

# Effect of water absorption on the mechanical properties of continuous carbon fibre reinforced polycarbonate composites

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## Abstract

Carbon fibre reinforced thermoplastics (CFRTP) attract attention due to their excellent features of specific strength, specific modulus, productivity and recyclability in various fields. In this research, polycarbonate (PC) was used as a matrix of CFRTP with high impact strength compared with other plastics. However, at high temperature and high humidity conditions, hydrolyzation of an ester linkage in PC occurs, at the same time crazes and cracks also occur and the mechanical properties of PC deteriorate. Water absorption testing and tensile testing were also carried out to investigate the influence of water absorption on the mechanical properties on the CF/PC composite and PC resin. Single fibre pull-out tests were carried out to investigate the influence of water absorption on CF/PC interfacial shear strength. The water gain of PC was saturated at 0.46%. For the CF/PC composite, water was absorbed not only in the PC resin but also in the fibre/matrix interface. The tensile strength of the PC resin showed a tendency to decrease as the water absorption time increases, while the tensile modulus of PC did not change. The CF/PC composite showed a tendency to decrease for tensile strength and modulus when water absorption time is at 400 hours. The CF/PC interfacial shear strength showed a tendency to decrease as the water absorption time increases.

*Keywords: carbon fibre, polycarbonate (PC), carbon fibre reinforced thermoplastics (CFRTP), water absorption, mechanical property.*



## 1 Introduction

Carbon Fibre Reinforced Plastics (CFRP) have advantages in high-specific strength and high-specific modulus, hence the demand of CFRP is increasing in the aerospace, automotive and sports industries etc [1–5]. In particular thermoset plastics, such as epoxies, are mainly used as a matrix of CFRP in the automotive industry. However, FRP using thermosetting resin has poor productivity, and it cannot be melted or reformed after moulding, making recycling difficult. On the other hand, Carbon Fibre Reinforced Thermoplastics (CFRTP) are recyclable, good in productivity and excellent in impact strength, thus they are expected to be widely applied within the industry.

Polycarbonate (PC) has a high impact strength compared to other plastics, thus it is expected to be used as the matrix of CFRTP. Due to the high viscosity and poor impregnation of PC resin, CF/PC composites are recognized to be rarely produced. Recently, the method of moulding CFRTP using PC has been developed by a high-speed compression moulding process (to be referred as the IH system) using an electromagnetic induction system (Roctool Co. Cage System<sup>®</sup>) in our previous research [6]. In addition, the mechanical property of CF/PC was evaluated and an excellent property was shown compared with CF/PP and CF/PA [6]. To extend the application of CF/PC in various fields, the evaluation of environmental strength of CFRP has become important. At high temperature and high humidity conditions, hydrolyzation of an ester linkage in the PC occurs, at the same time crazes and cracks also occur and the mechanical properties of PC deteriorate [7]. Therefore, it is important to clarify the influence of water absorption on the mechanical properties of the CF/PC composite. However, as the composite is composed of various parts, we must investigate the influence of water absorption on the individual component parts of the composite, such as the fibre, matrix, and the fibre/matrix interface.

In this study, the influence of water absorption on the mechanical properties of CF/PC composites, PC resin and CF/PC interfacial shear strength will be clarified.

## 2 Materials and experimental procedure

### 2.1 Materials

PC (L-1225LL, Teijin Chemicals Ltd., Japan) was used for the matrix. PC resin was melt-blown to a non-woven fabric (Kuraray Co., Ltd.) in the weight per unit area of 50 g/m<sup>2</sup>.

The non-crimp stitched carbon fabric (NCF, 300 g/m<sup>2</sup>, [0°/90°], Benny-Toyama Co. Ltd., Japan), using PAN-based carbon fibres, being stitched together by Polyester sewing thread, were used as the reinforcing fabric. The mechanical properties of carbon fibres are listed in Table 1.



Table 1: Mechanical properties of carbon fibre.

Tensile modulus [GPa]	260
Tensile strength [MPa]	3350
Filament diameter [ $\mu\text{m}$ ]	6.93
Density [ $\text{g}/\text{cm}^3$ ]	1.75

## 2.2 Moulding process

The specimens of PC resin were moulded by the injection moulding machine (ET-40V, Toyo Machinery & Metal Co., Ltd., Japan).

Composite specimen were moulded by high-speed compression moulding process (to be referred as IH system) using an electromagnetic induction system (Roctool Co. Cage System<sup>®</sup>) [6]. Kapton<sup>®</sup> film (200H, Du Pont-Toray Co., Ltd., Japan) was used as a vacuum bag with the help of sealing tape (213-3, General Sealants<sup>™</sup>, America). After putting the material inside the vacuum bag, its inside pressure is reduced to under 1 kPa before and during the moulding process by a vacuum pump. The tensile specimens were cut off from moulded composites using water jet technique.

## 2.3 Mechanical testing

Water absorption test for PC resin and CF/PC composite was performed to assess the amount of absorbed water against immersion time. The length, width and thickness of PC specimens were 50 mm, 10 mm and 4 mm respectively. The length, width and thickness of CF/PC specimens were 50 mm, 10 mm and 2 mm respectively. Specimens were immersed in distilled water at 80 °C after having been dried in constant-temperature oven of 120 °C for more than five hours. The specimen was taken out from the water at regular intervals, and moisture on the surface was wiped off, the specimen was then weighed with an electronic balance.

The water gain,  $C$  (Wt.%), was calculated by the following equation.

$$C = \frac{m - m_0}{m_0} \times 100$$

where  $m_0$ : specimen weight before the water absorption test and  $m$ : specimen weight.

The same carbon fibre used for NCF were used for a single fibre pull-out test [8], and PC resin was used for a matrix and polyester thin film was used as a tab. Fig. 1 shows the schematic drawing of preparation of pull-out specimen. After a single fibre was glued to the tab with adhesive, the tab was attached to a micromanipulator. After, the PC resin was placed on the aluminium plate which was heated at 300 °C, using the micromanipulator, the single fibre was embedded to the matrix, it and was air-cooled. Some specimens were immersed in distilled water at 80°C for 100 hours, 400 hours, and others were kept in

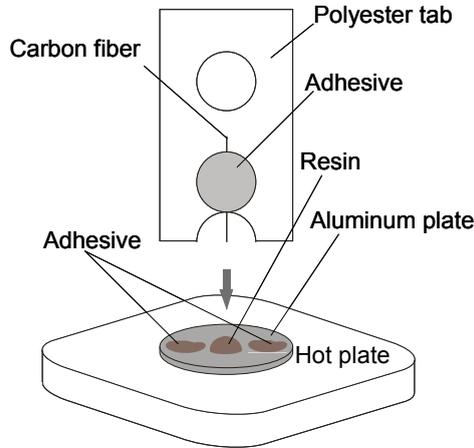


Figure 1: Preparation of the pull-out specimen.

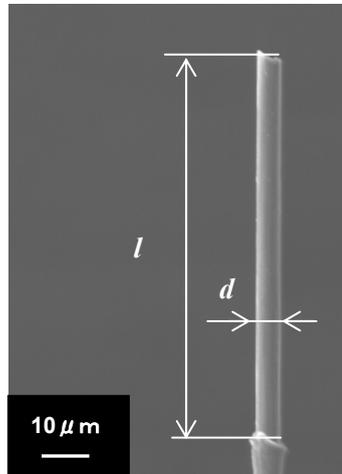


Figure 2: SEM observation of a pulled-out specimen.

laboratory air. These specimens will be referred to as 100 hours wet specimen, 400 hours wet specimen, dry specimen, respectively. Pull-out tests were performed using an electro hydraulic servo controlled testing machine for micro materials (MMT-11N, Shimadzu Co., Japan). After chucking a specimen, the supporting part of the tab was cut and the pull-out test was conducted with a constant displacement rate of  $1.67 \times 10^{-3}$  mm/s (0.1mm/min). Precise embedded fibre length was measured after the pull-out tests. Fig. 2 shows the SEM image of the pulled-out specimen. The embedded length,  $l$ , was measured from this SEM image. Fig. 3 shows the load-displacement curve for the fibre pull-out test.  $F_{max}$  is the maximum load at load-displacement curve. The interfacial shear strength,  $\tau$ , was calculated by the following equation.

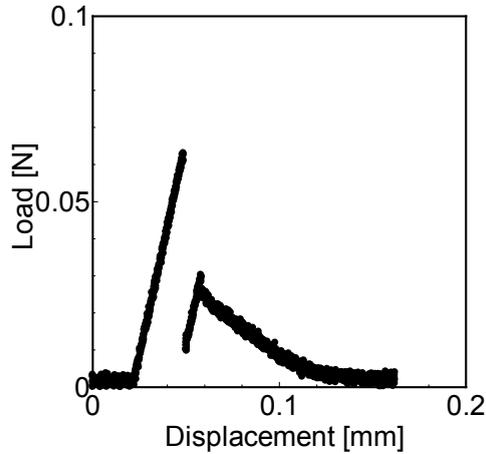


Figure 3: Load-displacement curve.

$$\tau = \frac{F_{\max}}{\pi dl}$$

where  $d$ : fibre diameter and  $l$ : embedded length.

The tensile tests were conducted by the universal testing machine (Autograph AG-100kNX, Shimadzu Co., Japan) and video non-contact extensometer (DVE-201, Shimadzu Co., Japan) for measuring the extension of specimen. The tensile tests were conducted following the recommended testing procedures as described in JIS-K7164 and JIS-K7113. The shape of specimens was in a dumbbell-shape. The gauge length of PC resin, width and thickness of the specimens were 50mm, 10mm and 4mm respectively and the gauge length of CF/PC composite, width and thickness of the specimens were 50mm, 10mm and 2mm respectively. The displacement rate was set for  $1.67 \times 10^{-2}$  mm/s (1mm/min). Some specimens were immersed in distilled water at 80°C for 100 hours, 400 hours, and others were dried in constant-temperature oven of 120 °C for more than five hours. These specimens will be referred to as 100 hours wet specimen, 400 hours wet specimen, dry specimen, respectively.

Cross sections of the specimens were observed by scanning electron microscope (SEM, SEM-6390LT, JEOL Ltd., Japan) for evaluating resin impregnation.

### 3 Results and discussion

#### 3.1 Water absorption test

Fig. 4 shows the relationship between water absorption times and water gain of PC resin and CF/PC composite. The water gain of the PC resin and CF/PC

composite were saturated with 0.46 wt.% and 0.38 wt.%. As CF cannot absorb water, the water gain of PC matrix was calculated by dividing the amount of water absorption of CF/PC composite by the weight of PC matrix. The calculated water gain of the PC matrix within CF/PC composite was 0.69%, which exceeded the water gain of the PC resin itself. One of these causes is that water was absorbed in the fibre/matrix interface in the composite.

**3.2 Pull-out test**

Fig. 5 shows the relationship between embedded fibre length and maximum load of the single fibre pull-out test. Interfacial shearing strength of the dry specimen, 100 hours wet specimen, 400 hours wet specimen were 78.4MPa, 48.1MPa, and

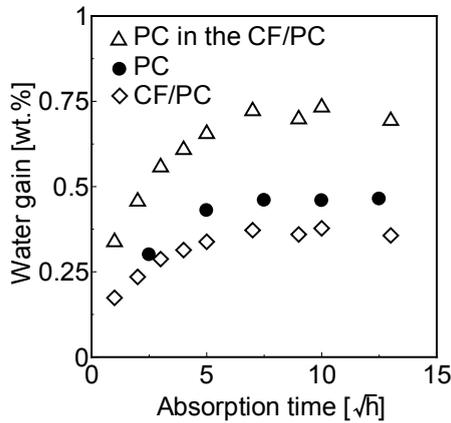


Figure 4: Relationship between water absorption times and water gain.

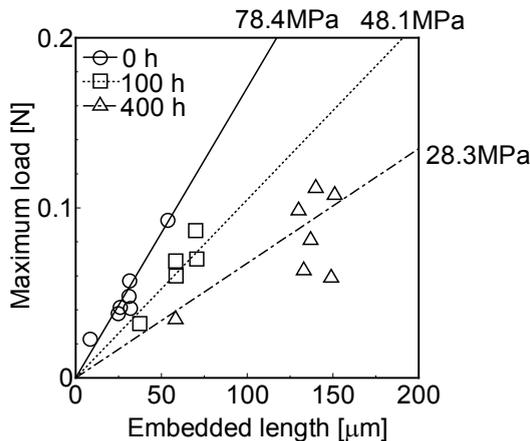


Figure 5: Relationship between embedded fibre length and maximum load of the single fibre pull-out test.

28.3MPa, respectively. Therefore, interfacial shear strength of CF/PC composite has decreased as water absorption time.

### 3.3 3.3 Tensile test

#### 3.3.1 PC resin

Figs. 6 and 7 show the stress-strain curve and the tensile properties of PC resin, respectively. The tensile modulus doesn't change, and the elongation has decreased with water absorption time. In addition, the tensile strength of the 100 hours wet specimen has decreased approximately 19% in comparison to the dry specimen; and for the tensile strength the 400 hours wet specimen has decreased approximately 30% in comparison to the dry specimen. Strength has decreased due to the decrease in the elongation. The elongation is reduced by water absorption with defects such as crazes and cracks occurring; such defects could be a fracture initiation site.

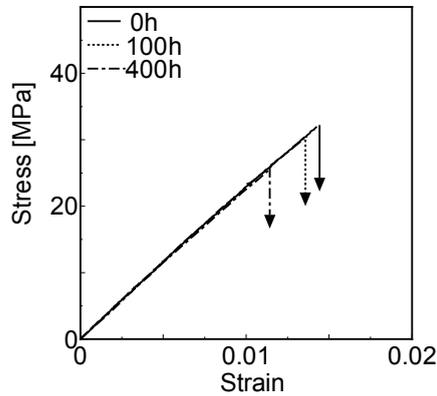


Figure 6: Tensile stress-strain curve of PC.

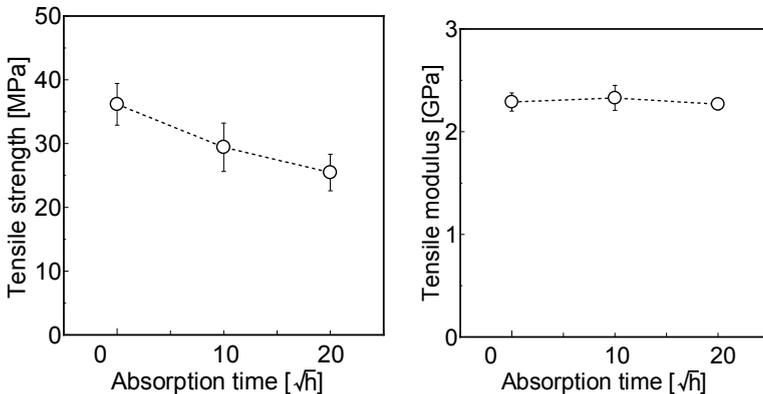


Figure 7: Tensile properties of PC.

**3.3.2 CF/PC composite**

Fig.8 shows the tensile properties of CF/PC composite. CF/PC composite showed a tendency of decrease the tensile strength and modulus when the water absorption time is at 400 hours. Fig. 9 shows the SEM images for the cross sections of CF/PC composites. As for the fracture surface of dry specimen and 100 hours wet specimen, some parts of fibre surface are covered with the resin residues, and it is coincident with the strong interfacial shearing strength shown

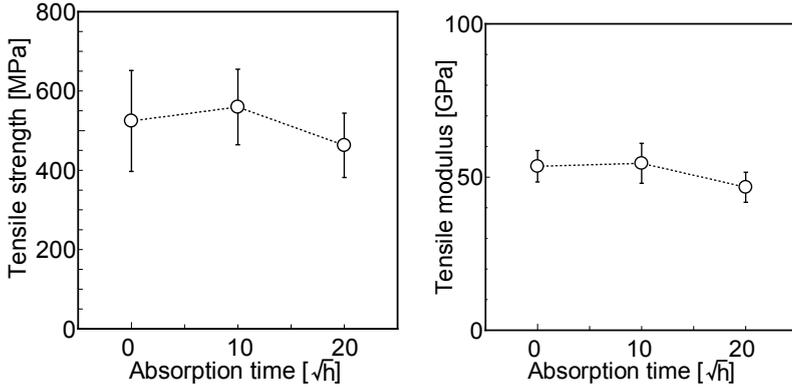


Figure 8: Tensile properties of CF/PC.

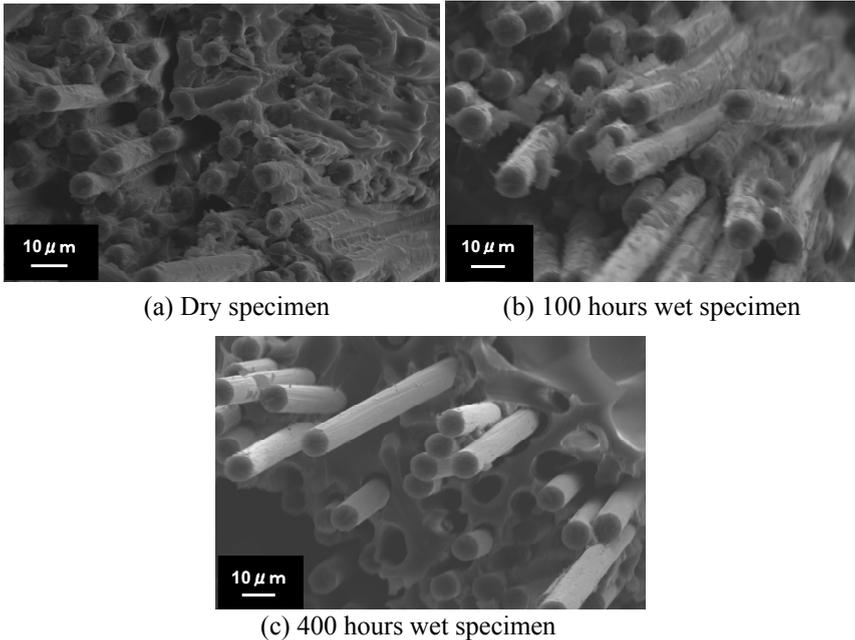


Figure 9: SEM images for the cross sections of CF/PC.

in Fig.5. On the other hand, for the fracture surface of the 400 hours wet specimen the resin hardly remained on the fibre. This is due to the decrease in fibre matrix interface strength as shown in Fig.5. Therefore, tensile strength and modulus of the 400 hours wet specimen decreased.

## 4 Conclusion

In this study, the influence of water absorption on the mechanical properties of CF/PC composites, PC resin and CF/PC interfacial shear strength will be clarified. The investigation yielded the following conclusions:

1. The water gain of PC was saturated at 0.46%. For CF/PC composite, water was absorbed not only in PC resin but also in the fibre/matrix interface.
2. Interfacial shear strength of the dry specimen, 100 hours wet specimen, 400 hours wet specimen were 78.4MPa, 48.1MPa, and 28.3MPa, respectively. Interfacial shear strength of CF/PC composite has decreased as the water absorption time increases.
3. The tensile strength of the PC resin showed a tendency to decrease as the water absorption time increases, while the tensile modulus of PC did not change. CF/PC showed a tendency to decrease for tensile strength and modulus when water absorption time is at 400 hours.

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