) Three test pieces is an adequate number as the purpose of the test is to make a relative comparison of the bonding characteristics of a CFRM.

4. FORMS

The conventional type of form already in use is adopted here.

5. CONCRETE QUALITY

The effects of the maximum aggregate size, slump and concrete strength on bond strength are not clear (**Figs. C 7,8**). The concrete quality provisions of JSCE-G 503-1988 have been retained as there is no obvious reason to change them for testing of CFRM. As CFRM are used almost exclusively in prestressed concrete, if necessary the bond strength with high strength concrete should also be tested.

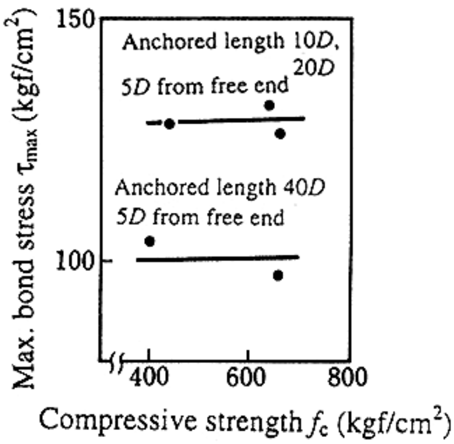

Fig. C 7 Relationship of concrete strength and bond strength

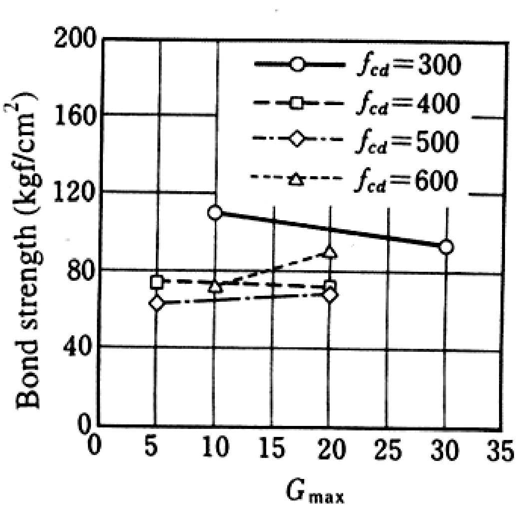

Fig. C 8 Effects of maximum aggregate size on bond strength

6. PLACING OF CONCRETE

(Comment on 6.2) The seal can consist of soft plastic tubing with an internal diameter more or less equivalent to the maximum diameter of the CFRM, in conjunction with oil putty. The external diameter of the covered section should be in the range of 1.2~1.5 times the diameter of the CFRM.

7. REMOVAL OF FORMS AND CURING

Care should be taken not to subject the CFRM to any shock.

8. TESTING MACHINE AND DEVICES

The testing machine and gauge are illustrated in **Fig. C 9**.

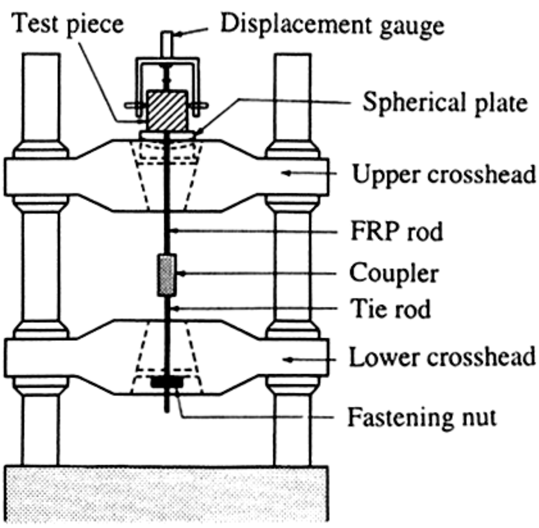

Fig. C 9 Outline of testing machine

(Comment on 8.2) Provision is made for a hole in the loading plate to allow for the diversity of CFRM likely to be tested.

(Comment on 8.3) The gripping device also serves to anchor the CFRM. A common practice is to place a sheath over the CFRM, filling the gap between the two with resin or expansive mortar. This is equivalent to the gripping device used in tensile test, and the test piece must not pull out before undergoing bond failure. The conditions for bond testing need not be as strict as those for tensile testing, and a gripping device similar to that used in tensile test is sufficient.

9. TEST METHOD

(Comment on 9.1) The spherical plate is necessary to minimize the effects of bending and torsion on the CFRM and the concrete.

10. CALCULATION AND EXPRESSION OF TEST RESULTS

JSCE-G 503-1988 stipulates adjustment of the bond stress using the concrete strength derived by dividing the pull-out load by the bonded area. While the bond strength in cases of bond splitting are governed by the concrete strength, for other cases a good correlation with the compressive strength of the concrete has not yet been established. For this reason no corrections based on concrete strength are specified here, and the compressive strength has only to be noted in the report.