Study on pilling performance of polyester-cotton blended woven fabrics

Rui Wang1* and Qi Xiao1,2*

Abstract
Aiming at the classic problem of pilling of polyester-cotton blended woven fabrics, pilling grades were evaluated by image analysis method to study the effects of yarn twist, spinning method, warp, and weft density, fabric cover factor and fabric singeing on pilling performance. The length and density distribution of fabric hairiness was studied by Nano measurer software. The respective roles of polyester and cotton fibers were studied by using scanning electron microscope and quantitative chemical analysis method. The experimental results showed that the factors for the best anti-pilling fabric are that yarn twist is 950 N/m, the spinning method is siro-compact spinning, warp density is 394 N/10cm, weft density is 265 N/10cm, fabric cover factor is 103.9%, and fabric should be singed. Cotton hairiness is fractured, which is wrapped by polyester hairiness to form pills. The frequency distribution of hairiness is approximately given by Gauss distribution. Mass ratio of polyester and cotton hairiness is nearly 66%/34%.

Keywords
Polyester-cotton blended woven fabric, pilling, hairiness, performance

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Introduction
Polyester-cotton blended woven fabrics are widely used in working textile markets. Because there are a plenty of overwhelming advantages, which include pressure resistance, wrinkle resistance, stiffening, moisture absorption, low cost and so on.1 However, pilling not only deteriorates appearance and feeling of polyester-cotton blended woven fabrics, but also affects wearing performance of fabrics. Therefore, it is important to study on pilling performance of polyester-cotton blended woven fabrics to solve pilling problem.

The pilling tendency of a fabric is associated with hairiness.2 Hairiness is a prerequisite that affects whether a pill is formed. However, hairiness is a factor that cannot be directly regulated. Actually, producers improved pilling performance by optimizing factors including fibers (morphology,3 modulus,4 friction coefficient,5 etc.), yarns (spinning method,6 yarn twist,7 yarn count,8 etc.) and fabrics (structure,9 cover factor,10 etc.). The synergy of these factors determines pilling performance of fabrics. Beltran et al.11 found that the larger fabric cover factor was, the lower pilling propensity of fabrics was. But the reason has not been detailed. Candan et al.12 analysed the effect of different spinning methods on the pilling performance of fabrics and found that open spun fabric had a lower propensity to pilling. The pilling mechanism was explained by SEM. However, the quantitative study of hairiness was not adopted to explain pilling. Rejali et al.8 found that

1School of textile science and engineering, Tiangong University, Tianjin, CN
2Changshu Institute of Technology, school of textile garment and design, Changshu, Jiangsu, CN
* These two co-first authors contributed equally to the article
Corresponding author:
Rui Wang, School of textile science and engineering, Tiangong University, No.399, Binshui West Road, Tianjin 300387, CN.
Email: wangrui@tiangong.edu.cn
higher yarn twist caused less pilling because of compactness and less number of protruding fiber on the yarn surface. The respective roles of different fibers on pilling were not studied. Lohrasbi et al.\textsuperscript{13} found that the more warp and weft density are engaged together in the fabric surface, the fewer pills will form on it. The study of fuzz on pilling was conducted to explain the essence. Naeem et al.\textsuperscript{14} observed that bamboo/cotton blended fabrics which were singed had a lower propensity to pilling. However, the effect of fabric hairiness on pilling has not quantitatively conducted. Based on previous studies, yarn twist, spinning method, warp and weft density, fabric cover factor and fabric singeing have important effects on pilling performance of fabrics. However, the relationship between these influencing factors and pilling propensity is quite complicated. Among the various researches conducted, there few studies on the relationship between fabric hairiness and these main factors to affect pilling propensity. And few have also evaluated the respective roles of different fibers on pilling of blended fabrics.

In this paper, pilling tests of a series of polyester-cotton blended woven fabrics are carried out by image analysis method. The effects of yarn twist, spinning method, warp and weft density, fabric cover factor and fabric singeing have important effects on pilling performance of fabrics. However, the relationship between these influencing factors and pilling propensity is quite complicated. Among the various researches conducted, there few studies on the relationship between fabric hairiness and these main factors to affect pilling propensity. And few have also evaluated the respective roles of different fibers on pilling of blended fabrics.

### Experimental

#### Material

Polyester fibers and cotton fibers are used in the experiment. The parameters of diameter and length of fibers are in Table 1. The fabric specifications are as follows. Blend ratios are 65% polyester fibers and 35% cotton fibers. This blending ratio can make the overall effect best, which not only exerts the spinnability, weaving and dyeability of cotton fiber, but also highlights the firmness, non-ironing and crispness of polyester. The yarn count is Ne 24. The fabrics are spun by four kinds of spinning methods, such as ring spinning, compact spinning, siro spinning and siro-compact spinning. And the structures of fabrics are plain.

#### Methods

**Fabric pilling performance test.** The image process method is adopted in order to test fabric pilling performance. The fabrics are conditioned for 24 h at 20°C and 65% relative humidity prior to testing. The samples are composed of three groups, and each group includes two specimens. The specimen is mounted on YG (B) 401T Martindale abrasion tester. Under a pressure of 415 g, one specimen is rubbed with the other specimen to trace a Lissajous figure. After each set of specimens is rubbed with pilling times of 125, 500, 1000, 2000, 5000, the specimen is processed by image analysis method. First, the specimen is photographed by USB microscope to obtain fabric image. Then pilling features are extracted by the method which connects Fourier transform with wavelet transform. This method has been presented in the literature.\textsuperscript{15} The pilling grade is confirmed by comparing the pilling features of the specimen with pilling features of standard pilling images. The pilling features include the pill number and pill area.

**Fabric surface morphology test.** The surface oil of the fabrics to be tested is extracted with acetone and absolute ethanol. Then the fabric is dried and conditioned for 24 h at 20°C and 65% relative humidity. After gold coating, the surface morphology of fabric is observed with TM3030 electronic scanning microscope, typically operating at a 10 KV acceleration voltage.

**The test of hairiness length and density distribution on the fabric surface.** The sample after pilling test is folded along the grain of the fabric. The folded portion is considered as the baseline. The portion where the fluff is exposed is outwardly placed on the background with a large contrast under an optical microscope. After magnifying 100 multiples, the sample is directly photographed with a digital imaging device to obtain a hairiness image on the baseline of the fabric. The image taken is processed by Nano Measurer 1.2 software, which is illustrated in Figure 1. The number of hairiness and the length of hairiness is measured and

| Fiber type | Diameter (µm) | CV (%) | Length (mm) | CV (%) |
|------------|---------------|--------|-------------|--------|
| Polymer    | 16.5          | -1.9   | 38          | 2.1    |
| Cotton     | 23.4          | 1.6    | 28          | 1.2    |
recorded. The number and length of hairiness on other baselines is also performed using the above method. Finally, the number and length of hairiness on each baseline are collected to obtain the hairiness length and density distribution on the specimen.

The test of mass of polyester fibers and cotton fibers. According to ISO 1833-11, quantitative chemical analysis of fabrics is conducted to test the mass of polyester fibers and cotton fibers in pills. After pilling test, all of the pills on the fabric surface were cut off. Put the pills in the oven to dry, and then weigh the mass of pills. The pills are placed in the conical flask, where 200 ml of sulfuric acid per gram of pills is added. The mass fraction of sulfuric acid is 75%. Maintain the flask at (50 ± 5)°C for 1 h, shaking the flask and contents gently at intervals of about 10 min. Filter the residual fibers of the flask through the weighed filter crucible using suction. Wash the residue successively several times with cold water, and drain the crucible using suction after each addition. Do not apply suction until washing liquor has drained under gravity. Finally, drain the crucible using suction, dry the crucible and residue, then cool and weigh them.

Results and discussion

The effect of yarn twist on pilling propensity

Seven kinds of polyester-cotton blended woven fabrics with different yarn twists which include 550 T/m, 650 T/m, 750 T/m, 850 T/m, 950 T/m, 1050 T/m, and 1150 T/m are woven. The other parameters of these fabrics are the same. Five specimens from fabrics with the same yarn twist are used to do pilling test. And the pilling grade is obtained by taking the average of five data. The effects of yarn twist on pilling performance of the fabric are depicted in Figure 2. It can be seen from Figure 2 that pilling grades gradually increase with the increase of yarn twist at the stage of 125 pilling rubs. After the number of pilling rubs is more than 500, pilling grades of the fabric obviously increase first and then decrease with the increase of yarn twist. The explanations are as follows. When yarn twist increases from 550 T/m to 950 T/m, the cohesion between the fibers enhances. The relative slippage between fibers becomes less, and the hairiness floating on the surface of the fabric is less. Therefore, pilling tendency gradually decreases and pilling grades increase. When yarn twist is increased from 950 T/m to 1150 T/m, the cohesion of the fibers is further tighter, which makes the rate of forming pills slower. On the other hand, the rate at which pills fall off becomes slower. The rate of falling pills is slower than forming pills. It may be attributed to the strong polyester fibers, which make the pills hung on the fabric surface, as shown in Figure 3. So the pilling grade has a decreasing trend. Therefore, frictional cohesion between fibers has a decisive effect on pilling performance of fabrics. Basing on the above analysis, pilling grade of polyester-cotton woven fabric is the best when yarn twist is 950 T/m.

The effect of spinning methods on pilling propensity

The effects of four spinning methods on pilling performance are presented in Figure 4. It can be seen from Figure 4 that when the number of pilling rubs increases under the same spinning method, pilling grades tend to decrease gradually. Pilling grades from low to high are ring spun fabric, siro spun fabric, compact spun fabric and siro-compact spun fabric, respectively. At the stage of 5000 pilling rubs, pilling grades of siro-compact fabric, compact fabric and siro fabric are 60.14%, 42.66%, and 13.99% higher than ring spun fabric, respectively.
Hairiness length and density distribution of ring spun fabric, compact spun fabric, siro spun fabric and siro-compact spun fabric is showed in Figure 5 when the number of pilling rubs is 5000. It can be seen from Figure 5 that fabrics which are woven by different spun yarns have different hairiness. When the length of hairiness is the same, the density of hairiness of these four kinds of fabrics is distributed from high to low, namely ring spun fabric, siro spun fabric, compact spun fabric, and siro-compact fabric. The siro-compact spun fabric has the least hairiness on the fabric surface in the pilling process. The reason may be that siro-compact spun fabric combines the advantage of siro spun fabric and compact spun fabric, which makes the original hairiness less on the fabric surface. The siro-compact yarn has a similar strand structure, which is not only tight, but also has a smooth appearance and less hairiness. And it is difficult to produce hairiness during pilling process. As a result, the overall appearance is not easy to pilling. As Hearle said, the interaction force between fibers affects the generation of new hairiness, which determines the degree of difficulty in pilling.  

The effects of fabric structure parameters on pilling propensity

The effects of warp and weft density, and fabric cover factor on pilling performance are discussed respectively. The specifications of the specimens are shown in Table 2. Fabric cover factor of fabrics is the percentage of the projected area of yarn to the fabric area, which is determined by warp cover factor $E_T$ and weft cover factor $E_W$. The formula of fabric cover factor is as follows.

$$E_T = d_T \times P_T$$  

$$E_W = d_W \times P_W$$  

$$E = E_T + E_W - 0.01E_T \times E_W$$  

Where $d_T$ is the diameter of warp yarn, mm; $d_W$ is the diameter of weft yarn, mm; $P_T$ is the warp density, N/10 cm; $P_W$ is the weft density, N/10 cm.

Figures 6 and 7 show pilling grades of different warp density and weft density when the number of pilling rubs is 125, 500, 1000, 2000, and 5000, respectively. It can be noted from Figures 6 and 7 that pilling grades increase when warp and weft density increase. The reason may be that with increasing of density, yarns are arranged more closely, and the number of yarns interlacing points per unit area is increased. The friction between fibers increases. It is less likely to slip out from fabric surface to form hairiness, which makes it not easy to form pills. Therefore, the effect of warp and weft density on pilling performance stem from frictional cohesion between fibers.

Figure 8 represents the effects of fabric cover factor on pilling performance. Fabric cover factor is from 103.9% to 119.3%, and pilling grades are measured after the number of pilling rubs is 125, 500, 1000, 2000, and 5000. It can be observed from Figure 8 that effect of fabric cover factor on pilling performance is complicated. It shows a cyclical decrease and increase discipline. This may be associated with the discrete proportional increasing of warp and weft density. The first reduction of pilling grades is responsible for 30% increase in warp density, and 60% increase in weft density. The increase in the weft density by beating is higher than that of warp density. It makes yarn hairiness and pilling become severe. The initial increase of pilling grades is attributed to fabric cover factor which is mainly increased by warp density. At this time, only the tightness between yarns is increased and the frictional resistance between fibers is increased. It makes the fibers hardly slipping out from the fabric surface. The second reduction in pilling grades is due to the increase in fabric cover factor,
which is increased by the reduced weft density. It leads to a decrease in the interlacing point per unit area on the fabric. The fibers are more apt to slip out from the fabric surface to form hairiness, which makes pilling severe. The subsequent increase in the number of pills is due to the fact that only the warp density is increased at this stage. The higher the warp density is, the more difficultly the fibers slip out from the fabric surface. It can be seen that the effect of fabric covering factor on pilling is due to the change of warp and weft density. Moreover, the effect of warp and weft density on pilling performance is attributed to the frictional force between fibers.

**The effect of fabric singeing on pilling propensity**

The effect of singeing on pilling propensity was also studied. The results are illustrated in Figure 9. Figure 9(a) is a SEM image of the surface of polyester-cotton blended woven fabric after singeing. Many small round head can be seen. These small round head are the broken ends of singed polyester fibers. Figure 9(b) is a SEM image of a broken head of polyester fiber at 800 multiples of magnification on the surface of singed polyester-cotton fabric. It can be obviously seen from Figure 9 that polyester fiber does not bond with the surrounding fibers after being singed, and the diameter of the broken ends of polyester fibers is larger than the original diameter. The reason may be that the speed of the locomotive is very fast during singeing. It makes the burning polyester fiber cool down very quickly without enough time to bond with the surrounding fibers. On the other hand, polyester fiber is a kind of chemical fiber. The singed polyester fibers form an

**Table 2. The specification of samples.**

| Sample no | $P_t$ (N/10 cm) | $P_w$ (N/10 cm) | Fabric cover factor (%) |
|-----------|----------------|----------------|------------------------|
| 1         | 335            | 185            | 104.1                  |
| 2         | 394            | 185            | 111.7                  |
| 3         | 453            | 185            | 119.3                  |
| 4         | 394            | 224            | 107.8                  |
| 5         | 394            | 264            | 103.9                  |

**Figure 6.** The effect of warp density on pilling grades.

**Figure 7.** The effect of weft density on pilling grades.

**Figure 8.** The effects of fabric cover factor on pilling.
isolated round head, which are larger than the original diameter.

After singeing, the fabric was dismantled, and polyester fibers with small round head were taken out to test the diameter, length and bending stiffness of these fibers. The diameter of these fibers was measured by automatic fiber fineness tester (DHU-10). The bending stiffness of these fibers was measured by single fiber compression bending instrument (JQW03C). The results are presented in Table 3. It can be seen from Table 3 that the diameter and bending stiffness of fibers with small round head is larger than original polyester fibers. And the length is shorter. So these fibers are less able to entangle with the surrounding fibers.

Figure 10 is pilling grades after singeing. It can be seen from Figure 10 that pilling grade of the singed fabric is significantly higher than that of the non-singed fabric. This happens because singeing can remove effectively the majority of hairiness on the fabric surface. The bending stiffness and diameter of the residual polyester fibers on the fabric are larger while the length is shorter. So the fibers are not easy to entangle and form pills.

Analysis of pilling mechanisms

The effects of yarn twist, spinning method, the warp and weft density, fabric cover factor and fabric singeing on pilling performance have been studied. The results demonstrate that the above factors have important effects on the pilling propensity of polyester-cotton blended woven fabrics. The effects are embedded in the degree of difficulty in forming hairiness when fibers are exposed to the fabric surface, the degree of difficulty in forming pills when hairiness is entangled, and the degree of difficulty in falling off pills. Therefore, the essence of pilling is that fibers are exposed out from the fabric surface to form fuzz, and entanglement between fuzz forms a pill. And then the pills fall off. Therefore, the formation of hairiness on the fabric surface and the interaction between the hairiness is the essential causes of pilling.

Table 3. Comparison of polyester fiber performance after singeing.

| Fibers                        | Diameter (µm) | Length (mm) | Bending stiffness (cN·cm²)/tex² |
|-------------------------------|---------------|-------------|--------------------------------|
| Original polyester fibers     | 14.8          | 34          | $5.82 \times 10^{-4}$           |
| Polyester fibers with small round heads | 20.4          | 25          | $6.43 \times 10^{-4}$           |
In order to further study the formation process of fuzzing and pilling of polyester-cotton blended woven fabrics, the best anti-pilling fabric is selected. Pilling grade of this fabric is 4.8. Yarn is spun by siro-compact method, yarn twist is 950T/m. Warp density is 394 N/10cm. Weft density is 264 N/10cm. Fabric cover factor is 103.9%, and fabric is singed. The fabric is defined as specimen 6.

The relationship between the number and length of hairiness of specimen 6 was analyzed. The curves were showed in Figure 11. The number of hairiness represents the number of hairiness per cm². The expression of the number and length of hairiness at different pilling times are illustrated in the formula (4) to (7). It can be seen from these formula that when the pilling rubs are between 125 and 500, the hairiness length with the largest number of hairiness is 7.1 mm. When the pilling rubs are between 500 and 1000, the hairiness length with the largest number of hairiness is 7.7 mm. When the pilling rubs are between 1000 and 2000, the hairiness length with the largest number of hairiness is 7 mm. When the pilling rubs are between 2000 and 5000, the hairiness length with the largest number of hairiness is 5.5 mm. And the largest number of hairiness per cm² is 25.8, 26.9, 10.4, and 65.2, respectively. The frequency distribution is approximately given by the Gauss distribution. The average correlation coefficients of Gauss distribution is 0.87.

\[ y = 4 + 21.8 \times e^{(-2y^2 / 5)} \]  
\[ y = 2.9 + 24 \times e^{(-2y^2 / 0.8)} \]  
\[ y = 1.7 + 8.7 \times e^{(-2y^2 / 5.5)} \]  
\[ y = 5.6 + 59.6 \times e^{(-2y^2 / 5.8)} \]  

Figure 12 is pilling grades of specimen 6 with different pilling rubs. It can be seen from Figure 12 that pilling grades gradually reduced when the number of pilling rubs increases.

In order to analyze qualitatively the respective functions of polyester hairiness and cotton hairiness during pilling process, the morphology of hairiness and pills of polyester woven fabric, cotton woven fabric and polyester-cotton blended fabric is analyzed. After the number of pilling rubs is 5000, the morphology is measured. The results are shown in Figures 13 to 15.

It can be observed from Figure 13 that the pill still exists relatively well on the surface of polyester woven fabric and is not easy to fall off. The reason may be that polyester fiber is strong in the process of pilling, which makes it difficult to fatigue. And it is very easy to entangle between polyester hairiness.

It can be observed from Figure 14 that the hairiness of cotton woven fabric is almost completely broken and no
Pills of specimen 6 were cut off after pilling rubs are 125, 500, 1000, 2000, and 5000, respectively. And the mass of polyester fibers and cotton fibers in pills was tested by ISO 1833-11:2006 in order to analyze quantitatively the respective roles of polyester fibers and cotton fibers. The mass of pills and the mass of polyester fibers and cotton fibers in pills are showed in Figure 16. It can be observed in Figure 16 that the mass of pills, polyester fibers, and cotton fibers increase with the increasing of pilling times. This is explained by the fact that the number and volume of pills on the fabric surface increase gradually. And the mass of polyester fibers is about 66% of total mass. Mass ratio of cotton fibers is about 34% of total mass. Mass ratio of polyester fibers is bigger than blended ratio. The reason may be that cotton fibers are more fragile. They are more easily prone to be broken and be wrapped by polyester fibers.

**Conclusion**

In this paper, six factors which influence pilling performance of fabrics are yarn twist, spinning process, warp density, weft density, fabric cover factor and fabric singeing, respectively. Their effects on the pilling propensity of polyester-cotton blended woven fabrics are investigated. And the factors for the best anti-pilling fabrics are that yarn twist is 950 N/m, the spinning method is siro-compact method, the warp density is 394 N/10cm, the weft density is 265 N/10cm, fabric cover factor is 103.9%, and the fabric should be singed.

By analyzing the formation of hairiness on the surface of the fabric and the relationship between the number and length of hairiness, the pilling essence and performance of the polyester-cotton blended fabric are revealed. The hairiness distribution is approximately taken by Gauss distribution. The cotton hairiness which easily fatigues after rubbing is entangled in the pills by the stronger polyester fibers.
hairiness which is not easily broken. Polyester anchor hairiness makes the pills difficult to fall off, resulting in an increase in the number of pills. And the mass ratio of polyester fibers and cotton fibers in pills is nearly 66%/34%.

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ORCID iD
Qi Xiao https://orcid.org/0000-0002-5515-1514

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