A Study on Wet and Dry Tensile Properties of Wood pulp/Lyocell Wetlace Nonwovens

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Abstract. A new biodegradable wood pulp/Lyocell moist wipe had been developed, which made from wetlaid/spunlace(wetlace) technology. The dry and wet tensile curve characteristics were described and the relationship between dry and wet strength in both machine direction (MD) and cross-machine direction (CD) were investigated. The results indicate that the fabricated wetlace materials are composed of the entanglements and cohesions of wood pulp/Lyocell fibres. The modulus and tensile strength of the materials were obviously decreased in wet state, and the tensile curves in the dry and wet state both can be divided into two parts. It is noted that there exists a high linear correlation between the dry and wet strength in MD or CD. Meanwhile, the diminished amplitude of wet strength in CD is larger than that of wet strength in MD and the relationship fluctuation between the wet and dry strength in CD is significantly higher than that in MD.

1. Introduction

With the economic development and improvement of life quality, the dispersible moist wipes increasingly were being sought by consumers for their convenience and effectiveness [1, 2]. As of now, wetlace method was an advanced processing technology as a result of 100% degradation or disintegration after use and sufficient dispersion and fabricated materials have became a current trend for moist wipes [3, 4]. Nevertheless, this existing technology still faced several difficulties and need to be examined. It is important to highlight that the wetlace nonwovens are completely made up of cellulose fibres, and MD or CD tensile properties of material will be changed significantly in wet state. As expected, this change is related to the fibre entanglement performances of the materials, and also importantly affects the material characteristics in-use and the product price [5]. But no published literature could be found yet to sufficiently investigate these respects.

In this paper, the wood pulp/Lyocell wetlace nonwovens were fabricated. The apparent structures of wetlace nonwoven were characterized by Scanning Electron Microscopy (SEM). The mechanism of the tensile properties of material dry and wet state was revealed in detail. The relationship between the dry and wet strength in MD or CD based on different basis weights and thicknesses was investigated. Overall, this may guide the dispersible wetlace nonwoven for high value moist wipes.

2. Methods and materials

Preparation of wood pulp/Lyocell wetlace nonwovens: the average lengths of wood pulp and Lyocell were 2.2 mm and 12 mm, respectively. According to required blend ratio (80/20) of wood pulp/Lyocell, two types of fibres both were mixed in water and then drained on an inclined wire to form the homogenous wet-laid nonwoven. Then the fibre web was bonded subsequent multiple passes of jet heads. Eventually, the wetlace nonwovens were dried in an online gas-fired, through-air drum dryer before being wound on to a roll at the end of the production. In this study, 30 samples with different basis weights and thicknesses were prepared at Hezhong Nonwoven Co. Ltd, Zhejiang, China. Characterizations: the prepared wetlace specimens were observed via SEM (TM3000) with 15kV electron. The determination of the dry and wet strength (both MD and CD) of the nonwoven fabrics had been implemented according to the guidelines of ISO 9073-3:1989 strip test method [6]. The width and the test gauge length of samples respectively were 50 and 200 mm and the stretching rate was100 mm/min. In order to determine the wet strength of materials, materials were firstly pre-wetted by water spraying to mimic moist wipes and then measured immediately. At least five samples were tested and the average values for tensile strength at break were recorded.

3. Results and Discussion

As can been seen in Figure 1(a), the wetlace nonwoven includes ribbon-like structure of relatively higher entanglement along the MD. It is noticeable that Lyocell fibre is longer than the wood pulp and is entangled to stride over several stripes. In addition, the Lyocell fibres aggregation forms the three dimensional skeleton structure involving a great number of wide-angle "*U*" shape entanglements and the wood pulp are entangled into it. Figure 1(b) shows pronounced fibre entanglements and cohesions structure of local fibres from Figure 1(a).

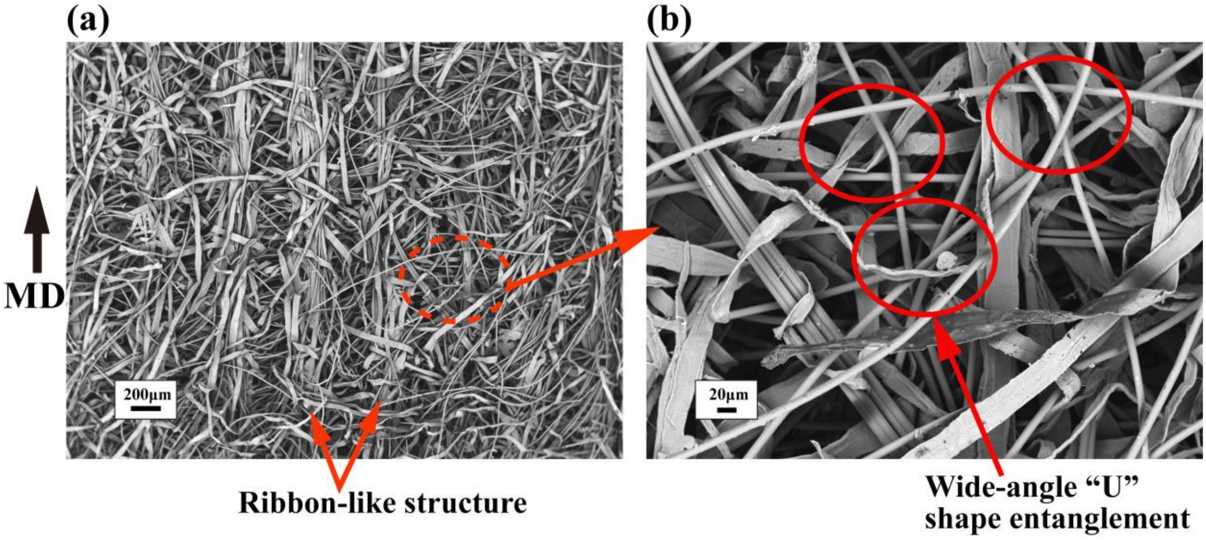

Figure 1. SEM images of wetlace nonwoven: (a) apparent structure and (b) fibre entanglements.

The MD or CD tensile curves of wood pulp/Lyocell wetlace nonwoven (65g/cm^2) in dry and wet state show in Figure 2(a) and (b), respectively. Compared with the condition of the dry state, the tensile strength and modulus in MD or CD decreased significantly in wet state. As mentioned previously, Lyocell fibres with longer length are easily entangled and form the entanglement structure to bear stretching. This entanglements are mainly based on the accumulation of basic "*U*" shape entanglement [7] and the bearing force from basic "*U*" shape entanglement depends on the friction coefficient and the wrapped angles between fibres [8, 9]. Although fibres swelling in wet state increase the fibre diameter as well as wrapped angles slightly, the friction coefficient has greater influence on the fibre displacement and the failure of entanglements than the wrapped angles. Therefore, the sharp decrease in friction coefficient in the wet state leads to decreasing the tensile strength greatly as well as modulus.

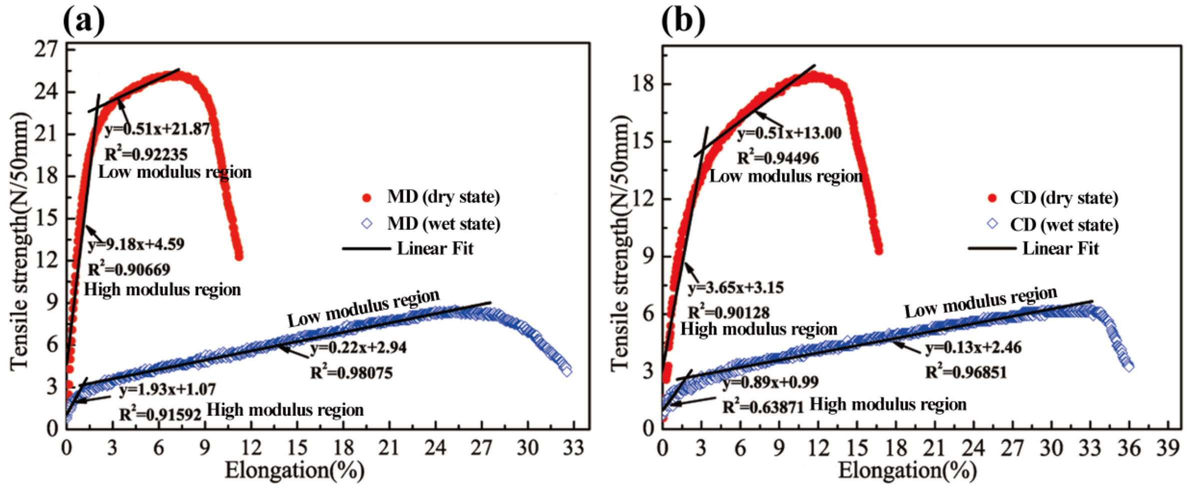

Figure 2. The tensile curves in dry and wet state: (a) MD and (b) CD.

Meanwhile, it is evident that the tensile curves of wetlace nonwovens (see Figure 2) can be divided into high modulus and low modulus regions. Besides, the region of high modulus is reduced substantially and the region of low modulus is increased greatly in wet state. Because the high modulus region attributes to the fibre initial displacement and the low modulus region mainly depends on the fibre straightening and slippage. The decrease of friction coefficient between fibres reduces the initial displacement of fibres and enlarges the fibres stretch time. Notably, in addition to the small correlation degree of CD high modulus region in wet state (see Figure 2(b)), the other parts of tensile curves all have highly linear fitting due to fibres MD arrangement after hydroentanglement [10, 11]. It is noticeable that the MD and CD tensile curves in the wet state have pronounced fluctuation as a result of small friction coefficient between fibres in the wet state. In addition, from the dry state to wet state, the MD high modulus ranges from 9.18 to 1.93 and the rate of decline is 78.98%, and the low modulus changes from 0.51 to 0.22 and the decreasing rate is 56.86%. The CD high modulus decreases from 3.65 to 0.89 and the decrease rate is 75.62%, and the low modulus falls from 0.51 to 0.13 and the reduction rate is 74.51%. The decline amplitude of the MD high modulus is larger than that of the CD high modulus, but the decline amplitude of the MD low modulus is smaller than that of the CD low modulus. This phenomenon is mainly due to the fibre entanglements and ribbon-like structures along MD.

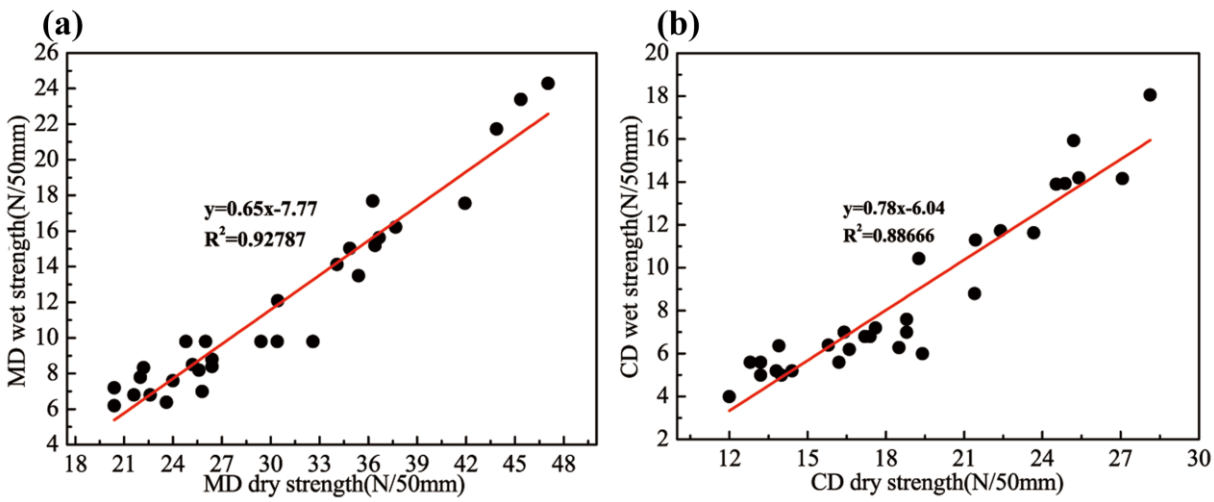

Figure 3. The relationship between the wet and dry strength: (a) MD and (b) CD.

Figure 3(a) and (b) respectively show the relationship between the dry and wet strength of 30 samples in MD and CD. No matter vertical or horizontal direction, it is evident that the increase in dry strength of samples results in increasing the wet strength, which present highly linear correlation. This trend is responsible for no structure change of material in dry or wet state. The fitting linear slope between the dry and wet strength in CD is larger than that in MD, namely that the CD wet strength is reduced relatively larger than that of the MD wet strength. Moreover, the correlation degree between the dry and wet strength in CD is smaller than that in MD, thus the relationship volatility of dry and wet strength in CD is larger than that in MD. This may be due to the results that the MD tensile strength is mainly affected by the fibre entanglement, and the CD tensile strength is primarily caused by the fibre displacement and entanglements. Additionally, the coefficient of friction in the wet state decreases sharply, which greatly weakens the friction force caused by fibre displacement and affects the failure of entanglement.

4. Conclusion

In this research work, the prepared wood pulp/Lyocell wetlace nonwovens have obvious ribbon-like structure. The Lyocell entanglements form the three dimensional skeleton structure, and the wood pulp is entangled into it. No matter wet or dry state, the MD and CD tensile curves both can be divided into high modulus and low modulus regions. The high modulus region significantly decreases but the low modulus region increases substantially in wet state. In addition to the small correlation degree of CD high modulus region in wet state, the other parts have the highly linear correlation. Furthermore, there is highly linear correlation relationship between the dry and wet strength in MD or CD.

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