Effect of Water Absorption of Natural Fiber Reinforced Polyester Composite: A Review

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Abstract
The development of natural fiber composite currently inclined as the increasing demand on green technology. In line with current situation, the natural fiber became a highly suitable additive material to growth the polymer composite industry. Water absorption was found to be the most important test in natural fiber reinforced polyester composites. The effect of water absorption on mechanical properties of natural fiber composites were improved as the fiber content increased. However, the tensile and flexural strength decreases as the moisture content increases. This paper will review on the effect of water absorption of natural fiber reinforced polyester composite on the mechanical properties. Current issues and suggestions for researches will be discussed and highlighted to enhance the natural fiber composite for the bright future of green technology industries.

Key Words: natural fiber; water absorption; mechanical properties

1.0 INTRODUCTION

Due to green technology demand, the natural fiber composite (NFC) became the potential usage replace of synthetic fiber. Sanjay, Arpitha, Naik, Gopalakrishna, & Yogesha (2016) show the comparison between the NFC and synthetic fiber in their studies as depicted in Table 1. These issues are attracted many researcher and engineer at big century to develop the NFC in industry sector. Dan-mallam, Abdullah, Sri, & Megat (2013) on their studies said the NF is environmentally friendly and economical to use. Then, it was supported by Alamri & Low (2012) ; Md Akil *et.al* (2014) which is natural fiber (NF) plant can be renewable with appropriate properties needed and during handling.

Table 1: Comparison between natural fibers and synthetic fibers (Sanjay *et.al* , 2016)

Aspect	Property	Natural Fibers	Synthetic Fibers
Technical	Mechanical properties	Moderate	High
	Moisture sensitivity	High	Low
	Thermal sensitivity	High	Low
Environmental	Resource	Infinite	Limited
	Production	Low	High
	Recyclability	Good	Moderate

There have been several studies in the literature reporting a lot of application of NF demand on automotive, aircraft, furniture, and manufacturing industries rapid growing currently. Mohammed *et.al* (2015) summarizes the application of NF applied in industry, as shown in Table 2.

Table 2: The applications of natural fiber composites in industry (Mohammed *et.al*, 2015)

Fiber	Application in building, construction and others
Hemp fiber	Construction products, textiles, cordage, geotextiles, paper & packaging, furniture, electrical, manufacture bank notes and manufacture of pipes.
Oil palm fiber	Building materials such as windows, door frames, structural insulated panel building systems, siding, fencing, roofing, decking and other building materials.
Wood fiber	Window frame, panels, door shutters, decking, railing system and fencing.
Flax fiber	Window frame, panels, decking, railing systems, fencing, tennis racket, bicycle frame, fork, seat post, snowboarding and laptop case.
Rice husk fiber	Building materials such as building panels, bricks, window frame, panels, decking, railing systems and fencing.
Bagasse fiber	Window frame, panels, decking, railing systems, fencing.
Sisal fiber	In construction industry such as panels, doors, shutting plate and roofing sheet; also manufacturing of paper and pulp.
Stalk fiber	Building panel, furniture panels, bricks and constructing drains and pipelines.
Kenaf fiber	Packing material, mobile cases, bags, insulations, clothing- grade cloth, soilless potting mixes, animal bedding and material that absorbs oil and liquids.
Cotton fiber	Furniture industry, textile and yarn, goods and cordage.
Coir fiber	Building panels, flush door shutters, roofing sheets, storage tank, packing material, helmets and postboxes, mirror casing, paper weights, projector cover, voltage stabilizer cover, a filling material for the seat upholstery, brushes and brooms, ropes and yarns for nets, bags and mats, as well as padding for mattresses, seat cushions.
Ramie fiber	Use in products as industrial sewing thread, packing material, fishing nets and filter cloths. It is also made into fabrics for household furnishings (upholstery, canvas) and clothing, paper manufacture.
Jute fiber	Building panels, roofing sheets, door sheets, door shutters transport, packaging, geotextiles and chip boards.

2.0 NATURAL FIBER COMPOSITES (NFC)

NF is defined by Jawaid, Abdul Khalil, & Abu Bakar (2010); Ticoalu, Aravinthan, & Cardona (2010); Md Akil, Santulli, Sarasini, Tirillò, & Valente (2014) and Mohammed *et.al* (2015) are fiber that produce by plants, animals and geological process.

A number of studies have found that the natural (plant) fibers are containing cellulose, hemicellulose, pectin and lignin. That classified by blast fiber, leaf fiber, seed fiber, grass and reed fiber, core fiber and as well as other kind of fiber as shown in Figure 1. The composition of natural (plant) fiber is given the biggest effect on the characteristic of composite. They are conclude on Table 3. Researchers have report the natural fiber have much higher strength and stiffness with the higher performance than animal fiber (Ramamoorthy, Skrifvars, & Persson, 2015).

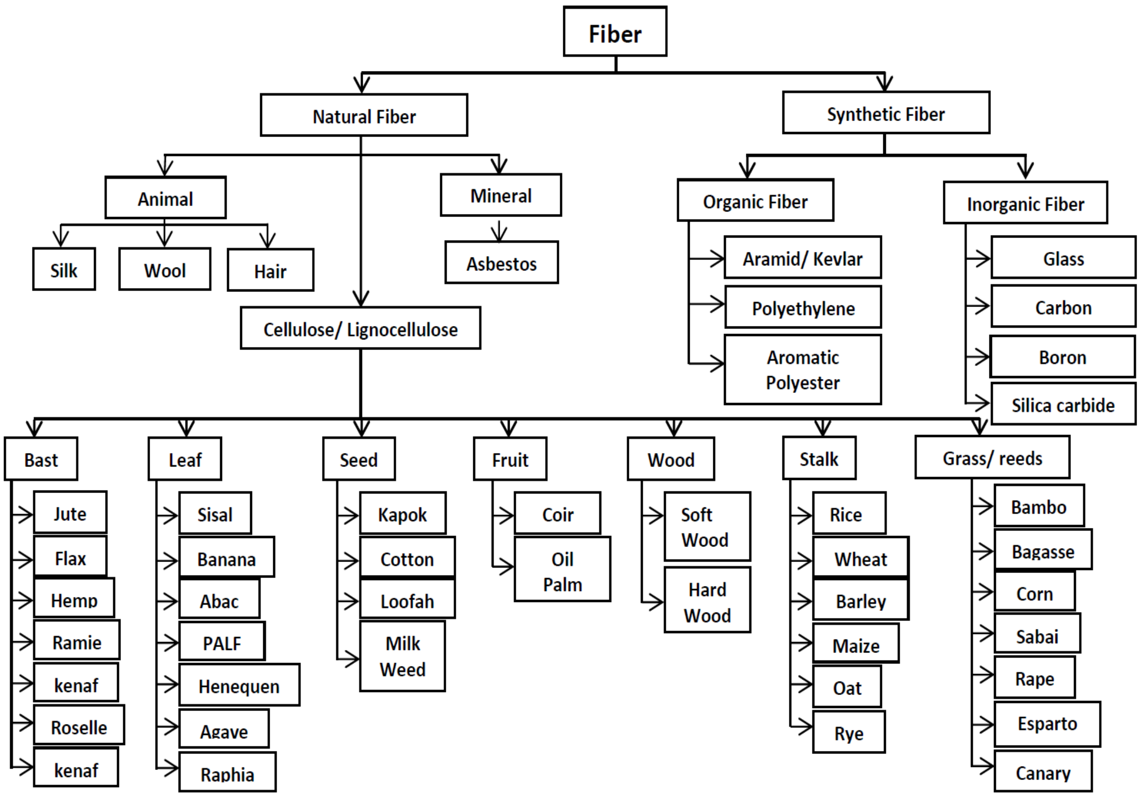

Figure 1: Classification of natural and synthetic fibers.(Jawaid & Abdul Khalil, 2011)

NF reinforced composite were fabricated with combination of the NF/ thermoset or Natural Fiber/ thermoplastic resin. In automotive applications are used the NF/ thermoplastic resin. Ticoalu *et.al*, (2010) said the infrastructure mostly used NF/ thermoset resin, Most of the N.F is generally containing large amount of cellulose or also known as semi-crystalline polysaccharide, which is responsible for hydrophilic in nature and most of the plastic is hydrophobic in nature. When the element of hydrophilic and hydrophobic (plastic/ resin) mixed together will result small increasing in mechanical properties

Table 3: Chemical composition of some common natural fibers. (Mohammed *et.al*, 2015)

Fiber	**Cellulose (wt %)**	**Hemicellulose (wt %)**	**Lignin (wt %)**	**Waxes (wt %)**
Bagasse	55.2	16.8	25.3	-
Bamboo	26 - 43	30	21 - 31	-
Flax	71	18.6 - 20.6	2.2	1.5
Kenaf	72	20.3	9	-
Jute	61 - 71	14 - 20	12 - 13	0.5
Hemp	68	15	10	0.8
Ramie	68.6 - 76.2	13 - 16	0.6 - 0.7	0.3
Abaca	56- 63	20 - 25	7 - 9	3
Sisal	65	12	9.9	2
Coir	32 - 43	0.15 - 0.25	40 – 45	
Oil Palm	65	-	29	-
Pineapple	81	-	12.7	-
Curaua	73.6	9.9	7.5	-
Wheat straw	38 - 45	15 - 31	12 -20	-
Rice husk	35 - 45	19 - 25	20	-
Rice straw	41 - 57	33	8 -19	8 -38

Bhoopathi, Ramesh, & Deepa, (2014) indicate that significant improvement of mechanical properties such as tensile strength, impact strength and flexural strength of natural fiber and synthetic fiber reinforced composite with different volume of fiber/ matrix adhesive. Therefore, several author agreed the NF as a quality alternative to conventional reinforcing fiber to develop high performance natural fiber reinforced composite (NFRC). Many experts believe the NFC has been actively developing in many applications on industries. It is because the NF has many advantages compare to synthetic composite such as low cost, low density, availability and biodegradability easier handling and processing and which endows them with excellent specific mechanical properties (Maslinda, Abdul Majid, Ridzuan, Afendi, & Gibson, 2017).

2.1 Water Absorption of Natural Fiber Composite, NFC

There are many methods used to determine percentage of water absorption on natural fiber composite. According to Rashdi, Sapuan, Ahmad, & Khalina, (2010) water absorption test can be conducted by using ASTM D570 where the percentage of apparent weight gain is calculated using equation 1. This method and equation also has been introduced by many researchers whose studies regarding percentage water absorption on natural fiber composite. Alamri & Low (2012a); Osman, Vakhguelt, Mutasher, & Sbarski (2012). This is supported by H. Akil, Santulli, Sarasini, Tirillò, & Valente,(2014) and Hoto *et.al*, 2014) on their studies regarding pultruded jute/ glass fiber –reinforced polyester hybrid composites.

$$Water\ absorption\ (\%) = \frac{[w_{initial} - w_{final}]}{w_{final}} \text{ x } 100 \quad (1)$$

The same equation was then used by Prambauer, Paulik, & Burgstaller, (2015) and Maslinda *et.al*, (2017) for their research studies. Even though the similar equation was used, there are several types of sample preparation and measurement technique applied by researchers. H. Alamri & I.M. Low, (2012a) carried out water absorption test by immersing samples of dimension 10mm x 10mm x 3.5mm in a water bath at room temperature for few hours. Venkateshwaran, ElayaPerumal, Alavudeen, & Thiruchitrambalam, (2011) used the same method but the immersion times until 80 hours. The samples were dried using a tissue before weighing weight periodically by using a mass balance.

Another researcher on 2012 also using the same method with immersion times continued until saturation period was reached after 1010h Osman *et.al* (2012). On the other hand, Mohd Hafiz Zamri, Hazizan Md Akil & Cheng (2011) used three types of aqueous environments which are distilled water, sea water and an acidic solution to determine the pultruded rod size samples with 12.7mm diameter. The specimens were immersed into all three solutions before been wiped dry and weighted by using an electronic balance.

Instance, Venkateshwaran, Elayaperumal, Alavudeen, & Thiruchitrambalam (2011); H. M. . Akil *et.al*(2014) and Maslinda *et.al*(2017) found out the individual fiber of woven kenaf (KK) are absorbed higher amount of water compared to woven jute (JJ) and woven hemp (HH) due to cellulose content in the fiber. Water absorption of studied NFC was determined by the weight gained relative to the dry weight of the samples. The moisture absorption of the samples increased with increasing fiber content in all the cases. Athijayamani, Thiruchitrambalam, Natarajan, & Pazhanivel (2009) in their study of roselle and sisal fiber hybrid polyester composite with different fiber length and fiber content observed that the moisture absorbed are increase when the fiber contents and length are both increase. Sreekumar, Thomas, Saiter, Joseph, & Uninikrishnan (2009) noted that the water absorption of sisal fiber- reinforced polyester composite at different temperature show it is less for treated fiber- reinforced composite at all temperatures compare to the untreated. Meanwhile, Osman et al.(2012) mention the water uptake increase as percentage fiber weight increased for kenaf fiber unsaturated polyester composite (KFUPC).

2.2 Effect of Water Absorption on Mechanical Properties

Mechanical properties were found to be the most important part in the study of NFC characteristic. Flexural, tensile and impact test are frequently focused in determining the mechanical behavior of stated composite.

2.3 Flexural behavior of natural fiber composite

The water absorption behavior of recycled cellulose composite showed higher flexural strength as the increased of fiber content Alamri & Low, (2012b). This phenomenon is depicted in figure 2.

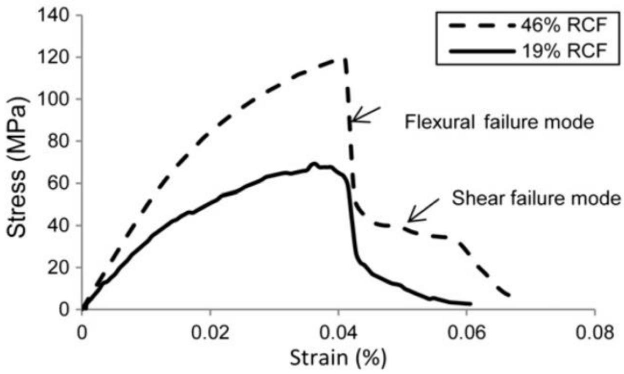

Figure 2: Flexural stress vs strain of recycled cellulose fiber (RCF) (Alamri & Low, 2012b)

The same trend of flexural properties was found by (Alamri & Low, 2012a) in their previous study regarding on mechanical properties of nanoclay filled recycle cellulose fiber composite. Sathishkumar, Navaneethakrishnan, & Shankar (2012) reported that the flexural modulus increase with increase of volume fraction from 10% to 25%. However, as the volume fraction is 30% the flexural strength suddenly drop to minimum value of strength. Meanwhile, the value of flexural strength fluctuated with different fiber lengths of 10mm, 30mm, 60mm, 90mm, 120mm and 150mm Sathishkumar *et.al* (2012). According to Kazemi Najafi & Younesi Kordkheili, (2011) whose working on water absorption at three types of water (distilled water, Caspian Sea water and Persian Gulf water) the flexural strength of sample immersed in distilled water is higher than Caspian Sea water and Persian Gulf water for both immersion time of 7 and 30 days. It was also found that incorporation of hemp fiber also give significant effect of flexural properties of the maleated polyethylene (MAPE) matrix. This was proved by Ramezani Kakroodi, Kazemi, & Rodrigue, (2013) where 60% hemp give a flexural modulus (F_m) over 260% compared to pure maleated polyethylene.

2.4 Tensile properties of natural fiber composite

A number of studies are using the dog bone sample to perform the tensile strength according to ASTM D638 standard and procedure. Maslinda *et.al* (2017) studied the woven composite of kenaf, jute and hemp). That summarizes the similar trend of tensile strength of woven kenaf/ kenaf (KK), jute/ jute (JJ) and hemp/ hemp (HH) composite around 80 MPa. Assarar, Scida, Mahi, Poilâne, & Ayad (2010) using an Instron 3382 testing machine to determine the tensile strength of rectangular form with 20 x 200mm^2 dimension. The result show that the flax- fiber composite loss 15% of their tensile strength at 20 days immersion.

Although, the tensile strength are reduce 30% between day 1 to days 20 of immersion. It is shown at figure 3 (M. Assarar , D. Scida , A. El Mahi , C. Poilâne, 2010).

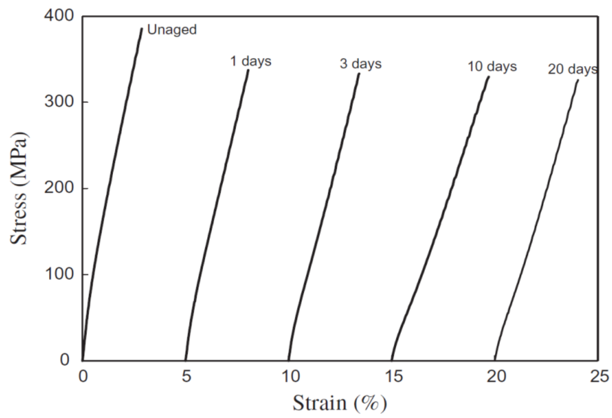

Figure 3: Evaluation according to the immersion duration of tensile behavior for flax-fiber reinforced composites. M. Assarar , D. Scida A. El Mahi , C. Poilâne, (2010)

Meanwhile in the 2010 researcher reported through an experiment where young modulus and tensile strength of KFUPC of water immersed samples were dramatically drop compared to un-immersed samples due to moisture uptake Rashdi *et.al* (2010). The same experimental procedures and material was then repeated by Osman et al., 2012)*et.al* on 2013 on their study regarding effect of water absorption on tensile properties of KFUPC. This supports the previous findings by Rashdi *et.al* where the tensile strength decrease as the immersion time increased. Figure 4 explain the details result reported by their studies.

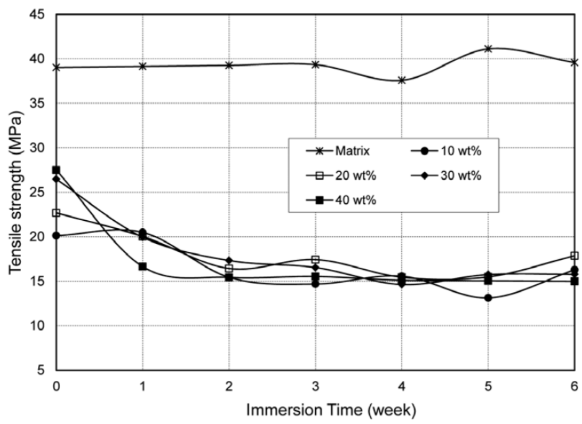

Figure 4: Tensile strength versus immersion time (Ekhlas Osman *et.al*, 2012)

There was a study on banana/ epoxy composite that explain the increasing of tensile strength until to certain limit as the increasing of fiber length and its composition (Venkateshwaran, Elayaperumal, *et.al*, 2011). The on other study, it was reported that the trilayer woven composite of Banana/ Jute/ Banana (B/J/J) claim higher tensile strength of 54.6MPa. Whereas, the trilayer composite of jute/ Banana/ jute has lower tensile strength of 32.63MPa (Venkateshwaran & ElayaPerumal, 2012).

From these result it can be revealed that the tensile strength and flexural modulus is higher in plant fiber because of the presence of cellulose in plant fiber (Aji, Zainudin, Abdan, Sapuan, & Khairul, 2012). This phenomena were actually supported experimentally by Jawaid, Abdul Khalil, & Abu Bakar (2010) where the good tensile strength and flexural strength in Banana/ Jute/ Banana achieved due to the presence of cellulose in banana. A study on the tensile properties of different models was done on 2012 by Osman et al.(2012) by means of experimental and theoretical tensile strength value as a function of weight fraction of fibers it was found that the experimental tensile strength exhibit the lowest value from theoretical as depicted in figure 5. There was five theoretical models have been compared in this study. They are Einstein & Guth Model, Hirsch' Model, Kelly and Tyson' Model, Bowyer and Bader's Model, Halpin- Tsai Model.

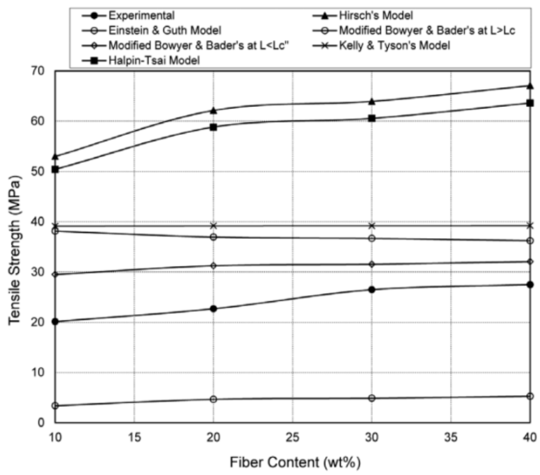

Figure 5: Variation of experimental and theoretical Tensile Strength (TS) values as a function of weight fraction of fibers. (Ekhlas Osman *et.al*, 2012)

2.5 Impact properties of natural fiber composite

The toughness of composite or impact strength is define as the ability of material to absorb energy until fracture under stress load applied. The absorption impact energy (J) is the total energy to break the specimens. Mostly, charpy impact method is used to investigate the behavior of material under impact load. Alamri & Low (2012; Alhuthali, Low, & Dong (2012) in their studies used equation 2 to determine the impact strength (σ_i).

$$Impact\ strength\ (\sigma_i) = \frac{E}{A} \quad (2)$$

Where, E is the impact energy to break the sample with a ligament of area A, at room temperature. The impact strength was determined by releasing the pendulum to strike the bar shaped sample as per ASTM D256. Ramezani Kakroodi *et.al* (2013) reported that the impact strength significantly decreased when the composition of hemp in maleated polyethylene (MAPE) matrix were increased. The impact strength by adding 10wt% - 60wt% of hemp fiber was observed to be 369.2J to 127.5J.

A study on impact strength of roselle and sisal fiber hybrid polyester composite contains the 10wt% to 30wt% fiber and with different fiber length and for both dry and wet condition was done on 2009. It was found in the experimental plot trend in figure 6, the values of impact strength at dry and wet condition for 15cm fiber have significant differences about 20J/m^2. The results indicate that impact value more depends on the length of the fiber compare to moisture content Athijayamani *et.al* (2009).

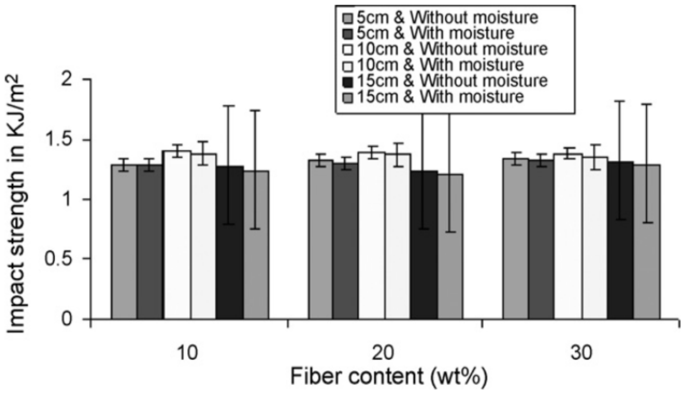

Figure 6: Effect of fiber composition on impact strength at dry and wet condition. (Athijayamani *et.al*, 2009)

Kongkeaw, Nhuapeng, & Thamajaree (2011) ; Sreenivasan, Ravindran, Manikandan, & Narayanasamy (2012) and Sumaila, Amber, & Bawa (2013) studied the effect of fiber length on physical and mechanical properties indicate that the impact strength of plant fiber composite can be improve with decreasing the fiber length and increasing the interfacial bonding between fiber and matrix. The lack of interaction bonding of the matrix and natural fiber will resulting the easy fracture the sample. On others study, Ramesh, Palanikumar, & Reddy (2012) claimed the maximum impact strength of 18.67J was obtained on sisal-Glass fiber reinforced polyester (GFRP) composite.

Comparing to Jute-GFRP and combination of sisal-Jute-GFRP. Then Rassmann, Reid, & Paskaramoorthy (2010) observed on their study, the fraction of volume fiber that laminate using wet fiber absorb more energy impact than lamination with dried fiber. Based on the study done by Prasad, Gowda, & Velmurugan (2017), regarding the impact characteristics of coir polyester, the thickness and fiber volume fraction will increase the impact strength either it is treated or untreated samples.

3.0 CONCLUSION

Natural fiber reinforced composite offer beneficial properties in many industries. Using the natural fiber (plant) is showing the good effect in water absorption and mechanical properties such flexural strength, tensile strength and impact strength. The study present the higher composition of cellulose in natural fiber was absorbs more water.

The mechanical properties of natural fiber depend on the factor, which is types of polymer matrix, fiber content, fiber length. The tensile strength improve with the increasing the fiber content. The flexural strength also improving with the increasing of fiber length and fiber content under the wet condition.

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