COMMENTARY ON THE TEST METHOD FOR TENSILE PROPERTIES OF CONTINUOUS FIBER REINFORCING MATERIALS (JSCE-E 531-1995)

INTRODUCTION

A test method for tensile properties of CFRM was first set out in a proposal by the JSCE ("The application of continuous fiber reinforcement materials to concrete structures", Concrete Library No. 72), followed by another proposal from the Architectural Institute of Japan ("Research on long fiber reinforced concrete (Report No. 3)"). These documents lie behind the test method proposed here.

The test method given here focuses on the CFRM itself, excluding the performance of the anchorage. For this reason, test data clearly showing failure or pull-out at the anchoring section is to be disregarded, and test findings based solely on test pieces failing in the test section.

1. SCOPE

Test pieces shall be linear or meshed CFRM formed from continuous fibers, matrices etc. as defined elsewhere and acting mechanically as a monolithic body.

2. DEFINITIONS

Of the terms used here, nominal diameter and nominal cross sectional area are used as defined in the "Quality Standard for Continuous Fiber Reinforcing Materials". Guaranteed tensile capacity has been added to provide a basic standard for testing at some future date when a guaranteed tensile capacity has been determined.

3. TEST PIECES

Tensile test conducted by various organizations has found that tensile strength ceases to vary in test pieces longer than 30 times their nominal diameter (**Fig.C 1**). At lengths of 30 times the nominal diameter, however, the anchoring section is apt to fail, resulting in variations in strain readings. It was therefore decided to specify lengths of not less than 100 mm, and not less than 40 times the nominal diameter, with the additional condition for CFRM in strand form that the length should be not less than 2 times the strand pitch. This requirement corresponds to the requirements in JIS G 3536 (Uncoated Stress-relieved Steel Wires and Strands for Prestressed Concrete), JSCE "Standard Specification for Design and Construction of Concrete Structures" and AIJ "Prestressed Concrete Design and Construction Standards", all of which call for test pieces "not less than 100 mm for wire; not less than 200 mm for 2-core strands and deformed 3-core strands; not less than 600 mm for 7-core strands and 19-core strands; not less than 2 times the strand pitch for other types of strands; not less than 40 times the basic diameter for multiple strands". The requirement also corresponds to the AIJ "Proposal for Tensile Breaking Strength Test for Long Fiber Reinforcing Materials" requirement for test pieces to be "not shorter than 300 mm", etc.

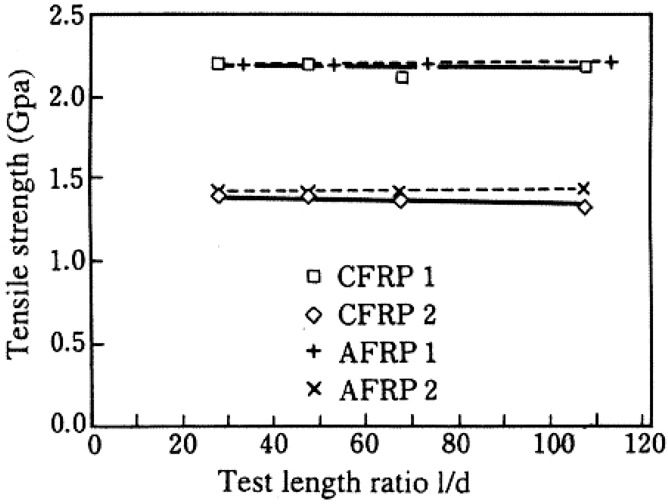

Fig. C 1 Effects of test length on tensile strength

The required numbers of test pieces were determined with reference to the statistical equation below:

$$N = (T \times CV / \mu)^2$$

where

N = number of test pieces
T = statistical value (T = 1.96 when confidence level = 95%)
μ = accuracy (%)
CV = coefficient of variation (%)

That is, when the data from the test pieces that failed in the test section in
tests conducted by the various organizations, for test pieces with a test length of not less than 38 times the nominal diameter, when N = 5~15 the coefficient of variation CV for the breaking load was less than 5.8%, with an average value of 3.0%. Applying accuracy μ = 5% with a confidence level of 95% to these results, the maximum value of N is found to be 5.2, and the average value 1.4. Based on this, the number of test pieces was set to not less than 5.

4. TEST TEMPERATURE

The standard test temperature for temperature-sensitive test pieces (i.e. test pieces showing a variation of more than 5% for failure tensile capacity, Young's modulus or ultimate strain over a temperature range of 5~35°C) was set at 20±2°C.

5. TEST METHOD

The gauge distance when using an extensometer was set at not less than 8 times the nominal diameter of the CFRM for linear materials, with an additional requirement for stranded materials that the gauge distance must be not less than the strand pitch. This sometimes results in a shorter gauge distance than that required in JIS G 3536 (Uncoated Stress-relieved Steel Wires and Strands for Prestressed Concrete), JSCE "Standard Specification for Design and Construction of Concrete Structures" and AIJ "Proposal for Tensile Breaking Strength Test for Long Fiber Reinforcing Materials", all of which call for a gauge distance of "not less than 100 mm", but the present requirement agrees with the gauge distance requirement in JIS G 3109 (Steel Bars for Prestressed Concrete) calling for a gauge distance "8 times the basic diameter of round bars, and 8 times the nominal diameter of deformed bars", and with the requirement in JIS Z 2201 (Test Pieces for Tensile Test for Metallic Materials; based on JIS G 3109) for a gauge distance of "3~8 times the diameter" of all types of rod-shaped test pieces.

When a strain gauge is used, this shall be fitted correctly in the direction of tension, without damaging the test piece. If fitting the gauge in the direction of tension is not feasible, as with stranded materials, it should be fitted in accordance with some other appropriate method.

The loading rate has been set at 100~500 N/mm^2/min, or equivalent fixed strain loading. This falls within the loading rate prescribed in the AIJ "Proposal for Tensile Breaking Strength Test for Long Fiber Reinforcing Materials" ("300~3,000 N/mm^2/min or 1%/min, whichever is the lesser"), and also falls within the ISO prescription of ("1~10 N/mm^2/sec (60~600 N/mm^2/min) for materials having a Young’s modulus not greater than 1.5×10^3 N/mm^2") in the ISO standards for test methods for metallic materials.

In AFRP rods, the range of loading rates corresponding to the above (0.2~0.9%/min), the variation in tensile strength is less than 1%, therefore these loading rates are deemed appropriate (**Fig.C 2**).

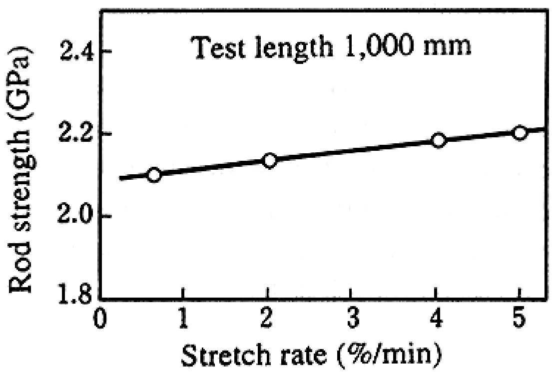

Fig. C 2 Effects of loading rate on tensile strength

6. CALCULATION AND EXPRESSION OF TEST RESULTS

(1) CFRM show elastic behavior in all zones leading to failure in many cases the Young’s modulus varies depending on the load; in carbon and Aramid fiber reinforcement materials, significant variation in the Young’s modulus is found in the region under 20% of the tensile capacity (**Fig. C 3**). Since the load range in actual service is below 60% of the tensile capacity, it was decided to derive the Young’s

modulus from the secant gradient of the strain-load curve at 20% and 60% of the tensile capacity.

If a guaranteed tensile capacity is set for the CFRM in question, or if the manufacturer can guarantee a specified tensile capacity, calculations can be based on the secant gradient at 20% and 60% of the guaranteed tensile capacity, rather than the tensile capacity. in Aramid CFRM, the Young's modulus under repeated loading is greater than that on virgin loading, although in the present test method, only the virgin loading is taken into account (**Fig. C 4**)

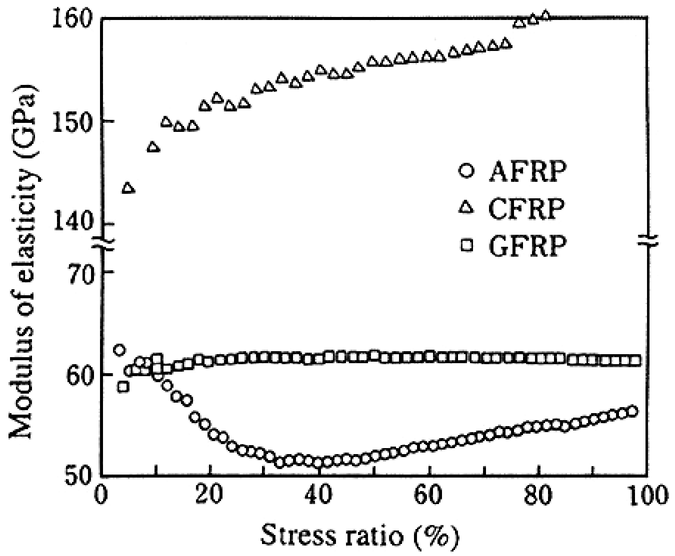

Fig. C 3 Effects of load on Young's modulus

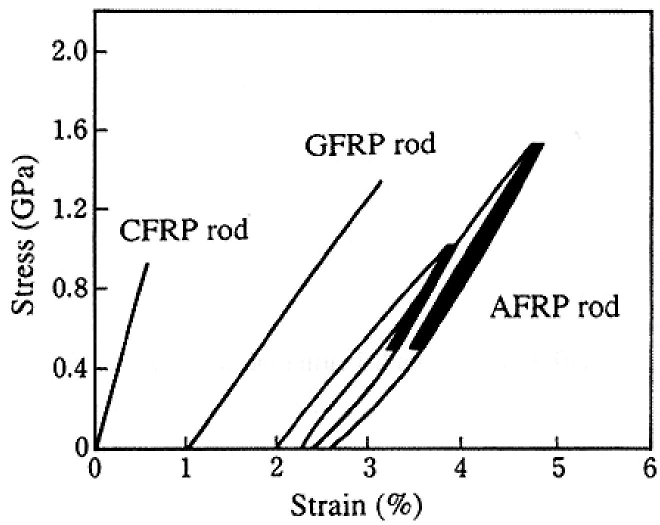

Fig. C 4 Effects of repeated loading on Young's modulus

(2) Where strain can be accurately measured up to failure using a strain gauge or similar apparatus, it was decided to identify ultimate strain with the strain corresponding to the tensile capacity. This ultimate strain corresponds to the ultimate strain used in design. Conversely, if strain cannot be accurately measured up to failure using a strain gauge or similar apparatus, ultimate strain is extrapolated based on the Young's of elasticity and the tensile capacity. This method results in errors for materials (Aramid etc.) where the Young's modulus varies with the load, and the value obtained is

around 5% greater than the measured ultimate strain. Extrapolated ultimate strain, strictly speaking, is not identical with the failure strain, but the variation is minor and the value can safely be substituted for failure strain for design purposes.

REFERENCES

1) Section III, "DOCUMENTATION" of the present volume

2) Kakibara, Kamiyoshi and Kawasaki: Dynamic Characteristics of AFRP Rods, Proceedings of Symposium on Application of CFRM to Concrete Structures, pp. 79~82, 1992

3) Uomoto and Nishimura: Static Strength and Elastic Modulus of FRP Rods, JSCE Papers, No. 472/V-20, pp.77~86, 1993