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Effect of Polyethylene Film Lamination on the Water Absorbency of Hydrophilic-finished Polypropylene Non-woven Fabric

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Abstract: Polyethylene/Polypropylene (PE/PP) composite non-woven fabrics have been used widely for surgical packages due to its dual features of PE surface and PP surfaces. PP fabric pre-treated by hydrophilic agent provides high water absorbency, while PE surface is responsible for high barrier functions. However, the PP water absorbency declines once PE film is laminated, and no report devoted to study the extent and the reasons of this declining. Herein, the hydrophilic finishing of the PP non-woven fabrics was processed via Kiss-roll method, then the PE/PP fabrics were obtained using a normal hot melt adhesive PE film laminating process. The wicking height, water absorption specific gravity (LAC%), static contact angle, as well as the complete wetting time of the finished PP and PE/PP fabric were measured and compared. Meanwhile, the SEM was used to detect the morphology changing. The results revealed that the pores between fibers in the PP non-woven were filled with non-hydrophilic hot melt adhesive penetrated during PE lamination, so that the PP structure changed to be less porous. Moreover, the laminated PP layer actually blocks the water flow channel in the system, resulting in the absorbency reduction after lamination. As a result, comparing with the PP non-woven fabric, the wicking height of the PE/PP fabric decreased by 25.3 %, the LAC % value reduced by 40.83 %, and the complete wetting time extended from 0.29 s to 1.74 s.

Keywords: PE/PP, Lamination, Hydrophilic, Water absorbency, Static contact angle

Introduction

Polyethylene/Polypropylene (PE/PP) laminated non-woven fabrics possess the dual features of hydrophobic PE surface and hydrophilic PP surface, accompanying by advantages of excellent softness, regularity, light weight and low cost, which are usually processed into disposable surgical supplies such as surgical drapes, surgical gowns and etc [1,2]. The PE surface could effectively block the penetration of blood and inhibit the invasion of bacteria, whereas, the hydrophilic-finished PP surface exhibits water absorption and can rapidly absorb effusion and waste liquid generated during operation. Therefore, the PE/PP composite surgical supplies can avoid crossing infection and ensure high biosafety in the field of medical and health care [3,4], and have become more widely adopted especially in recent years.

However, as we know, the normal PP non-woven fabric itself has no hydrophilic properties [5]. In order to improve its water absorbency, numerous techniques have been proposed such as surface modification [6-8], radiation grafting [9-11], plasma-modification [12-15], hydrophilic finishing [16-19] and etc. But now in commercial production, only the finishing with hydrophilic agents is considered to be the most frequently used technique owing to its advantages of high efficiency, short flow, simple process and low processing cost. For hydrophilic finishing, there are many kinds of hydrophilic finishing agents, which can be classified into polyesters, acrylics, polyamides, epoxy, polysiloxanes, polyurethanes, and other types. Compared to dip-pad and other finishing processes, Kiss-roll method has the lower limits of wet pickup. What's more, for the same coating thickness, Kiss-roll enables higher finishing speed, which is especially suitable for finishing PP and other synthetic fabrics [20-24].

The water absorbency of the PP surface is an important indicator in evaluating the quality of PE/PP composite non-woven fabrics. But, in fact, the water absorbency of the finished PP non-woven declines when laminated by PE film. However, research literature about the decrease of the water absorbency caused by film lamination is quite limited, and there is no paper devoted on the effect of PE film lamination on the water absorption properties of PP non-woven fabric. Therefore, this study was set out to assess the effect of PE film lamination on the water absorbency of PP non-woven. Before lamination, the PP non-woven fabrics were hydrophilically finished by Kiss-roll process in advance. Meanwhile, the effect of agent concentration on the absorbency was studied. Then, the wicking height, LAC %, and the static contact angle, as well as the complete wetting time of the PP non-woven, were measured and compared with those of the PP surface of the PE/PP composite fabrics. Moreover, the SEM was used to detect the changing of morphology. This paper gives an account of the specific impact of PE film lamination on the absorbency of PP non-woven, as well as the reasons of this impact. The contribution of this study provides an experimental basis for the development and usage of PE/PP composite non-woven fabrics.

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Experimental

Materials and Chemicals

PP non-woven fabric with an areal density of 30 g/m^2, PE film with an areal density of 21 g/m^2 and the modified rosin hot melt adhesive with the molecular weight of 30000 kDa were all kindly supplied by Hefei Cobes Non-woven Fabric Co., Ltd.; Release paper used in this paper was supplied by Kunshan Baojing Paper & Plastic Co., Ltd. Industrial TF-629B hydrophilic agent with the main component of fatty acid ester was purchased from Zhejiang Transfar Co., Ltd and used without further treatment; All other reagents used in this research were analytical grade and obtained from Shanghai Aladdin Bio-chem Technology Co., Ltd.

Besides, the 0.9 % normal saline used in this experiment was prepared by the following method: 9 g NaCl was added to the pure water of 991 m*l*, stirring until completely dissolved.

Preparation of the PE/PP Composite Non-woven Fabrics

The PE/PP composite non-woven fabrics were conducted following the process as shown in Figure 1. Hydrophilic finishing of PP non-woven fabric was carried out through the Kiss-roll method, with the speed of 12 r/min and the roller pressure of 1.5 kg/m^2. And the TF-629B hydrophilic agent concentration was set at 4 g/*l*, 6 g/*l*, 10 g/*l*, 12 g/*l*, 15 g/*l*, respectively, and the temperature of the finishing solution was set at 45 ^{o}C. Afterward, the finished wet PP non-woven fabric was dried by the hot dryer with the guide of roller. Then, with hot melt adhesive in between the PP fabric and a PE film, the PE/PP composite non-woven fabrics were obtained using a normal hot melt adhesive laminating process, which can get high peel strength [25]. The laminating process was conducted with the spray amount of 3 g/m^2 and under the roller pressure of 1.0 kg/m^2, and finally the PE/PP composite non-woven fabric was coiled on the last tube.

In the experiment, another composites were prepared through the same laminating process as described above but using a release paper instead of PE film. The release paper was then peeled off from the composite, the PP non-woven with the hot melt adhesive (PP-adhesive composite) was obtained (as shown in Figure 2). The water absorbency of the PP-adhesive composite was measured and compared with that of PE/PP composite fabrics.

Characterization

The morphological structures of PP non-woven fabric before and after hydrophilic finishing were detected by scanning electron microscopy (SEM, S-4800, Hitachi Limited, Japan), and a small amount of gold was painted onto the surface of all samples to get a clear photograph.

The Contact Angle System (DSA-25, ThetaBiolin Co., Sweden) was used to monitor the change of the contact angle of PP non-woven fabrics and the PP surface of the PE/PP composite non-woven fabric, and the wetting process of the tested samples obtained.

The textile structure change of the PP non-woven fabrics before and after lamination was detected by MC-D500U(C) HD Digital camera (Phoenix Co. Ltd., China).

The wicking height was measured according to the DIN 53924-1997 standard, the mean value of five measurements

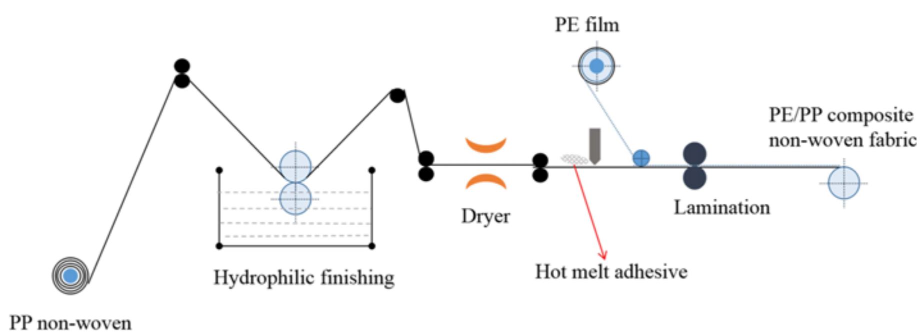

Figure 1. Preparation process of the PE/PP composite non-woven fabrics.

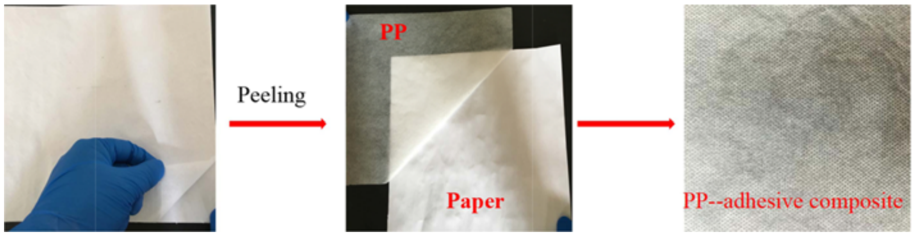

Figure 2. Preparation of the PP-adhesive composite.

was measured.

The water absorption capacity was measured according to the ISO 9073-6:2000 standard, the mean value of five measurements was measured, and the water absorption specific gravity (LAC_P %) for PP non-woven fabric was calculated according to equation (1).

$$LAC_P(\%) = \frac{m_P - m_{Po}}{m_{Po}} \times 100 \tag{1}$$

where m_{po} is the initial weight, and m_p is the weight after water absorption, of the PP non-woven fabric. The LAC_P % is the water absorption relative to its original weight, which is an indicator of the hydrophilicity of the PP non-woven fabric.

Similarly, the LAC_{EP} % for PE/PP composite non-woven fabric was calculated according to equation (2).

$$LAC_{EP}(\%) = \frac{m_{EP} - m_{EPo}}{m_{Po}} \times 100 \tag{2}$$

where m_{po} is the net weight of PP non-woven side of the PE/PP composite non-woven fabric, and can be easily calculated by its areal density and the size; m_{EPo} is the initial weight of the PE/PP composite fabric; and m_{EP} is the weight of the PE/PP fabric after water absorption. So LAC_{EP} % is the water absorption of the PE/PP system relative to the weight of its PP portion, which is an indicator of the hydrophilicity of the PE/PP system.

It should be noted that the PE/PP composite non-woven fabric here shows double wetting behaviors; the PP side is hydrophilic and PE side remains hydrophobic.

Results and Discussion

Testing and Analysis of Wicking Height and LAC_p%

The PP fabric was finished with the hydrophilic agent at different concentrations. The wicking height varying with the time of the finished PP non-wovens were shown in Figure 3.

As it can be seen from Figure 3, without hydrophilic finishing, the wicking height of the PP fabric is very low, almost zero, and independent of time. This result is in accordance with the previous studies that the PP non-woven itself is highly hydrophobic. However, once hydrophilically finished, its water absorption is significantly improved. With the prolongation of impregnation time, the wicking height gradually rises until leveling off at its highest value. Meanwhile, the maximum value of wicking height is also closely related to the concentration of the finishing agent. As the concentration increases from 4 g/*l* to 12 g/*l*, the maximum wicking height increased gradually. But further increasing to 15 g/*l*, the curve is virtually identical to that of 12 g/*l*. This result may be explained as follows: the TF-629B hydrophilic finishing agent is a hydrophilic surfactant. At low concentration, the finishing agent is adsorbed on the

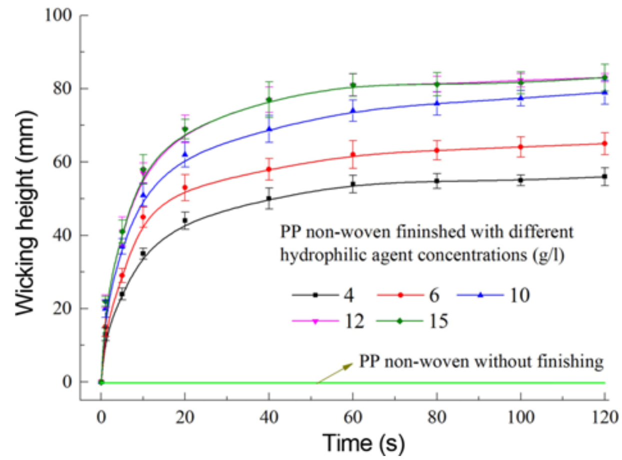

Figure 3. Curves of wicking height varying with time of PP non-woven fabric.

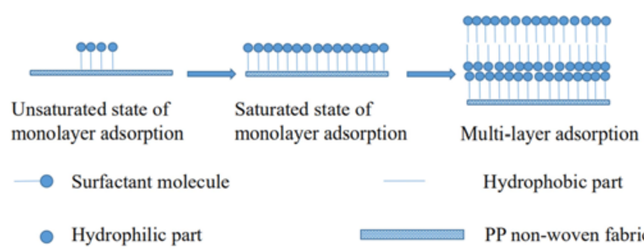

Figure 4. Adsorption form changing of hydrophilic agent on PP non-woven fabric.

surface of PP non-woven by a hydrophilic single molecular layer. With the increase of the concentration of the finishing agent, the amount of hydrophilic molecular layer increases and the system hydrophilicity improves. However, as the concentration continues to rise, the monolayer adsorption becomes saturated, and the hydrophilic agent begins to form a multi-layer adsorption layer, that is, adsorption in the form of micelles. Consequently no further increase in system hydrophilicity (as shown in Figure 4).

Actually the LAC_p % values of finished PP fabric with different TF-629B concentrations were tested, and the same results with that in Figure 3 are obtained as shown in Figure 5.

It can be seen from Figure 5, the LAC_p % value, increases with the concentration of the TF-629B agent in the concentration range of 4-12 g/*l*. Further increasing of the TF-629B agent leads to the stagnation in LAC_p % value at this time did not increase comparing with the value at the concentration of 12 g/*l*.

Therefore, in order to obtain high water absorbency PE/PP composite non-woven fabric without waste of finishing agent, the PP non-woven fabric, which was hydrophilically finished with the TF-629B concentration of 12 g/*l* in the present work, was used for the preparation of the PP/PE

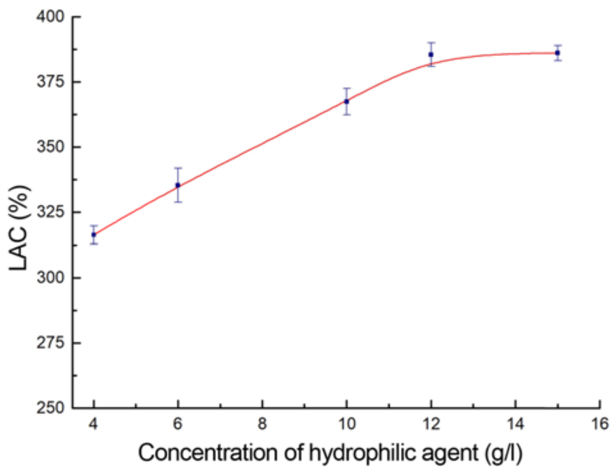

Figure 5. LAC_p % values of the finished PP non-woven fabrics.

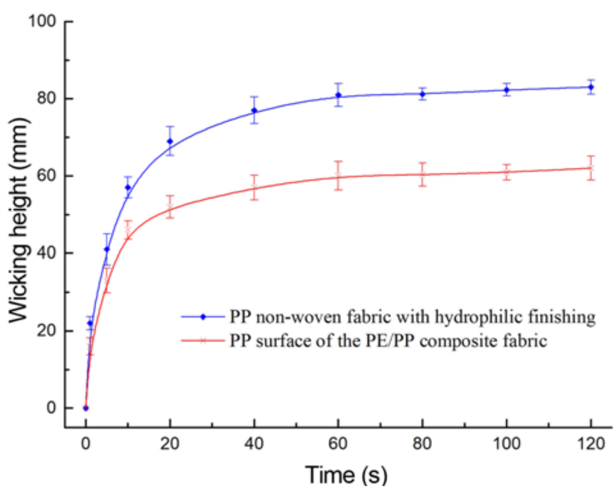

Figure 6. Wicking height curves of the finished PP non-woven and the PP surface of the PE/PP composite non-woven fabric.

composite fabric. Figure 6 shows curves of wicking height varying with the time of the finished PP non-woven and the PP side of the PE/PP composite non-woven fabric.

As shown in Figure 6, both the wicking heights of the finished PP non-woven fabrics and the PP side of the PE/PP composite non-woven fabric increase gradually with the extension of impregnation time, each of them basically reach their respective maximum wicking height after 60 s. What stands out in Figure 6 is the huge difference between the two maximum wicking heights. The height peak of the finished PP non-woven is 83 mm, while that of the PP side of the PE/PP composite is only 62 mm. The difference between them is up to 21 mm. The result indicates that the wicking height of the finished PP non-woven is significantly reduced after PE film lamination, and the reduction is 25.3 %. In other words, after PE film lamination, the water absorbency of the finished PP non-woven is weakended considerablly.

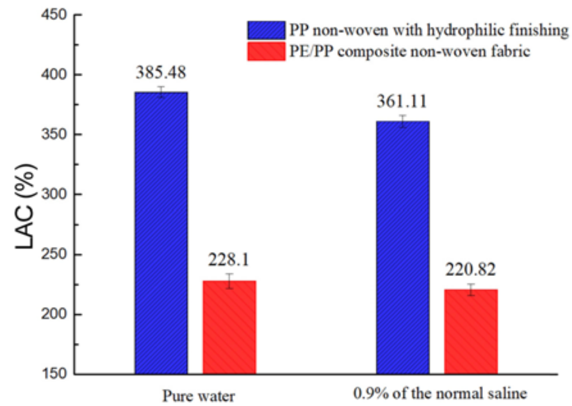

Figure 7. LAC_{EP} % values of the finished PP non-woven and the PE/PP composite non-woven fabrics.

At the same time, the LAC_{EP} % values of the PE/PP composite in pure water and 0.9 % normal saline were measured and compared with the same hydrophilically finished PP non-woven fabric with the TF-629B concentration of 12 g/*l*. The results are shown in Figure 7.

Similar results as in Figure 6 are obtained here in Figure 7. The LAC_{EP} % value, relative water absorbency, of the finished PP non-woven fabric is always higher than that of the PE/PP composite, it is 385.48 % versus 228.1 % in pure water and 361.11 % vs. 220.82 % in 0.9 % normal saline.

So, it is highly desirable to clarify the reasons why the water absorption properties of the finished PP non-woven fabric are depressed after the PE lamination, and if possible to eliminate or at least alleviate the depression.

Surface Wetting Process Analysis

In order to further study the effect of the PE film lamination on the hydrophilic properties of the finished PP non-woven fabric, the time required for the surface to be completely wetted was recorded by monitoring the surface contact angle of the samples. The images captured during the process are shown in Figure 8. It is worth noting that the finished PP non-woven fabric samples and the PP non-woven fabric processed the PE/PP composite non-woven fabric samples in this test with the same hydrophilic finishing process with the TF-629B concentration of 12 g/*l*.

As it can be seen from the Figure 8, the contact angle of the normal PP non-woven fabric without hydrophilic finishing is 90.74 ^{o} and so that the fabric can't be completely wetted. This result is consistent with the wicking height as described above, that is, the PP non-woven fabric itself without hydrophilic finishing does not have water absorption properties. On the contrary, the finished PP non-woven fabric has a contact angle of 0 ^{o} and its surface can be completely wetted in such an extremely short time of 0.29 s, indicating that the hydrophilic finishing can improve the hydrophilicity of the PP non-woven fabric significantly. For

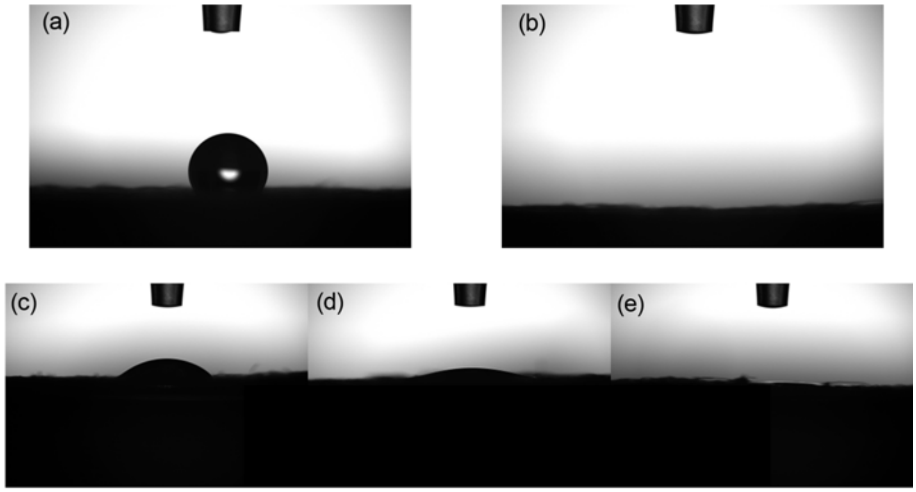

Figure 8. Images during the surface wetting process of the test samples (images (c) to (e) are the images of the PP surface of the PE/PP composite non-woven fabric); PP without hydrophilic finishing (θ=90.74 °), (b) the finished PP (θ=0 °, t=0.29 s), (c) θ=41.74 °, t=0.30 s, (d) θ=14.87 °, t=1.10 s, and (e) θ=0 °, t=1.74 s.

the Figure 8(c)-(e), although the PP surface of the PE/PP composite non-woven fabric can also be completely wetted, the time required for wetting is significantly extended. The wetting time extends from 0.29 s to 1.74 s, compared with that of the finished PP non-woven fabric before lamination, indicating the water absorption rate of the PP surface after PE lamination is also slowed down.

Mechanism Analysis

Figure 9 shows the morphology of PP non-woven fabric before and after the hydrophilic finishing. The PP non-woven fabric without hydrophilic finishing has a smooth surface. In contrast, for the finished PP non-woven fabric, the surface of the PP fibers is covered with the TF-629B hydrophilic agent, resulting in rough fiber surface. Still it is clear that the effect of hydrophilic finishing on the porosity of the fabric is tiny and negligible.

The PE/PP composite non-woven fabrics prepared by the hot melt adhesive PE lamination have a high peeling strength, which is attributed to the penetration of adhesive into the PP fabric and the surface of the PE film, thus increasing the adhesive force between the PP non-woven and the PE film. Figure 10(a) depicts the penetration of hot melt adhesive to the PP non-woven fabric during the PE/PP composite fabrics preparation. Consequently the PE/PP composite non-woven fabrics prepared in this experiment is strong against delamination.

Therefore, because of the penetration of the adhesive, the pores of PP non-woven fabrics are filled by the non-hydrophilic hot melt adhesives, and some random water repellent sheets formed on PP non-woven fabric (as shown in Figure 10(b)), yielding a less porous PP fabrics and leading to the decrease of water absorption rate and the prolongation of wetting time of the finished PP non-woven fabric. That is, even without the PE film, just the adhesive penetration into the PP fabric alone, significantly impairs the hydrophilic-finished PP non-woven,

Once the PE layer is added to form PE/PP composite, its effect can be seen from Figure 11. It is noticeable that PE lamination indeed further reduced the water absorption of the system, even though the difference between the PP-adhesive sample and the PE/PP composite in Figure 11 is no

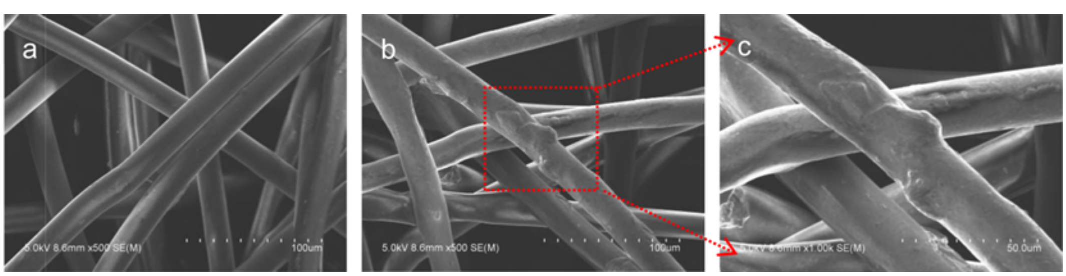

Figure 9. Morphology images of PP non-woven fabrics; (a) the PP non-woven without hydrophilic finishing, (b) the finished PP non-woven, and (c) detail enlargement.

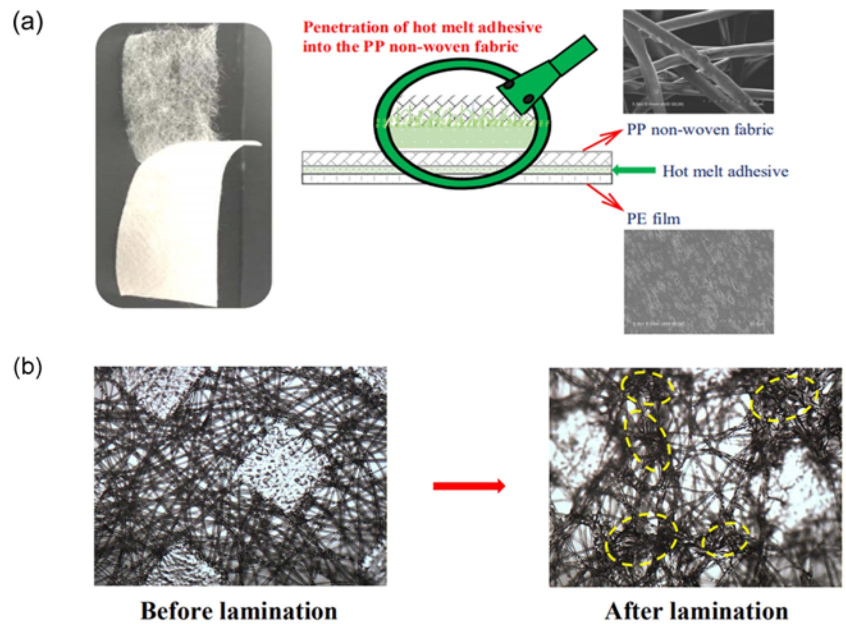

Figure 10. Penetration of hot melt adhesive into the PP non-woven fabric; (a) schematic of this penetration and (b) optical image of textile structure change before and after lamination.

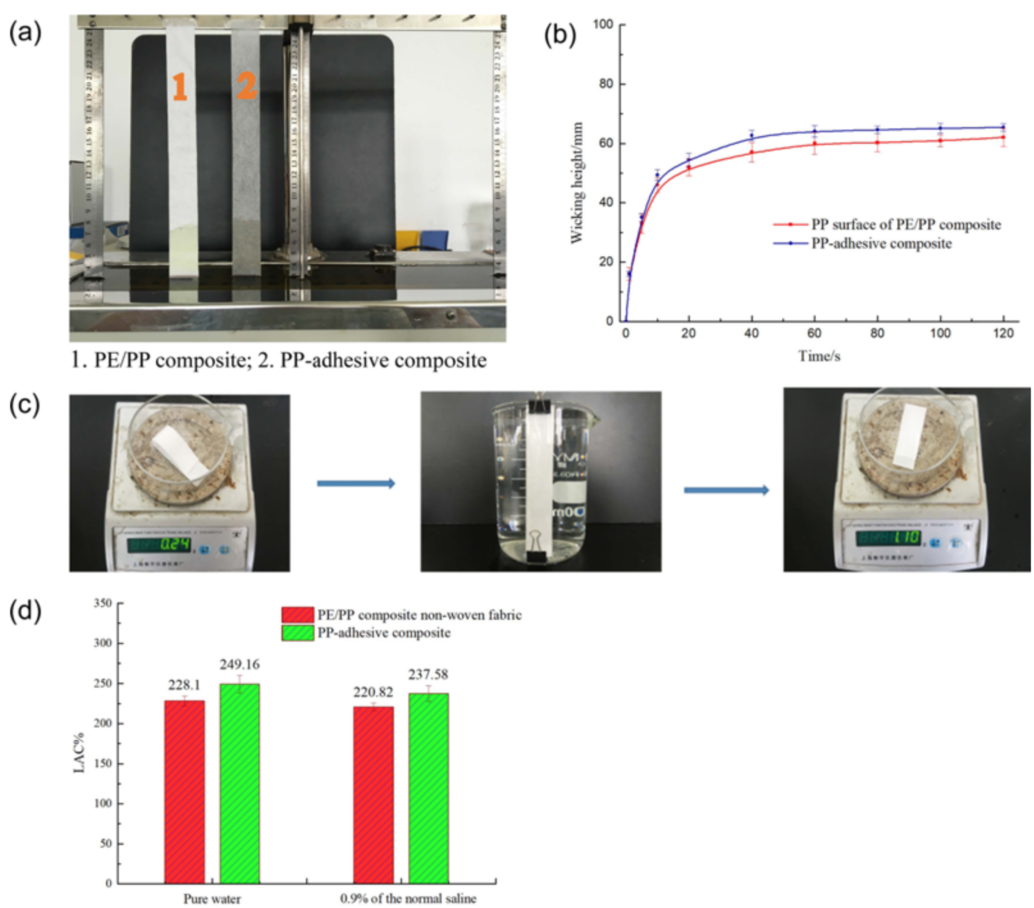

Figure 11. Water absorbency of PP-adhesive composite and compared with PE/PP composite fabric; (a) optical photo of wicking height measuring, (b) curves of wicking height with time, (c) optical photo of LAC% measuring, and (d) comparison chart of LAC % values.

as huge as the adhesive penetration effect discussed in Figure 10(b). It is likely attributed to the hydraulic blocking from the PE layer.

Therefore, of the two main reasons causing the depression of the water absorbency of the final PE/PP composite, if the PE layer has to be retained, the only solution is to choose a more hydrophilic or less disintegrative hot melt adhesive used for PE film lamination.

Conclusion

In this paper, the mechanisms and factors influencing the water absorbency of the finished PE/PP laminated composite were studied. Both techniques of wicking height and the relative water absorbency LAC % values provide consistent results. First, in finishing the PP non-woven fabric with TF-629B hydrophilic agent, the optimal level of TF-629B agent was 12 g/*l* at which the the water absorbency of the PP fabric reaches maximum. Then once the finished PP non-woven fabric was laminated by a PE film with adhesive, the system water absorbency is impaired by two factors. The one is that the adhesive would disintegrate during the hot melting process and fill into the pores of the PP fabric, leading the fabric less porous and water absorbing. The other is that the PE layer also blocks the water flow in the system as well.

Acknowledgments

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