TRANSVERSE COMPRESSIVE PROPERTIES OF NOVEL CARBON/GLASS HYBRID THERMOPLASTIC COMPOSITE RODS

Kimiyoshi Naito[1], Chiemi Nagai[2] and Yoshihisa Tanaka[3]

[1] National Institute for Materials Science, Research Center for Structural Materials, Polymer Matrix Hybrid Composite Materials Group, 1-2-1 Sengen, Tsukuba, Ibaraki, 305-0047
Email: naito.kimiyoshi@nims.go.jp,
Web Page: http://www.nims.go.jp/eng/research/group/polymer-matrix/index.html
[2] National Institute for Materials Science, Research Center for Structural Materials, Polymer Matrix Hybrid Composite Materials Group, 1-2-1 Sengen, Tsukuba, Ibaraki, 305-0047
Email: nagai.chiemi@nims.go.jp
[3] National Institute for Materials Science, Research Center for Structural Materials, Polymer Matrix Hybrid Composite Materials Group, 1-2-1 Sengen, Tsukuba, Ibaraki, 305-0047
Email: tanaka.yoshihisa@nims.go.jp

Keywords: carbon fiber, glass fiber, thermoplastic epoxy, transverse compressive

Abstract
The transverse compressive properties and fracture behavior of the hybrid rods were investigated. The compressive load per unit length-displacement (*F*-*U*) curve showed large nonlinear behavior and complicated shape. In the initial stage, the load gradually increased with increases in the deformation. This behavior was caused by the increase in the contact zone. In the second stage, the load-displacement relation was almost linearly proportional to the displacement (stable deformation region). Subsequently, the slope d*F*/d*U* decreased slightly. Finally, the load-displacement curve showed a clear slope d*F*/d*U* increase as the deformation proceeds. The transverse compressive modulus and strength of the hybrid rods were ranged 639-655 MPa and 8.05-15.26 MPa.

1. Introduction

Tendons are widely used as tension members for constructing civil, building, and offshore engineering infrastructure. Tendons and traditional reinforced concrete used in high-tensile-strength steel wires, bars, and rebars. Corrosion and fatigue of steel cables and classical steel reinforcing bars are serious issues [1]. Therefore, the use of fiber-reinforced polymer matrix composites, particularly carbon fiber reinforced polymer matrix composites have been proposed [2].

Novel carbon/glass hybrid thermoplastic composite rods called “CABKOMA” have been developed by Komatsu Seiren Co., Ltd. Recently, Naito et al. characterized the morphology and tensile properties of the hybrid rods under static and fatigue loading [3,4].

Additionally, it is necessary to characterize compressive and flexural properties of these hybrid rods to understand their structural features and mechanical properties.

In this present study, the transverse compressive properties of the three types of hybrid rods having differing carbon/glass ratios (24K1P, 24K2P, and 24K3P) were evaluated.

2. Experimental procedure

2.1. Materials

The novel carbon/glass hybrid thermoplastic composite rods were developed by the Komatsu Seiren Co., Ltd. Three types of hybrid rods having different carbon/glass ratios were fabricated and described as 24K1P, 24K2P, and 24K3P [3.4].

2.2. Transverse compressive test

The transverse compressive tests for the hybrid rod were performed through in situ observation using a digital microscope (VHX-5000 and VH-ZST, Keyence) with a compression module system (5 kN load cell, Kammrath & Weiss GmbH). The displacement was applied quasi-statically at a crosshead speed of 1.0 μm/sec to obtain the transverse compressive properties of the hybrid rods. All tests were conducted in the laboratory environment at room temperature (at 23 ± 3°C and relative humidity of 50 ± 5%).

The transverse compression test yielded a load, P, as a function of the deformation curve, U^*, up to failure. The calibration was performed by applying a compressive load without a sample to estimate the system compliance, C_S. The true deformation, U, is given as follows:

$$U = U^* - C_S P. \tag{1}$$

Studies by Ward et al. derived the deformation, U, in a circular cross-section fiber as a function of the transverse compressive load, P, for an anisotropic body [5]. The equation is as follows:

$$U = \frac{4F}{\pi}\left(\frac{1}{E_T} - \frac{\nu_{LT}^2}{E_L}\right)\left(0.19 + sinh^{-1}\frac{R}{b}\right). \tag{2}$$

where

- F = compressive load per unit length (= P/L);
- E_L = longitudinal modulus (= E_{LC});
- E_T = transverse modulus (= E_{TC});
- ν_{LT} = Poisson's ratio;
- R = radius of the hybrid rod (= d/2);
- b = half-width of contact zone and is given as follows:

$$b = \sqrt{\frac{4FR}{\pi}\left(\frac{1}{E_T} - \frac{\nu_{LT}^2}{E_L}\right)}. \tag{3}$$

When the relation $\frac{\nu_{LT}^2}{E_L} << \frac{1}{E_T}$ is assumed, Eqs. (4) and (5) correspond to a simplified form as follows:

$$U = \frac{4F}{\pi}\left(\frac{1}{E_T}\right)\left(0.19 + sinh^{-1}\frac{R}{b}\right). \tag{4}$$

where

$$b = \sqrt{\frac{4FR}{\pi}\left(\frac{1}{E_T}\right)}. \tag{5}$$

The transverse compressive modulus, E_{TC}, was calculated from Eq. (4) and the *F*-*U* curve obtained from the transverse compression test.

3. Results and discussion

Fig. 1 shows the typical transverse compressive load per unit length-displacement (*F*-*U*) curves for the hybrid rods. The figures also depict the line obtained from Eq. (4) by curve fitting. The *F*-*U* curves showed large nonlinear behavior and complicated shape. In the initial stage, the load gradually increased by increasing the deformation. This behavior was caused by the increase in the contact zone. In the second stage, the load-displacement relation was fitted by the analytical relation obtained from Eq. (4) (stable deformation region). Subsequently, the slope d*F*/d*U* decreased slightly. Finally, the load-displacement curve showed a clear increase in slope d*F*/d*U* as the deformation proceeded.

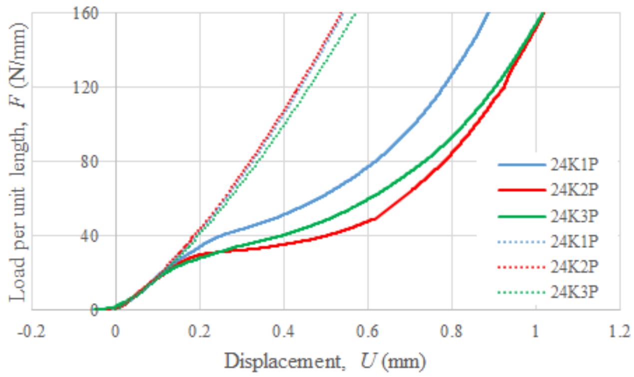

Figure 1. Typical transverse compressive load per unit length-displacement curves for the hybrid rods.

The transverse compressive modulus, E_{TC} of the hybrid rods were determined as 0.655 (24K1P), 0.644 (24K2P), and 0.639 GPa (24K3P), respectively. The transverse compressive stress, σ_{TC}, is given as follows:

$$\sigma_{TC} = \frac{F}{d} = \frac{P}{L \cdot d}. \tag{6}$$

Fig. 2 shows typical transverse compressive stress-displacement (σ_{TC} -*U*) curves for the hybrid rods. The transverse compressive stress at which these tangent lines intersect is defined as the transverse compressive strength, σ_{TCf}. The transverse compressive strengths, σ_{TCf}, of the hybrid rods were measured as 15.26 (24K1P), 8.79 (24K2P), and 8.05 MPa (24K3P), respectively.

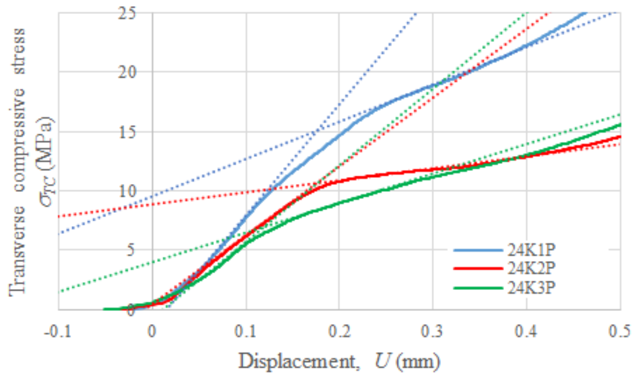

Figure 2. Typical transverse compressive stress-displacement curves for the hybrid rods.

Digital micrographs of cross-sectional views of the transverse compressive fractured surface of the hybrid rods are shown in Fig. 3. The observed fracture paths formed almost straight lines running through the loading point, the center of the cross section of the carbon fiber bundles/thermoplastic epoxy, as well as the interface between the glass fiber bundles/thermoplastic epoxy and the carbon fiber bundles/thermoplastic epoxy.

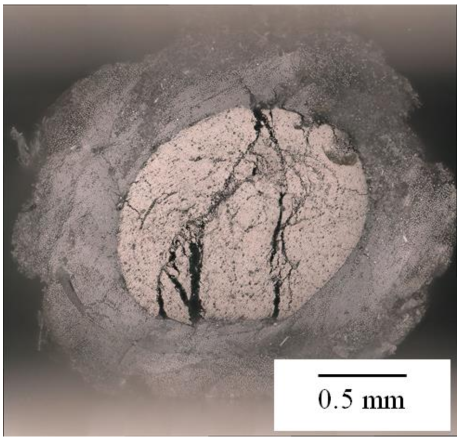

Figure 3. Digital microscope micrographs of cross-sectional views for the transverse compressive fractured surface of the 24K1P hybrid rods (P = 200 N, F = 38.82 N/mm, σ_{TC} = 16.91 MPa).

4. Conclusions

The results of the transverse compressive tests of the hybrid rods are summarized as follows:
(1) The load-displacement curve showed large nonlinear behavior and complicated shape. In the initial stage, the load gradually increased by increasing the deformation. In the second stage, the load-displacement relation was almost linearly proportional to the displacement (stable deformation region). Subsequently, the slope decreased slightly. Finally, the load-displacement curve showed a clear slope increase as the deformation proceeded.
(2) The transverse compressive moduli of the hybrid rods were 0.655 (24K1P), 0.644 (24K2P), and 0.639 GPa (24K3P), respectively. Transverse compressive strengths of the hybrid rods were 15.26 (24K1P), 8.79 (24K2P), and 8.05 MPa (24K3P), respectively.

(3) The observed fracture paths formed almost straight lines running through the loading point, the center of the cross section of the carbon fiber bundles/thermoplastic epoxy, as well as the interface between the glass fiber bundles/thermoplastic epoxy and the carbon fiber bundles/thermoplastic epoxy.

Acknowledgments

This research was promoted by COI program "Construction of next-generation infrastructure using innovative materials ~ Realization of safe and secure society that can coexist with the Earth for centuries ~ supported by Japan Science and Technology Agency (JST).

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