COMMNETARY ON THE TEST METHOD FOR COEFFICIENT OF THERMAL EXPANSION OF CONTINUOUS FIBER REINFORCING MATERIALS BY THERMOMECHANICAL ANALYSIS (JSCE-E 536-1995)

INTRODUCTION

The test method presented here is based on the JSCE "Test Method for Thermal Expansion Coefficient Testing of Continuous Fiber Reinforcing Material (Tentative Proposal)", published in Vol. 72 of the Concrete Library, April 1992, which was based on JIS C 2141 "Testing Methods of Ceramic Insulators for Electrical and Electronic Applications", as the coefficients of thermal expansion of CFRM are relatively close to those of ceramics. Subsequent investigations with commercially available testing machines for measuring thermal expansion coefficients revealed that the TMA machine is the most widely available machine, and furthermore requires no particular expertise in handling. JIS standards have already been established for thermal expansion coefficient test of plastics using the TMA and the technique has been confirmed to be sufficiently accurate. These facts have been borne in mind in drawing up the present test method. The following standards are referenced:

JIS R 3102-1993 "Test Method for Average Linear Thermal Expansion of Glass"
JIS K 7197-1991 "Testing Method for Linear Thermal Expansion Coefficient of Plastics by Thermomechanical Analysis"
JIS K 7100-1981 "Standard Atmospheres for Conditioning and Testing of Plastics"
JIS B 7502-1979 "Micrometer Calipers"

1. SCOPE

This test using the TMA device is to be applied to linear or meshed CFRM test pieces formed from continuous fibers, matrices etc. as defined elsewhere and acting dynamically as a monolithic body.

2. DEFINITIONS

(Comment on 1) A non-vibrating load refers to a load applied slowly enough to prevent the load changes over time from being affected by the viscoelasticity of the material.
(Comment on 3) Coefficient of thermal expansion is generally defined as a value obtained by dividing the differential of the ratio between the length change and temperature change at a given temperature (dL/dT) by the length of the test piece as measured at room temperature. Strictly speaking, however, the length of the test piece ΔL in relation to a finite temperature difference ΔT is a measured variable rather than a differential value, hence the term average coefficient of linear thermal expansion at representative temperatures.

3. TEST PIECES

(Comment on 3.1) Unlike metals, inorganic materials etc., in plastics the dimension changes due to adsorption and desorption of moisture, or to the release of residual strain during molding, processing etc. are not negligible in comparison to the linear thermal expansion. In order to ensure the reliability of measurements, provision has therefore been made for curing of CFRM based on JIS K 7100 "Standard Atmospheres for Conditioning and Testing of Plastics ", with the aim of eliminating moisture and strain resulting from molding and processing. Clearly, if pre-test curing is inadequate, the test piece will shrink due to desorption of moisture as the temperature rises, resulting in an exaggerated value being obtained for the coefficient of thermal expansion.

(Comment on 3.2) The length of the test piece is based on JIS R 3102 "Test Method for Average Linear Thermal Expansion of Glass", where out of consideration for the capacity of the testing machine the standard length is set at no more than 20±0.025 mm, and the diameter or length of one side is set at no more than 5 mm. If a test piece of such dimensions is difficult to obtain from the CFRM in question, test pieces of different dimensions may be used.

4. TESTING MACHINE

(Comment on 4.1) A standard TMA apparatus allows measurements in various modes - expansion, compression, penetration, tension etc. - depending on the choice of loading method and the geometry of the detector rod, but the test described here will normally be conducted in compression mode. A typical TMA apparatus is illustrated in **Fig. C 1**.

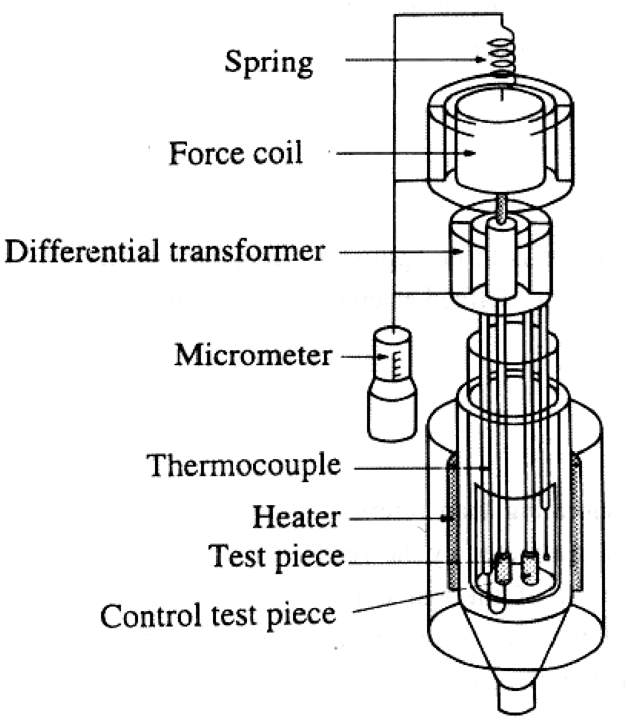

Fig. C 1 Configuration of a typical TMA apparatus

(Comment on 4.2) As the accuracy of measurements of the coefficient of thermal expansion is intimately connected with the accuracy of temperature measurements, temperature calibration is particularly important. Temperature calibration materials feasible for this test would include ice water (0°C) for low temperature calibration, and indium (melting point 156.4°C) for high temperature calibration.

(Comment on 4.3) The TMA apparatus should preferably be mounted on a vibration-proofing base during the test, to eliminate the effects of vibration.

5. TEST METHOD

(Comment on 5.1) As measurement accuracy in the order of μm is required to ascertain dimensional changes, care must be taken to remove extraneous materials such as grease, and to mount the test piece stably.

(Comment on 5.4) The service temperature range for CFRM in actual service is assumed to be 0~60°C. If service temperatures are expected to fall outside this range, the test temperature range must be extended accordingly.

(Comment on 5.5) A limit has been imposed on the rate of temperature increase to minimize temperature measurement errors resulting from the temperature increasing too rapidly.

(Comment on 5.6) According to JIS K 7197 "Testing Method for Linear Thermal Expansion Coefficient of Plastics by Thermomechanical Analysis", the compressive stress acting on the tip of the detector rod is to be in the order of 3±0.1 mN/mm^2, and this standard has been referenced in setting the compressive stress acting on the test piece at around 3 mN/mm^2. This requirement need not apply if the effects on measurements within the test temperature range of softening of the matrix are minimal.

6. CALCULATION AND EXPRESSION OF TEST RESULTS

The coefficient of thermal expansion of unidirectional fiber-reinforced plastics along the fiber axis is approximated by the following equation according to compounding:

$$\alpha_F = (E_f \alpha_f V_f + E_m \alpha_m V_m) / (E_f V_f + E_m V_m) \qquad \text{(Eq. C 1)}$$

where

α_F = coefficient of thermal expansion of unidirectional fiber-reinforced plastics along the fiber axis

α_f = coefficient of thermal expansion of fiber material

α_m = coefficient of thermal expansion of matrix

E_f = modulus of elasticity of fiber material

E_m = modulus of elasticity of matrix

V_f = fiber material content by volume

V_m = matrix content by volume

As the Young's modulus of the fiber binding material is generally very small compared to the Young's modulus of the fiber material, the coefficient of thermal expansion of unidirectional fiber-reinforced plastics along the fiber axis will be close to the coefficient of thermal expansion of fiber material.

Similarly, the coefficient of thermal expansion perpendicular to the fiber axis is approximated by the following equation:

$$\alpha_{Fr} = (1+V_m)\alpha_m V_m + (1+V_f)\alpha_f V_f - \alpha_F (v_f V_f + v_m V_m) \qquad \text{(Eq. C 2)}$$

where

α_{Fr} = coefficient of thermal expansion of unidirectional fiber-reinforced plastics perpendicular to the fiber axis

v_f = Poisson's ratio of fiber material

V_m = Poisson's ratio of matrix

Approximate values obtained for various fiber materials and CFRM using them are listed in **Table C 1**. It can be seen from the table that, since the coefficient of thermal expansion of unidirectional fiber-reinforced plastics along the fiber axis is approximately equivalent to that of the fiber material, the coefficient of thermal expansion of the fiber material may be substituted for that of the unidirectional fiber-reinforced plastic along the fiber axis.

As few measurements have been made of the coefficient of thermal expansion of CFRM perpendicular to the fiber axis, an example for one type of unidirectional fiber-reinforced plastic is also given in the table (1). The coefficient of thermal expansion perpendicular to the fiber axis is extremely high in relation to that in the axial direction, and tends to approach the order of magnitude of the coefficient of thermal expansion of the fiber binding material.

Table C 1: Approximate values for coefficient of thermal expansion

Material	Coefficient of Thernal Expansion ($\times 10^{-6}$/°C)		
	Fiber	CFRM or Other Materials	
		Longitudinal Direction	Transverse Direction
Carbon	-2 ~ 8	0.6 ~ 1	25
Aramid	-8 ~ -3	-6 ~ -2	30
Glass	8 ~ 10	8 ~ 10	23
Epoxy	55 ~ 60		
Unsaturated Polyester	80 ~ 100		
Steel	12		
Concrete	7 ~ 12		

REFERENCE

1) H. Miyairi et al. (ed.) Dictionary of Composite Materials, Asakura Shoten publishers, pp.278~279, 1991