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Rotation of a natural cellulosic fibre about its fibre axis due to absorption of moisture

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This paper describes the rotation of white jute fibres (*Corchorus capsularis*) about the fibre axis due to absorption and desorption of moisture. It was observed that the rotation increases with an increase in the percentage of relative humidity. The rotation also increases with the applied stress and shows a hysteresis for the absorption and desorption cycle. A hydrogen bonding scheme between the microfibrils has been proposed to explain this rotation due to absorption of moisture. This hydrogen bonding scheme also explains the hystereses for the moisture regained (%) vs relative humidity and relative increase in length vs relative humidity curves during absorption and desorption of moisture, for cellulose fibres. Copyright © 1996 Elsevier Science Ltd.

(Keywords: jute fibre; microfibrils; rotation)

Introduction

Jute is a naturally growing fibre having about 60–72% α-cellulose, 10.5–14% lignin, 17–26% hemicellulose, and traces of pectin, fats and waxes[1–4]. Natural cellulose fibres have birefringence exceeding 0.06. These hygroscopic fibres show hystereses in the curves for moisture regain (%) vs relative humidity and relative length vs relative humidity for cellulose fibres[5,6]. Treloar in his classic work[5,6] did not observe any hysteresis of relative length vs relative humidity for hair at the small load of 5 g (*ca.* 120 kN m^{-2}) which was about the minimum necessary to ensure straightness of the specimen. This paper reports, for the first time, a third hysteresis in the rotation vs. relative humidity during absorption and desorption of moisture for a natural fibre at the small load of about 5.4 g (*ca.* 5.4 kN m^{-2}) when the fibre is allowed to rotate freely after suspension.

A hydrogen bonding scheme for the absorption and desorption of moisture has been proposed that can explain both the angular rotation and the corresponding hysteresis in angular rotation during the absorption and desorption of moisture. This hydrogen bonding scheme can also explain the other two hystereses during the absorption and desorption of moisture in cellulose fibres, as observed by Treloar.

Experimental

White jute fibres (*Corchorus capsularis*) were clamped at the top and suspended with a rotor at the bottom, similar to the arrangement in a torsion pendulum. These were placed in an airtight glass flask where the fibres could rotate freely. Saturated salt solutions placed at the bottom of the flask kept the percentage relative humidities constant in the airtight environment of the flask[7]. The fibres were dried *in situ* by radiant heat, using an infrared lamp (Philips Infraphil, 150 W) as this method needs considerably less drying time (about 1 h) compared to the oven drying method[8,9]. The lamp was removed when the rotor stopped rotating, indicating that the specimen was completely dried. On removal of the lamp the specimen started rotating due to absorption of moisture in a direction opposite to that while drying. Angles of rotation for the absorption and desorption of moisture were recorded for various relative humidities at low constant stress and at a room temperature of 30 ± 2°C.

Results and discussion

Figure 1 shows graphs of rotation about the fibre axis against relative humidity due to absorption or desorption of moisture at two constant stresses. The following important aspects were observed:

(i) the fibres rotate about the fibre axis due to absorption of moisture;
(ii) the angle of rotation increases with the increase of relative humidity;
(iii) the angle of rotation also increases with stress;
(iv) at higher applied stress the rotation shows hysteresis;
(v) the fibres rotate about the fibre axis in the direction of rotation of a right-handed screw towards the point of suspension;
(vi) the direction of rotation remains unchanged by interchanging the point of suspension and the point of rotation or *vice versa.*

Figure 2 shows a linear relationship between the angles of rotation during absorption and percentage of moisture regained. The values for moisture regained were taken from the absorption curve for jute fibre in Reference 4, assuming no changes in these values at the stresses applied in this experiment[5,6].

All these observations are explained by considering elementary fibrils and microfibrils as the structural entities beyond the basic unit cell. For cellulose the larger microfibrils are about 3.5–10 nm thick, 10–30 nm

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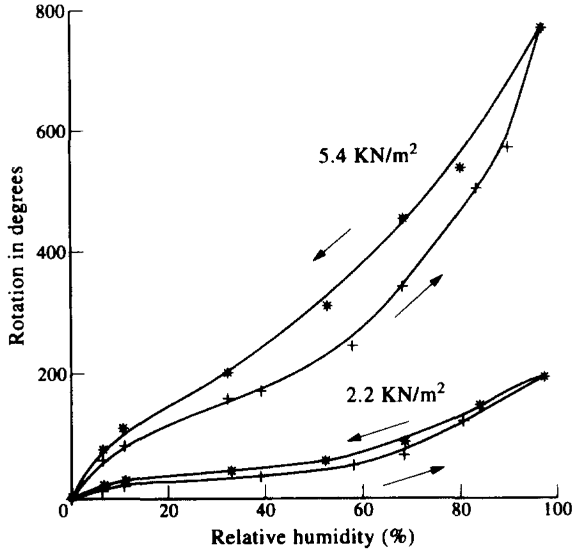

Figure 1 Graphs showing angles of rotation about the fibre axis vs percentage relative humidity for white jute fibres (*Corchorus capsularis*) at constant stresses for 5.4 kN m^{-2} and 2.2 kN m^{-2} during absorption and desorption of moisture

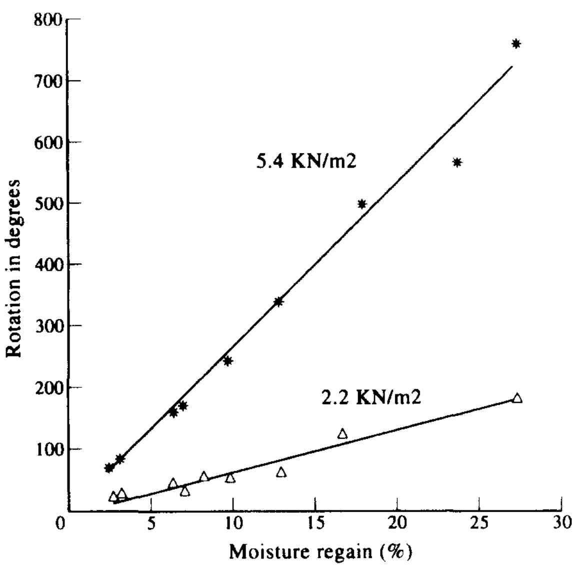

Figure 2 Graphs showing angles of rotation vs moisture regained for stresses of 5.4 kN m^{-2} and 2.2 kN m^{-2}

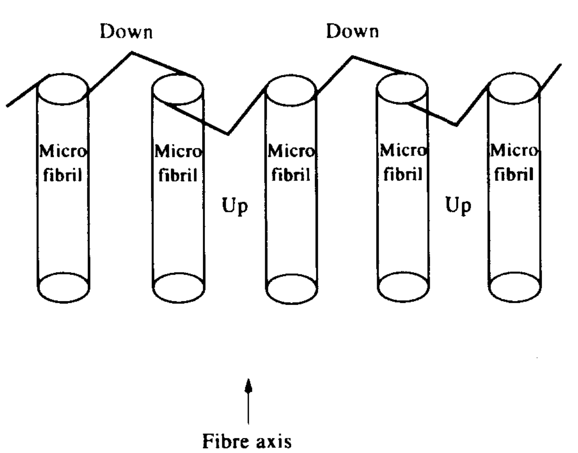

Figure 3 Proposed hydrogen bonding scheme between the OH-groups of the microfibrils and water molecules as seen in a plane parallel to the fibre axis

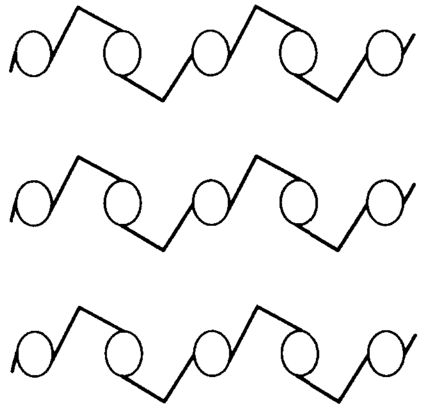

Figure 4 Proposed hydrogen bonding scheme between the OH-groups of the microfibrils and water molecules as seen in a plane perpendicular to the fibre axis

wide and 10–60 nm long depending on the source of the cellulose[10]. There can be interfibrillar spaces, 1.2–5 nm wide, with water present in the wet state[11]. There has never been any microscopic evidence for amorphous materials in native cellulose microfibrils[12]. For white jute fibres (*Corchorus capsularis*), 2.5 nm thick, 3.5 nm wide and 13.7 nm long microfibrils were observed by the X-ray diffraction technique[13,14]. The interfibrillar space was found to be as wide as 10 nm in raw jute fibres[15]. Thus the microfibrils may be considered as rodlike structures embedded in a matrix of amorphous lignin and hemicellulose. In many cellulosic materials the amorphous contents consist of rodlike chains which are found parallel to the microfibrils[16].

Figures 3 and *4* show the proposed hydrogen bonding due to absorption of moisture between the OH-groups on the surface of the microfibrils and water molecules, as seen in planes parallel and perpendicular to the fibre axis respectively. Such hydrogen bonding could also take place between the microfibrils and the rodlike amorphous contents. Preliminary study shows similar rotation due to absorption of moisture in other cellulose fibres, suggesting a similar hydrogen bonding.

The torque produced by such a hydrogen bonding scheme always produces a rotation in the direction of a right-handed screw rotated along the fibre axis towards the point of suspension irrespective of which end the fibres are suspended from. More absorption of moisture produces more hydrogen bonding and more rotation with respect to the dry fibre. The rotation due to absorption of moisture confirms that in the case of jute fibres cellulose chains in the fibrils are parallel (cellulose I)[17], as an antiparallel conformation would produce no rotation, and that at no stage of moisture absorption does the antiparallel chain (cellulose II) transformation takes place.

The average orientation of the microfibrils about the fibre axis varies between 11° and 14° for jute fibres, as found by the X-ray diffraction technique[18]. At low stress the microfibrils are aligned along the fibre axis with absorption of moisture, thus producing more hydrogen bonding and torque. At higher stress the microfibrils slide against each other while absorbing moisture and, for short microfibrils as in jute, the fibres break easily while wet.

The proposed hydrogen bonding scheme suggests that absorption of moisture should produce swelling mainly in the transverse direction, supporting the findings of Roy and Sen[19]. It is proposed that internal fibrillation would occur through intrusion of water and swelling of amorphous content in the interlamellar layers. Thus the fibrils can easily slide along the fibre axis on absorption of moisture and on increasing the stress, without altering the zig-zag hydrogen bonding as seen in a plane parallel to the fibre axis. Increased stress produces sliding of the fibrils and creates space for the absorption of more moisture.

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