Mechanism and Optimization of Pilling Propensity of Wool Fabric Drying in Dryer

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Abstract. In order to explore the pilling mechanism of fabrics drying in domestic dryers, the pilling propensity and surface morphology of wool fabrics after drying were intensively investigated and compared under different rotating-drying models with help of pilling box and Scanning Electron Microscope (SEM). Results showed the pilling mechanism of wool fabric drying in dryer is not temperature mechanism but rotating-drying models (mechanical movement models of drum) mechanisms. Therefore, the model of alternating clockwise and counterclockwise rotating-drying in dryer should be regarded as appealing rotating-drying model for the wool fabrics drying in dryer.

1. Introduction
Wool fabrics are widely used in commodity or luxury apparels owing to its remarkable properties like warmth retention, resiliency, comfort, and wide aesthetic qualities [1-3]. However, wool fabrics easily form pilling during wear and care (washing and drying), and then becomes an undesirable phenomenon that affects the hand and the appearance of garments [4-6]. This is because clothes are permanently subjected to friction of themself or other objects of day life during use [3,7,8]. The long-term abrasion leads to damage fibers, yarn and structures of fabric [9,10]. In other words, abrasion significantly affects pilling of fabric surface. While fabric drying in dryer is a process that involves continuous abrasion and mechanical actions such as beating, falling, entanglement and rubbing of fabric itself, aggressive agitator actions, repeated actions by high temperature and humidity air flow [11-13]. Hence, it is necessary to systematically investigate or well define the mechanism and factor of pilling propensity of wool fabric drying in dryer to reduce pilling propensity of wool knit fabric drying in daily care.

In addition, a series of previous study have reported the mechanism of pill formation and the factors of affecting pilling of fabric including fabric structure, fiber characteristics, process and technology of finishing, but results of these studies did not fully explain pilling mechanism of wool knitted fabric in the drying process due to characteristics of drying environment in drum [14-16]. However, few studies published in the literature can fully explain pilling mechanism of wool knitted fabric in the drying process due to characteristics of drying environment in drum. Therefore, the mechanism of pilling formation of wool fabric drying in dryer was systematically investigated and clarified in this study.
2. Experiments and Methods

2.1. Materials
100% wool knitted fabrics were used to study the factors and mechanism of pilling of wool fabric after drying, and further details about sample as shown in Table 1.

Table 1. Experimental material used in the study.

| Fabric content | Fabric structure | Fabric density (picks/cm) | Yarn linear density (Tex) | Twist (m⁻¹) | Mass/unit area (g/m²) | Thickness (mm) |
|----------------|------------------|--------------------------|--------------------------|-------------|----------------------|---------------|
| 100% wool      | Interlock stitch | 28                       | 11×2                     | 630         | 740                  | 165.5         |

2.2. Washing Pretreatment and Drying Test
In order to obtain the initial moisture content of fabric 70.0% ± 5%, specimens were prepared by soaking in tap water for 15 minutes in an automatic washing machine (MD80-1407LIDG, little Swan, Wuxi, China) followed by a spin cycle of 5 minutes with a speed of 1000 rpm as shown in Table 2. After the specimens were wash-prepared, they were dried in a dryer that was modified and established by using the current traditional domestic clothes dryer on the market (GDZ10-977, Haier, Qingdao, China) for the purpose of understanding the impact of different rotating-drying models on pilling propensity and drying efficiency. Drying parameters were listed in Table 3.

Table 2. Washing pretreatment parameters.

| Prewashing treatment | RSM* (rpm) | Rinsing time (min) | Dehydration time (min) |
|----------------------|------------|--------------------|------------------------|
| Single rinse and dehydration | 1000      | 15min              | 5min                   |

*is rotating speed of washing drum.

Table 3. Parameters of drying experiment.

| Test | Load (g) | IMC (%) | Power (W) | AV (m/s) | RSM (rpm) | RSD(rpm) |
|------|----------|---------|-----------|----------|-----------|----------|
| 1#   | 1493     | 69.5    | 0         | 0        | 0         | 0        |
| 2#   | 1490     | 68.7    | 4000      | 6.8      | 0         | 0        |
| 3#   | 1501     | 70.2    | 4000      | 6.8      | 1100      | 42-48    |
| 4#   | 1503     | 68.7    | 4000      | 6.8      | 1100/11000| 42-48/42-48|

1# is the model of hang drying in ambient; 2# is the model of static hang drying in dryer; 3# is the model of single clockwise rotating-drying in dryer; 4# is the model of alternating clockwise and counterclockwise rotating-drying in dryer. IMC is intimal moisture content of fabric; AV is air flow velocity; RSM is rotating speed of motor; RSD is rotating speed of drum.

2.3. Test Methods

Pilling test Pilling performance of wool fabrics after drying under different rotating-drying conditions was evaluated by standard testing method for pilling, EN ISO 12945-1 (ICI pilling box method).

Scanning Electron Microscope (SEM) the surface morphology of wool knitted fabrics after pilling was examined by the JSM-5310 Scanning Electron Microscope. In order to avoid wool discharge, all samples were sputter-coated with gold prior to the observation. And operating acceleration voltage of 10 kV is adopted in test.

3. Results and Discussion
Table 4 shows the variation of pilling grade observed for samples after different rotating-drying models. It is clear that the model of rotating drying has a dramatic effect on the degree of pilling: Wool fabric drying by the model of single clockwise rotating-drying condition exhibited the worst appearance (pilling grade=2.0) compared with other three drying models in our study, with only severe
fuzzing on the fabric surface as shown in Figure 1 (c) (g) (k); the pilling grade of wool fabric after alternating clockwise and counterclockwise rotating-drying in dryer (pilling grade=3.0) slightly increased pilling propensity of wool fabric drying compared with other two models of hang-drying in ambient and static hang-drying in dryer (pilling grade=3.5), with only slight pilling on the fabric surface as shown in Figure 1 (d) (h) (i). This is because drying is a process of persistent agitation of fabric (Figure 2 and Figure 3), which inevitably causes migration of fibers. The migration of individual fibers in drying process is irreversible owing to interlocking of the scale structure and the directional frictional effect (DFE) of wool fibers, resulting into entangling of pull-out fibers on the fabric. And as drying proceeded, migration of the tip-to-root direction increased significantly. Additionally, compared with the model of clockwise and counterclockwise alternatingly rotating-drying in dryer, pilling grade of wool fabric after drying by the model of single clockwise rotating-drying was reduced one grade. This is because the model of alternating clockwise and counterclockwise rotating-drying in dryer greatly eased entanglement of the fabric forming in drying process. Because long-term entanglement maybe lead to fiber mobility by changing the Young's modulus, the torsional modulus, bending rigidity, torsional fatigue and biaxial fatigue of wool fibers which are associated with the mechanisms of pills, and hence rotating-drying model in drying drum affects pilling of wool fabric drying.

In addition, combined with Table 5, more drying time was need, when using the model of single clockwise rotating-drying in dryer. This indicated that more mechanical (drying) agitation and forces in the drying process was subjected to fabric, therefore increased fibers migration and entanglement. Therefore, it is easy to see that rotating-drying model is a more important factor than air temperature for the pilling of fabric. This can be attributed more to the input of energy by agitation, which leads to the transformation of force applied on fabric surface, and then increases pilling propensity of fabric. On contrary, after alternating clockwise and counterclockwise rotating-drying in dryer, pilling propensity of wool fabric developed slowly as the result of low frequency of twisting, appropriate acting force and direction. It can be inferred that the model of alternating clockwise and counterclockwise rotating-drying in dryer is optimal drying model for wool fabric drying.

### Table 4. Pilling grades.

| 100% wool knitted fabric | Rotating-Drying model | 1# | 2# | 3# | 4# |
|--------------------------|-----------------------|----|----|----|----|
| Pilling grade            |                       | 3.5| 3.5| 2.0| 3.0|

### Table 5. Results of energy consumption and time consumption under different drying conditions.

| Drying test | Energy consumption (KW·h) | Drying time (min) | Final moisture of fabric (%) |
|-------------|---------------------------|-------------------|-------------------------------|
| 1#          | 0                         | 1680              | 5.67                          |
| 2#          | 4.78                      | 120               | 2.98                          |
| 3#          | 2.67                      | 35                | 2.47                          |
| 4#          | 2.56                      | 30                | 2.87                          |
Figure 1. SEM images for 100% wool knitted fabric drying after different rotating-drying models at different magnification: (a) – (d) the detailed images for wool fabric surface (50X) of each model, respectively; (e)–(h) the detailed images for yarn (150X) of each area, respectively; (i)–(l) the detailed images for single fiber (500X) of each area, respectively.

Figure 2. Conceptual diagrams on anchor models of fibers.

Figure 3. Conceptual diagrams on entanglement models of anchor-fibers.

4. Conclusions
The pilling mechanism and factor of wool knitted fabric drying in dryer was rotating-drying model rather than air temperature with scanning electron microscopy (SEM) observations and pilling test. And founded that pilling properties of wool fabric after drying greatly depended on the surface morphology of fabric, yarns and fiber. In addition, the model of alternating clockwise and counterclockwise rotating-drying in dryer not only significantly reduced the pilling propensity of wool.
knitted fabrics (1.0 grade), but also saving energy consumption (4.29%) and drying time (16.7%) compared to the conventional model of single clockwise rotating-drying in dryer. The model of alternating clockwise and counterclockwise rotating-drying in dryer was therefore the most appropriate rotating-drying model for wool fabric drying in dryer. Meanwhile results from this study were helpful in development of new drying product and daily care of wool fabric.

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