Contact Angles of Single Fibers Measured in Different Temperature and Related Humidity

Hong CHEN, Benhua FEI, Ge WANG, Haitao CHENG

International Center for Bamboo and Rattan, Beijing, 100102, China

Abstract

Studying single fiber wettability plays an important part in many areas, such as textile, paper treatment, and material-selection procedures of fiber-reinforced composite. Contact angles, which provide useful information about wettability, are needed in the modification of fiber surfaces or adjustment of rheological properties of the wetting prepolymer of polymer melts. Meanwhile, the contact angle measured in different environment is probably different. Knowing the changing of contact angles caused by various environment factors, such as temperature and humidity, is also important. So the contact angle of single bamboo fibers and terylene fibers in different temperatures and humidities were further studied. The results showed that when the temperature went up and related humidity kept in constant, contact angles of bamboo fibers decreased, whereas that of terylene fibers increased. However, contact angles of the two fiber types changed in the same trend that both increased with the increasing humidity and constant temperature. And the contact angle of bamboo fiber increased significantly, while that of terylene fibers ascended a little. These findings will aid researchers in better understanding the requirements needed for consideration of measuring the contact angle of different fiber types.

Key words: single fibers, contact angles, temperature, humidity
Introduction

Mounting concerns for the environment have sparked renewed interest in the development of biodegradable, mechanical bio-composite in which the natural fibers serve as a reinforcement by enhancing the strength and stiffness to the resulting composite (A. K. Mohanty, 2000; Alexis Pietak, 2007). Due to low density, high mechanical performance and problem-free disposal, natural fibers derived from plant offer a good promising alternative to other technological reinforcing fibers presently available (A. K. Mohanty, 2000; Ibon, 2003). For better utilization of natural fibers as reinforcements in composites, it is essential to know information on the wettability of the natural fibers and the interrelationships between wettability and measurement environment conditions. Contact angles provide useful information about wettability, and the degree to which liquids wet a fiber determines how easily the liquid can penetrate fiber assemblages (Ibon, 2003). Contact angle measurement is probably the most common method of wettability measurement. One of the most frequently used methods of contact angle assessment is the sessile drop technique (M. Amaral, 2002). However, detailed knowledge about whether the contact angle are affected by the measurement conditions is still lacking. As attempt has therefore been made, to investigate the change occurring in contact angle of single bamboo fiber due to different temperature and humidity of environment, and single terylene fibers were measured as control samples to find how the environment conditions affect the contact angles of different fiber types (natural plant fibers and chemical synthetic fibers).

Materials and Methods

Material was taken from 2-yr-old Cizhu bamboo (Neosinocalamus affinis) grown in Qionglai, Chendu, Sichuan Province, China. The bamboo was cut into strips (20 mm longitudinally and 2×2 mm in cross-section), then the strips were immersed in the chemical solution (one part H2O2, four parts distilled water, and five parts HAc) kept at 60°C for 42 h to separate. And the bamboo fibers were washed to neutrality and air-dried to a constant weight before being kept in humidity chamber. The terylene fibers were provided by Ningbo Shuaibang Chemical Fiber Company Limited. The terylene fibers were washed in the distilled water and acetone in turn to get rid of dust and grease, if there are any.

Contact angle testing of distilled water on single fibers was conducted with Kruss DSA 100 equipped with an environmental chambers assisting of a temperature chamber and a humidity chamber. The given temperature and humidity limits was 160 °C or -30 °C and 0 or 100%. Single fibers were obtained using fine-tipped tweezers and mounted on a slatted platform with double-sided tape. Then the platform was put in the environmental chambers and moved into position using CCD cameras in the x, y, and z directions. First of all, the humidity in the environment chamber was kept at 30%, but the temperature was changed from 20 °C to 70 °C. And then the temperature in the environment chamber was kept at 20 °C while the humidity
was changed from 10% to 80%. The temperature and the humidity in the environment chamber were kept 5 min after being adjusted to target value. The CCD cameras recorded the process of the water droplet dropping on the single fiber until disappearing gradually. The baseline for a sessile drop static contact angle measurement was made at the liquid-solid interphase with droplet size held to a constant 10 uL. Contact angle were calculated using the ellipse method in the DSA 3 software (Fig. 1). Six samples were tested for each fiber type.

![Image](image1.png)

**Figure 1** Contact angle measured by Kruss 100 and calculated by DSA 3 software.

### Results and Discussion

**Contact angle of single fibers measured in different temperature**

![Image](image2.png)

**Figure 2** Contact angle measured in different temperature

When the humidity in the environment chamber was kept at 30%, the contact angle of single
bamboo fiber decreased with the increasing temperature, but the contact angle of single terylene fiber increased. (Fig. 2). Meanwhile, the contact angle of single bamboo fiber changed a little when the temperature changed between 20°C and 40°C, whereas that decreased significantly when the temperature increased above 40°C. 

The single bamboo fiber is a kind of complicated and unstable natural plant fiber and is mainly made up of cellulose, hemicellulose and lignin which are easily affected by the environment conditions, especially the hemicellulose (Mohanty, 2000). The changing of temperature lead to changing of water in the fiber which makes the ability of fiber for adsorbing water change. What is observed macroscopically is the contact angle of single fibers change differently (Prasad, 2004; Pietak, 2007). With the increasing temperature, the single fiber loses water, and the ability for absorbing water is increasing, which lead to higher contact angle. Moreover, the trend of changing about contact angle is more distinct when the temperature is higher and higher, which also can be observed in Figure 1. However, single terylene fiber, consisting of polyethylene terephthalate, is a kind of chemical synthetic fibers and the component of which is simplex and stable. Therefore, the single terylene fiber is scarcely influenced by the environment conditions. The contact angle of single terylene fiber may be affected mainly by the surface tension of water. As known, there are three-phase equilibrium in the sessile drop experiment. The interfacial tensions of the solid-vapour, liquid-vapour, solid-liquid interface, and the contact angle are related through

\[
\cos \theta = \frac{\gamma_{sv} - \gamma_{lv}}{\gamma_{sl}}
\]

Young's Equation (Adamson, 1990): \( \theta \) is the contact angle. \( \gamma_s \) and \( \gamma_l \) represent, respectively, the interfacial tension of the solid and the liquid in equilibrium with liquid vapour. \( \gamma_{sl} \) is the interfacial tension between the solid and the liquid. When the temperature increased, the surface tension of water increased, but not significantly (Mei, 2008), namely \( \gamma_s \) and \( \gamma_l \) increased a little, from the equation, it can be deduced the contact angle of the single terylene fiber increased a little, because it is mainly determined by the change of surface tension of water. However, for single bamboo fiber, the change caused by the fiber itself is much more significantly than that caused by surface tension of water so that the change caused by surface tension of water can be ignored.
As shown in Figure 3, the contact angle of both single bamboo fiber and single terylene fiber increased when the humidity increased, while the former increased much more significantly than the latter. Besides, when humidity changed between 20%-30%, contact angle of single bamboo fiber increased little, and yet it increased significantly when humidity changed above 30%. There were a large number hydrophilic radical in single bamboo fibers (Bismarck, 2002), which may be responsible for increase of contact angle when humidity increased. The bamboo fiber attract moisture through hydrogen bonding because because the cell wall polymers contain hydroxyl and other oxygen-containing groups (R. M. Rowell, 1985). The hemicelluloses are mainly responsible for moisture sorption, but the accessible cellulose, noncrystalline cellulose, lignin, and surface of crystalline cellulose also play major roles (A. K. Mohanty, 2000). However, the single terylene fiber, lacking hydrophilic radical, was a kind of chemical synthetic fibers. So the contact angle of single terylene fiber almost did not change with increasing humidity.

Conclusions

The contact angle of natural plant fibers, such as single bamboo fibers, changed significantly when environmental temperature and humidity changed, especially humidity. The contact angle of chemical synthetic fibers, single terylene fiber for example, changed a little with changed temperature and almost kept the same when humidity changed. Therefore, it is necessary to confirm the environment temperature and humidity before measuring the contact angle of natural plant fibers. However, measuring the contact angle of chemical synthetic fibers only need to consider temperature of environment.

References


Acknowledgment

This work is funded by the Project of Manufacturing Technology of Bamboo High Value-added Building Products (201004005).