CREEP RUPTURE LIFE AND INTERLAMINAR SHEAR STRENGTH OF WATER-ABSORBED GREEN COMPOSITE WITH PLAIN WOVEN NATURAL FIBER CLOTH

HIDEAKI KATOGI[1], KENICHI TAKEMURA[2] & ATSUHIRO HAYAMORI[2]
[1]Department of Human Environmental Sciences, Jissen Women's University, Japan
[2]Department of Mechanical Engineering, Kanagawa University, Japan

ABSTRACT

To ensure safety of electric vehicles using green composites, this study examined the interlaminar shear strength, creep rupture strength, and useful life of plain woven jute fiber cloth reinforced polylactic acid after water immersion. The fiber volume fraction of the green composite was 40%. Water absorption tests were conducted of the green composite comprising jute fiber and polylactic acid (PLA). Tensile creep tests of green composite and jute fiber were conducted after water immersion. The maximum stress was 60–90% of tensile strength. The environmental temperature was room temperature. Short beam testing of double-notched green composite was also conducted after water immersion. Results show the following. When water absorption tests were conducted, the water absorption rates of green composite, jute fiber and PLA at 24 hr were 9%, 3.4% and 0.3%, respectively. The creep rupture strength of 9% water absorbed green composite was lower than that of non-water-absorbed (non-absorbed) green composite. However, the creep rupture strength of 3.4% water absorbed jute fiber was slightly higher than that of non-absorbed jute fiber. For maximum stress of 40 MPa, the creep rupture life of 9% water absorbed green composite was much shorter than that of the non-absorbed green composite. Interlaminar shear strength of 9% water absorbed green composite was lower by 11% than that of the non-absorbed green composite. Water penetrated to the fiber–resin interface when water absorption test of green composite was conducted until 24 hr. Therefore, the interlaminar shear strength, creep rupture life, and green composite strength were decreased mainly because of the decrease of fiber–resin interfacial adhesion as a result of water penetration.

Keywords: green composite, creep rupture, interlaminar shear strength, natural fiber, polylactic acid, residual tensile strength, water absorption.

1 INTRODUCTION

Green composites incorporating natural fiber and biodegradable polymer have been specifically examined as structural materials used in electric vehicles because the tensile strength of green composites incorporating unidirectional natural fiber approaches that of aluminum [1]. Recently, the LINA electric vehicle was developed using green composites [2]. Many electric vehicles using green composites are expected to be developed. Mechanical properties of green composites and constituent materials have been examined [3]–[13], but green composite creep behavior must be studied further for long-term safety.

Takemura et al. [14] reported the tensile creep behavior of green composites treated with a silane coupling agent. The creep compliance of such treated green composites became lower than that of non-treated green composites at 60°C. Morreale et al. [15] reported on the creep behavior of green composites incorporating flax fiber cloth. The normalized deformation of green composite incorporating flax fiber cloth at 60°C was higher than that of such composites at 40°C.

Electric vehicles are used in rainy environments. For wider application, many reports have described water absorption properties of green composites [16]–[18].

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Nam et al. [19] reported the effects of fiber volume fraction on water absorption properties of jute-fiber-reinforced polybutylene succinate (PBS). The water absorption rate of jute-fiber-reinforced PBS during 256 hr increased with increased fiber volume fraction.

The creep behavior of green composites after water immersion must be investigated for long-term safety. Katogi and Takemura [20] examined the creep rupture strength of green composite after water immersion. The creep rupture strength of water-immersed green composite was lower than that of a non-immersed green composite. Furthermore, yarn pull-out from the fracture surface of the water immersed green composite was found. For more details, the mechanism of water-absorbed green composites must be investigated under constant loading.

For clarification of related mechanisms, this study examined the creep rupture life and interlaminar shear strength of a green composite after water absorption.

2 MATERIALS AND MOLDING METHOD

The matrix was a polylactic acid (PLA) sheet (Ecodear 250-1B01CA; Toray Co. Ltd.). It was reinforced with plain woven jute fiber cloth knitted from spun jute yarn.

Regarding the green composite molding conditions, vacuum compression molding was used with molding pressure was 1.8 MPa. The molding time was 10 min. The molding temperature was 190°C. Subsequently, the mold was cooled to room temperature. The fiber volume fractions of non-absorbed and water-absorbed green composite were 40%.

For molding of the PLA plate, vacuum compression molding was used. The molding pressure was 0.4 MPa. The molding time was 10 min. The molding temperature was 190°C. Subsequently, the mold was cooled to room temperature.

3 TESTING METHODS

3.1 Water absorption tests

Water absorption tests of green composite and constituent materials were conducted in distilled water. The environmental temperature was room temperature. The maximum immersion time was 24 hr. Numbers of specimens for the green composites and PLA were, respectively, five. Green composite specimens were 200 mm long, 10 mm wide, and 1.0 mm thick. The PLA specimens were 50 mm long, 50 mm wide, and 4.0 mm thick.

The jute fiber mass was found using an electronic balance (MSA2.7S-000-DM; Sartorius AG) for 20 specimens. In addition, the masses of 20 specimens were measured together when jute fiber water absorption tests were conducted. Measurements were conducted three times. The jute fiber length was 40 mm.

3.2 Quasi-static tensile tests

Before and after water absorption tests, quasi-static tensile tests of green composite were conducted. For residual tensile strength measurements, quasi-static tensile tests of green composites were conducted after creep testing when the loading time was 10^{-2} hr to 10 hr. The number of specimens was five. The crosshead speed was 1.0 mm/min. The environmental temperature was room temperature. The specimen was 200 mm long, 10 mm wide, and 1.0 mm thick. The gauge length was 25 mm.

Quasi-static tensile tests of jute fiber were conducted before and after water absorption tests. As test conditions, the crosshead speed was 1.0 mm/min. The environmental temperature was room temperature. The gauge length was 10 mm. The number of specimens was 20. Tensile strengths of non-absorbed and water-absorbed jute fiber were

calculated using a Weibull distribution. Young's moduli of non-absorbed and water-absorbed jute fiber were calculated at seven points using the cross-sectional area.

3.3 Tensile creep test

Tensile creep tests of non-absorbed and water-absorbed composites were conducted based on Japanese Industrial Standard (JIS) K 7115. The maximum stress was 60–90% of tensile strength. The environmental temperature was room temperature. The specimens were 200 mm long, 10 mm wide, and 1.0 mm thick.

Tensile creep tests of non-absorbed and water-absorbed jute fibers were conducted. The maximum stress was 60–90% of tensile strength. The environmental temperature was room temperature. The gauge length was 10 mm.

3.4 Short beam test

Short beam tests of double-notched green composite were also conducted before and after water immersion. The environmental temperature was room temperature. The crosshead speed was 1.0 mm/min. The gauge length was 20 mm. For water absorption rate control, the specimen used for short beam tests was immersed in distilled water for immersion time of 240 hr. The number of specimens was five. Fig. 1 presents a schematic drawing of double-notched specimens.

4 RESULTS AND DISCUSSION

4.1 Water absorption properties

Fig. 2 portrays water absorption properties of the green composite and constituent materials. The water absorption rate of the green composite increased with increased immersion time. However, the water absorption rate of PLA remained almost unchanged with increased immersion time. The water absorption rate of jute fiber increased with increased immersion time until 4 hr. Subsequently, scattering of the water absorption rate of jute fiber was slight. Water absorption rates of green composite, jute fiber and PLA at 24 hr were, 9%, 3.4% and 0.3%, respectively. One can infer that the water absorption rate of green composite was increased mainly because of the water absorption rate of jute fiber and water penetration into the fiber–resin interface.

4.2 Tensile properties and interlaminar shear strength

Fig. 3 presents the tensile strength and Young's modulus of non-absorbed and 9% water absorbed green composites and jute fiber. The tensile strength and Young's modulus of 9% water absorbed green composite were lower by 29% and 35%, respectively, than those of the non-absorbed green composite.

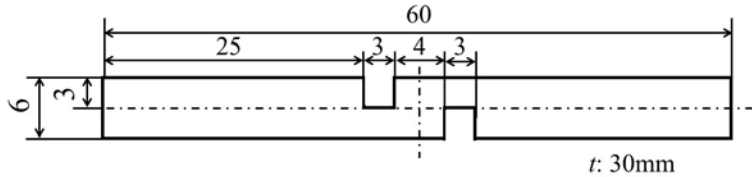

Figure 1: Schematic drawing of double-notched specimen.

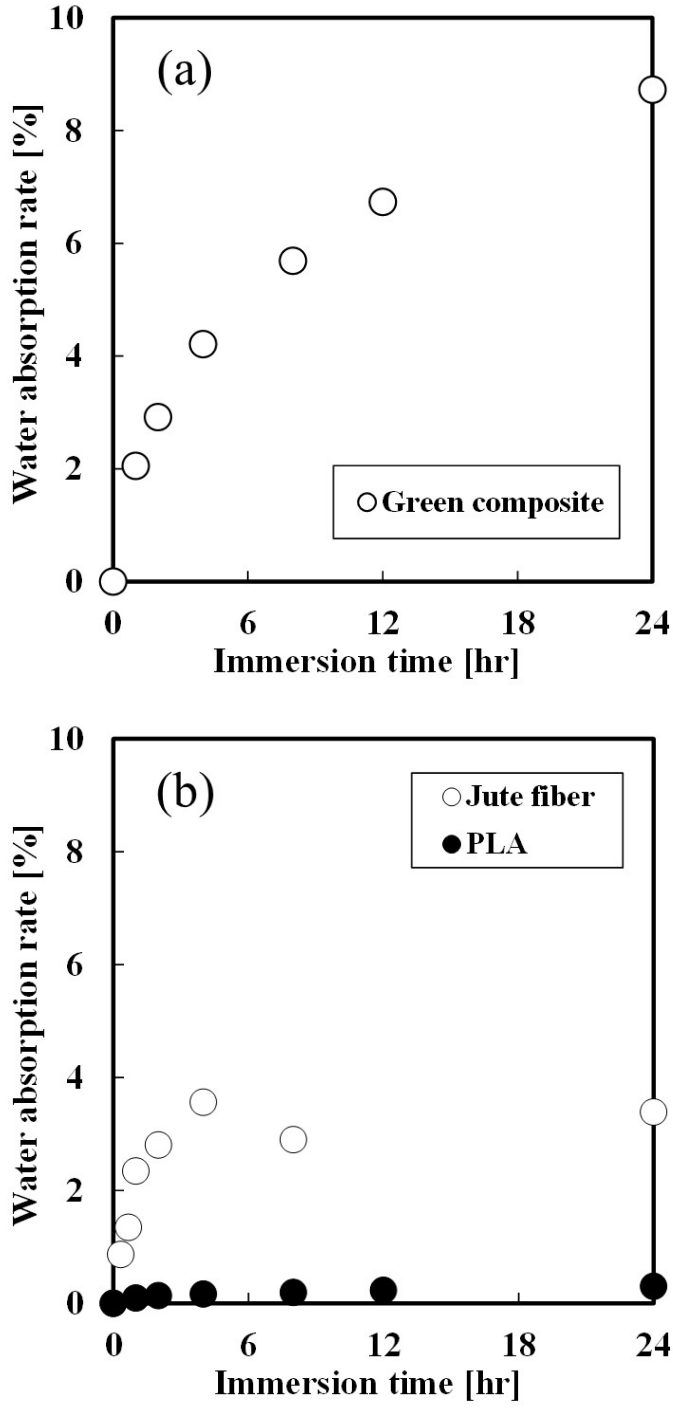

Figure 2: Water absorption properties of green composite and constitutional materials. (a) Green composite; and (b) Jute fiber and PLA.

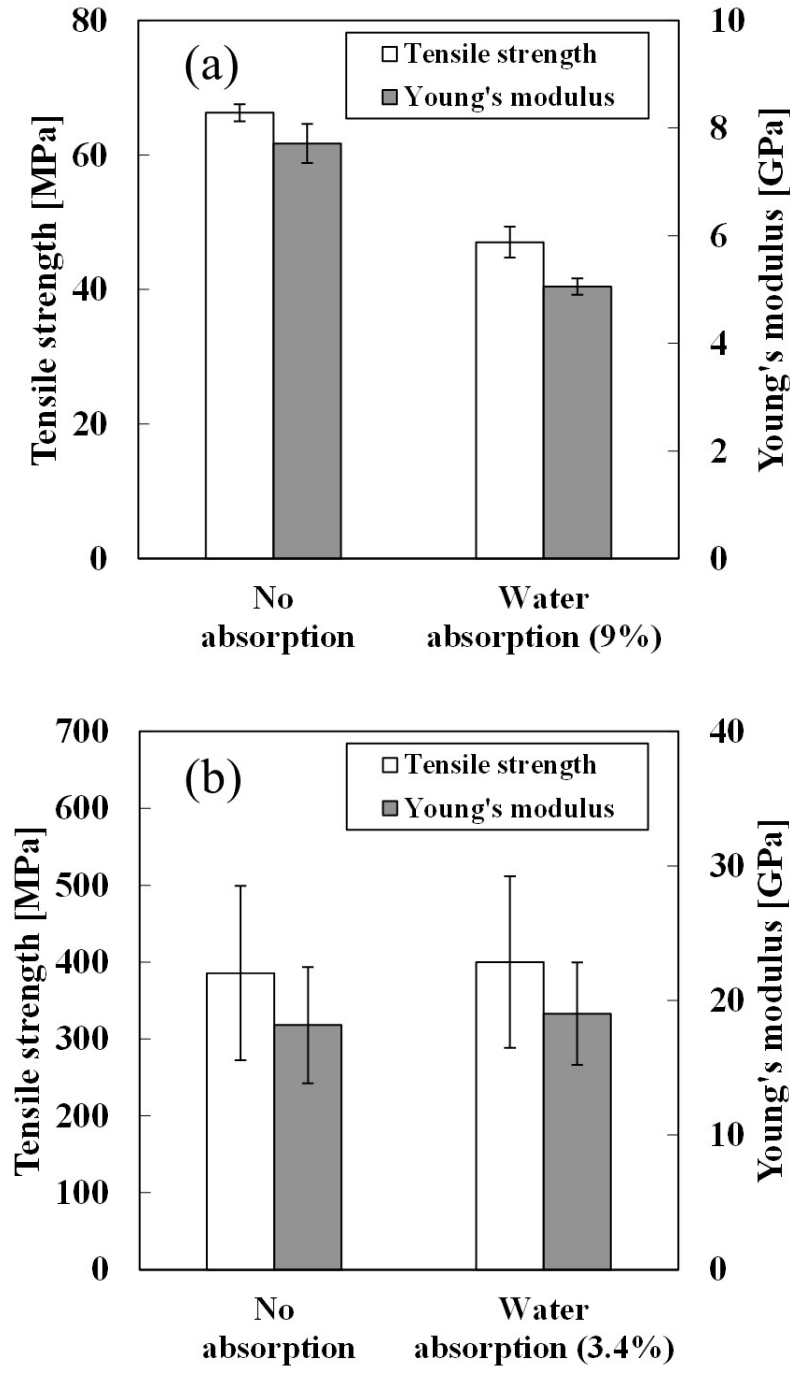

Figure 3: Tensile properties of non-absorbed and water-absorbed green composites and jute fibers. (a) Green composite; and (b) Jute fiber.

Tensile strengths and Young's moduli of non-absorbed and 3.4% water absorbed jute fibers remained almost unchanged. Scattering of tensile strengths and Young's moduli of non-absorbed and 3.4% water absorbed jute fibers was great, but the scattering of tensile strength and Young's modulus of 3.4% water absorbed jute fiber were generally equal to those of non-absorbed jute fiber. We can infer that the tensile properties of the water-absorbed green composite were unaffected by the jute fiber water absorption.

Fig. 4 shows interlaminar shear strengths of non-absorbed and water-absorbed green composites. The interlaminar shear strength of 9% water absorbed green composite was 11% lower than that of non-absorbed green composite. In this way, the interlaminar shear strength of green composites was decreased because of water penetration into the fiber–resin interface.

4.3 Creep rupture strength and life

Fig. 5 depicts creep rupture curves of non-absorbed and water-absorbed jute fibers and green composites. Creep rupture strengths of non-absorbed and 9% water-absorbed green composites decreased with increased loading time. The creep rupture strength of 9% water absorbed green composite was lower than that of non-absorbed green composite. Creep rupture strengths at 10 hr non-absorbed and 9% water absorbed green composites were 39% and 35%, respectively, compared with tensile strengths of non-absorbed and 9% water absorbed green composites. For maximum stress of 40 MPa, the creep rupture life of 9% water absorbed green composite was much shorter than that of non-absorbed green composites.

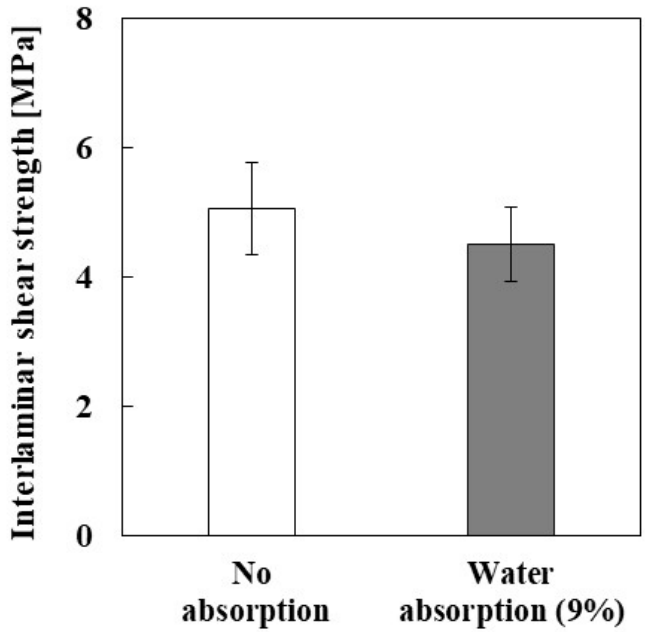

Figure 4: Interlaminar shear strengths of non-absorbed and water-absorbed green composites.

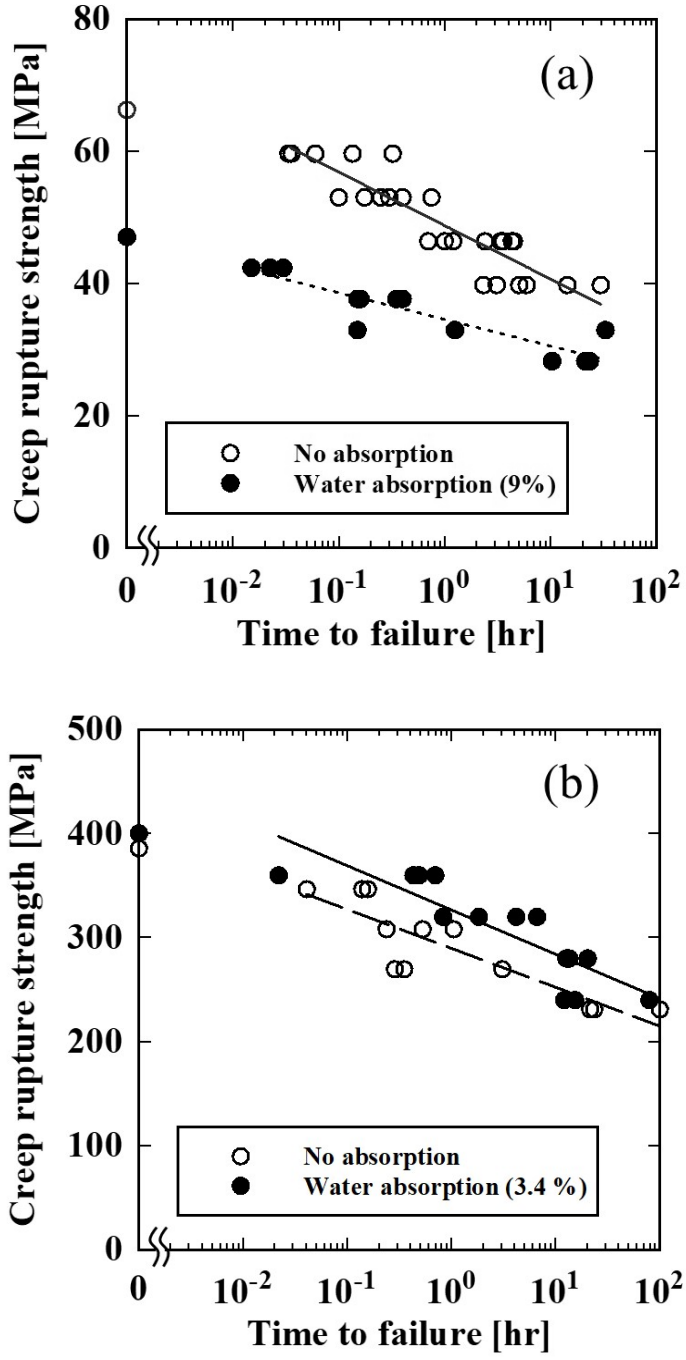

Figure 5: Creep rupture curves of non-absorbed and water-absorbed jute fibers and green composites. (a) Green composite; and (b) Jute fiber.

Creep rupture strengths of non-absorbed jute fibers decreased with increased loading time. The creep rupture strength of 3.4% water absorbed jute fiber was slightly higher than that of non-absorbed jute fiber. The creep rupture life of 3.4% water absorbed jute fiber was slightly longer than that of non-absorbed jute fiber. The jute fiber consists mainly of cellulose, hemicellulose, and lignin [21]. Cellulose and hemicellulose in jute fiber constituent materials have hydrophilicity. Therefore, the creep rupture strength and jute fiber life were affected slightly by water absorption of cellulose and hemicelluloses in jute fiber constituent materials.

Generally, the creep rupture strength of PLA decreases with increased loading time [22]. Nevertheless, the creep rupture strength and life of PLA were unaffected because the water absorption rate of PLA remained almost unchanged. The creep rupture strength and useful life of the green composite were affected by water penetration into the fiber–resin interface.

4.4 Residual tensile properties of non-absorbed and water-absorbed green composites under constant loading

Fig. 6 presents residual tensile properties of green composite under constant loading. Tensile strengths of non-absorbed and 9% water absorbed green composites decreased monotonously with increased loading time. The tensile strength and Young's modulus of a 9% water absorbed green composite were lower than those of a non-absorbed green composite under all loading times. The Young's moduli of non-absorbed green composite remained almost unchanged under all loading times. Their results implied that tensile strengths of non-absorbed and 9% water absorbed green composites decreased because of decreased interfacial adhesion between fiber and resin under constant loading. Therefore, the creep rupture strength and life of green composite decreased mainly because of decreased interfacial adhesion between the fiber and resin caused by water penetration.

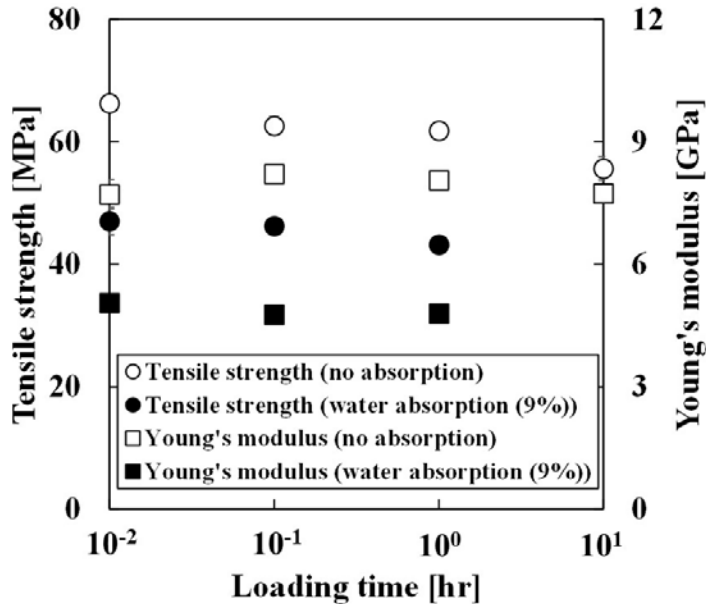

Figure 6: Residual tensile properties of non-absorbed and water-absorbed green composites under constant loading.

5 CONCLUSIONS

This study examined interlaminar shear strength, creep rupture strength, and the useful life of water-absorbed green composites for long-term safety. Water absorption rates of the green composite, jute fiber, and PLA at 24 hr were, respectively, 9%, 3.4% and 0.3%. The creep rupture strength of a 9% water absorbed green composite was lower than that of non-absorbed green composite. However, the creep rupture strength of 3.4% water absorbed jute fiber was slightly higher than that of a non-absorbed jute fiber. With maximum stress of 40 MPa, the creep rupture life of 9% water absorbed green composite was much shorter than that of the non-absorbed green composite. The interlaminar shear strength of 9% water absorbed green composite was lower by 11% than that of a non-absorbed green composite. Tensile strengths of non-absorbed and water-absorbed green composites under constant loading decreased with increased loading time. Therefore, interlaminar shear strength, creep rupture life, and strength of green composite were mainly decreased because of decreased interfacial adhesion at the fiber–resin interface caused by water penetration.

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