COMMENTARY ON THE TEST METHOD FOR TENSILE FATIGUE OF CONTINUOUS FIBER REINFORCING MATERIALS (JSCE-E 535-1995)

INTRODUCTION

The test method presented here is based on the JSCE "Test Method for Fatigue of Continuous Fiber Reinforcing Material (Tentative Proposal)", published in Vol. 72 of the Concrete Library, April 1992. Given the need to confirm the fatigue characteristics of CFRM used in concrete structures subject to prevailing repeated loads due to traffic, wave action etc., the April 1992 proposal is presented as a fatigue test method for isolated CFRM, with reference to JIS K 7118 "General Rules for Testing Fatigue of Rigid Plastics", JIS K 7119 "Testing Method of Flexural Fatigue of Rigid Plastics by Plane Bending, JIS Z 2273 "General Rules for Fatigue Testing of Metals", and the JSCE standard "Proposed Method for Fatigue Testing of Reinforcement Joints”. The method given here is a revised version of the April 1992 proposal, narrowed down to tensile fatigue test as this is the most fundamental test, with reference to JIS K 7083 "Testing Method for Constant-Load Amplitude Tension - Tension Fatigue of Carbon Fiber Reinforced Plastics".

Ideally the fatigue characteristics of CFRM in concrete structures should be tested on concrete members incorporating the CFRM, but as such tests would have to be done on a large scale and are unsuitable for accumulation of data, it was decided to set up a fatigue test method for isolated CFRM. Once a certain quantity of data has been accumulated, tests using concrete members to confirm fatigue characteristics will also be necessary.

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. Various forms of fatigue test are possible, such as tension-tension, tension-compression, compression-compression testing etc., and various methods of loading are also possible, but it has been decided to define the present test as a tensile and tensile fatigue test under constant cycle load, this being considered the most basic method for evaluating material characteristics.

2. DEFINITIONS

Definitions of terms for this test shall follow those given in the "Test Method for Tensile Properties of Continuous Fiber Reinforcing Materials", with reference also to JIS K 7083 " Testing Method for Constant-Load Amplitude Tension - Tension Fatigue of Carbon Fiber Reinforced Plastics ".

(Comment on (1)~(6)) As testing machines are load-controlled, the term load is used in the description of the test, although the term stress is more usual in reporting of results. In the context of this test, therefore, both terms are used interchangeably (see **Fig. C 1**).

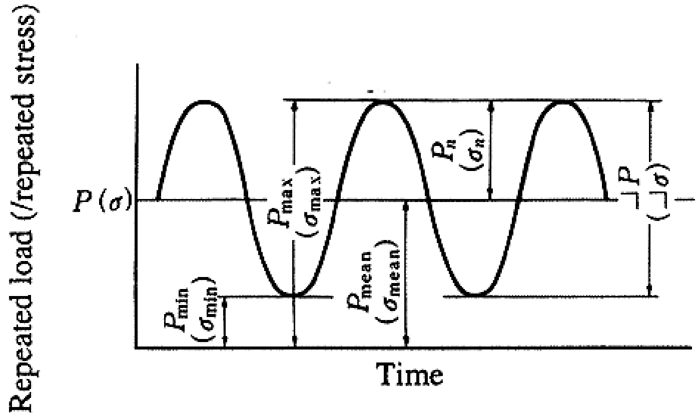

Fig. C 1 Repeated load (/repeated stress)[1)]

(Comment on 8) The number of cycles is represented by *N* or *n*, where *N* is the number of cycles to fatigue failure, and *n* is the number of cycles carried out during fatigue testing.

(Comment on 9) If the test piece has not failed by the end of the test, this fact is to be indicated by the addition of an arrow at the right-hand end of the curve (see **Fig. C 2**). The vertical axis of the *S-N* plot may represent repeated maximum stress (σ_{max}), stress range ($\Delta\sigma$), stress amplitude (σ_a) etc., depending on the purpose of the test. "Stress" may be replaced by "load" depending on the purpose of the test.

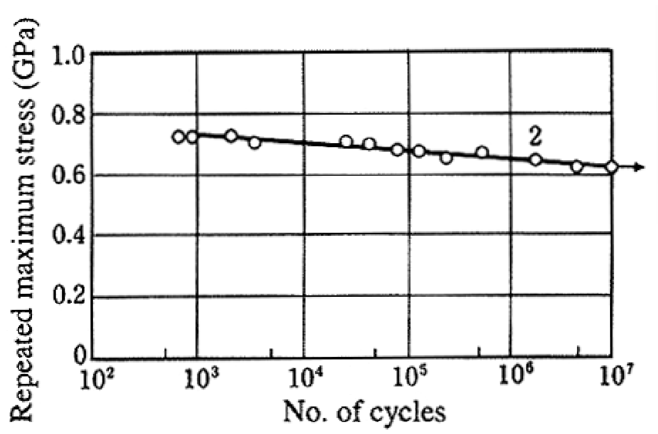

Fig. C 2 Typical *S-N* plot

(Comment on 10) Fatigue strength is generally taken to be a generic term for fatigue limit and fatigue strength at N cycles, where the fatigue limit specifically refers to the point at which the *S-N* curve becomes parallel to the horizontal axis (representing number of cycles). Fatigue strength at N cycles is the upper limit for the repeated stress that can be borne by the test piece over a specified number of cycles (N). While fatigue limits are recognized for steel materials, for plastics and FRPs the S-N curve continues to slope downwards even after 10^8 cycles. So-called fatigue limits are therefore considered not to exist for these materials, and the maximum stress at which the material does not fail after N cycles is substituted for the fatigue limit. That is, this fatigue limit is equivalent to fatigue strength at N cycles, and for CFRM also, the maximum stress at which the material does not fail after N cycles is substituted for the fatigue limit. Fatigue strength is indicated with the number of cycles N appended in parentheses, e.g. σ_m (2×10^6).

(Comment on 11) The unit normally used is Hz.

3. TEST PIECES

(Comment on 3.1) Except for the fact that the load acting on the test piece is a constant load applied repeatedly, the loading conditions for test pieces are similar to those for tensile test, therefore the test pieces for this test are to be in accordance with the "Test Method for Tensile Properties of Continuous Fiber Reinforcing Materials".

(Comment on 3.2) The requirement for at least three (3), for each of at least three (3) levels of loading / stress is imposed to ensure proper plotting of the downward-sloping *S*-*N* curve, but if the *S*-*N* curve cannot be properly plotted because of unsuitable stress level settings or wide variations in data, additional test must be performed as necessary. The static tensile strength on which the loading levels for this test are based should be calculated on the basis of not less than five tests conducted according to the "Test Method for Tensile Properties of Continuous Fiber Reinforcing Materials", using identical test pieces to those used in the fatigue test.

4. TESTING MACHINE AND DEVICES

(Comment on 4.1) The testing machine should preferably be fitted with an automatic load maintenance mechanism. If a test machine with electrohydraulic control is to be used, steps must be taken to ensure the knobs on the excitation side are fixed, i.e. cannot rotate during the test (see **Fig. C 3**).

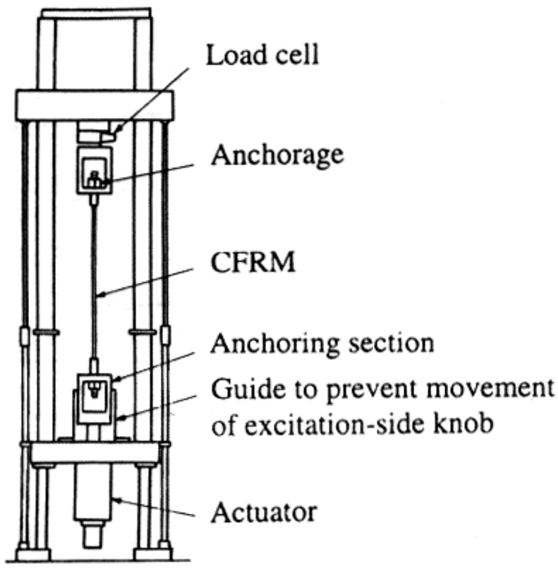

Fig. C 3   Typical testing machine

(Comment on 4.2) Some reports indicate that the type of anchorage device used has a greater effect on the test results in fatigue test than in tensile test, and this issue remains to be studied. Provisionally, therefore, the anchorage used should be identical in all tests.

5. TEST TEMPERATURE

As the effects of temperature and humidity on fatigue tests remains to be clarified, the provision given here is based on the "Test Method for Tensile Properties of Continuous Fiber Reinforcing Materials".

6. TEST METHOD

(Comment on 6.1) If any slight horizontal movement or rotation of the knob on the excitation side of the test machine is noted, fitting of a guide to prevent such movement before the test is performed may minimize or eliminate any variations in data.

(Comment on 6.2) If the effects of creep failure strength on the tensile fatigue strength are known in advance, this should be taken into account in the setting of the test load and the frequency. Typical *S-N* curves for FRP using various types of fibers are shown in **Fig. C 4**, where the maximum-minimum stress ratio *R* is fixed at 0.1. As the fatigue life (i.e. number of cycles to fatigue failure) is generally affected not only by the maximum stress ratio, but also by the stress amplitude, different results may be obtained is the maximum and minimum stress ratios vary. In actual concrete structures subject to variable loads, permanent loads such as dead weight etc. can be considered as the minimum load, and the design load can be considered as the maximum load. In almost all cases, the maximum-minimum stress ratio *R* is greater than the value adopted in **Fig. C 4**, therefore the *S-N* curve obtained in such a case can be taken to be more conservative than that shown in **Fig. C 4**.

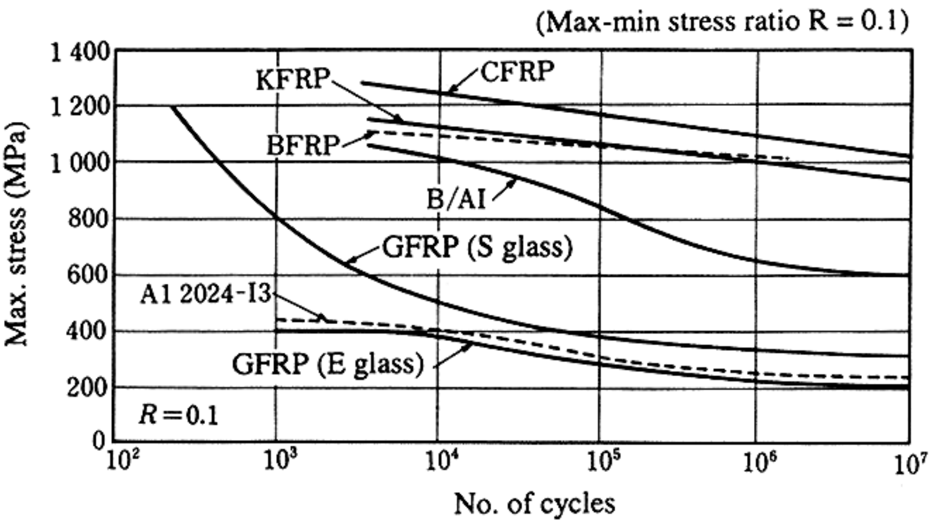

Fig. C 4 Typical *S-N* curves for various FRP

The following procedure may be employed where the maximum stress level for the initial test is difficult to determine:

(1) Select an appropriate stress level in the range 20~60% of the static tensile strength, and commence

fatigue test with this value as the repeated maximum stress.
(2) If the test piece ~~is~~ still did not fail after 10^4 cycles at this repeated maximum stress, add 5% of the static tensile strength to the repeated maximum stress, and perform the test using the same test piece. In this case, if possible the test should be carried on uninterruptedly, with the repeated maximum stress incorporating 5% of the static tensile strength.
(3) If the test piece still did not fail after a further 10^4 cycles following step (2), a further 5% of the static tensile strength should be added to the repeated maximum stress.
(4) Repeat step (3) until the test piece fails.
(5) The initial tensile-tensile fatigue repeated maximum stress should be set at the repeated maximum stress level where the test piece fails, minus 5% of the static tensile strength.

(Comment on 6.3) The frequency is set to eliminate the effects of inertia of the moving parts of the test machine, with an upper limit placed at the frequency to prevent excessive heating of the test piece. The entire series of tests should preferably be performed with the same frequency. If the frequency is too low the test will be prolonged accordingly, while if the frequency is too high, the effects of heating will accelerate fatigue damage of the test piece, thus reducing the number of cycles to failure. Further limitations are imposed by the capacity of standard testing machines etc. For these reasons, the frequency has been set at 1~10 Hz, based on previously conducted tensile fatigue tests on CFRM. Depending on the type of CFRM and the stress level, heating may occur even in this range. If heating is suspected, the frequency should be kept below 5 Hz, and the temperature of the test piece should be monitored.

(Comment on 6.4) It should be noted that load variation may occur during a test due to variations in the rigidity of the test piece. If the test machine is not equipped with an automatic load maintenance mechanism, the load must be checked and corrected as necessary during the test.

(Comment on 6.5) The number of cycles is expressed as a multiple of 10^n, e.g. 2.34×10^5, rounded off to three significant digits. The maximum value for the number of cycles to failure (i.e. the number of cycles at which the test may be halted) is 2×10^6.

7. CALCULATION AND EXPRESSION OF TEST RESULTS

(Comment on 7.2) In the case of repeated loading, the stresses corresponding to the maximum and minimum loads respectively are the maximum repeated stress (σ_{max}) and the minimum repeated stress (σ_{min}). Which of the terms load and stress is used will depend on the purpose of the test.

In fatigue test with constant average load or constant minimum repeated load, the relationship generally sought is that between maximum repeated stress or stress amplitude, and the number of cycles to failure (the *S-N* curve). For some test purposes, though, fatigue strength after a given number of cycles may be plotted with stress amplitude on the vertical axis and average stress on the horizontal axis, or with maximum stress on the vertical axis and minimum stress on the horizontal axis.

In the present test, it is hard to draw a distinction between tensile fatigue strength and creep failure strength; this issue awaits further study. In the calculation and expression of test results, therefore, the number of cycles and the repetition rate, i.e. the length of time the repeated load is applied, must be made clear. Where the creep failure strength is known, this may be plotted in a fatigue strength graph etc.

8. TEST REPORT

(Comment on 6) If the test piece did not fail or the test is halted after the specified number of cycles, this fact should be noted in the test report. For cases of failure other than normal failure, the condition of the test piece during the test, and the mode of failure, should also be noted.

REFERENCE

1) JIS K 7083 " Testing Method for Constant-Load Amplitude Tension - Tension Fatigue of Carbon Fiber Reinforced Plastics "