EFFECT OF WEAVE STRUCTURE ON PILLING RESISTANCE OF WOVEN FABRICS AT VARIOUS WASHING INTERVALS

Mehreen Ijaz*
Department of Home Economics, Lahore College for Women University, Lahore, Pakistan
**Corresponding author: Mehreen Ijaz > mehreenijaz@hotmail.com*

Abstract
This study determines the pilling resistance of woven fabrics, made with plain, basket, rib, twill, and satin weaves, following several launderings and rubbing cycles. Fabrics with different fibre compositions, including 100% cotton and cotton-polyester blends, were subjected to 0, 3, and 5 washing and 50, 100, 150, 200 and 250 rubbing cycles to determine their pilling behaviour in accordance with ASTM D 4970 test standard. The plain weave constructed of a cotton-polyester blend (B1) had the best pilling resistance due to its tight interlacement and strong polyester component. Satin weave specimens performed poorly, disintegrating quickly due to long yarn floats, which caused yarn slippage and increased friction. Twill weaves, famed for their diagonal patterns, had good abrasion resistance, whereas basket and rib weaves, with their looser structures, were more prone to pilling. The findings indicate that fibre blend and weave structure play important roles in fabric durability. Polyester blends and tightly woven structures, including as plain and twill weaves, are more resistant to pilling, making them perfect for applications that require high durability.

Keywords: Pilling; Weave; Plain; Satin; Washing Cycles

1. INTRODUCTION

Woven fabrics are considered as the most adaptable materials to be worn in all seasons. These fabrics are made by weaving two sets of yarn, one in the lengthwise direction known as warp and the other in crosswise direction known as weft. These fabrics have unique characteristics with different interesting patterns. It is possible to create a variety of patterns, including plain, twill, satin, and others in interlacement. The geometry of the fabric reinforcement is important to obtain the optimal mechanical performance of the materials. Certain characteristics of fabrics such as texture, drape, stability, smoothness, and flexibility are ensured using various weaving techniques [1]. Understanding the mechanical characteristics of woven textiles is crucial for creating and designing clothing and other applications. The most crucial performance factors influencing fabric quality are strength and elongation [2].

By rubbing against another surface, the components of the fabric undergo abrasion, which is a mechanical degradation. Abrasion eventually causes a loss in performance such as reduction in strength, but also has affects the appearance of the fabric. In textile materials, especially woven fabrics, pilling is a serious quality problem that compromises the appearance and durability of the material. It occurs when fibres become tangled during washing, drying, testing, or wearing resulting in pills that protrude outward from the surface of a fabric. When fibres pill, the surrounding strands join this entangled structure and create a more pronounced defect on the surface of the fabric [3]. The tiny fibre balls that adhere to the surface of the fabric are known as pills. These are natural tangles and looks unattractive in the clothing. They take a spherical shape in a result of rubbing [4].

Multiple factors, including fabric construction, fibre type, yarn kind, and washing conditions, have a significant impact on the pilling phenomenon. It is critical for both manufacturers and customers to comprehend and assess the pilling performance of woven fabrics over multiple washing cycles, given the growing demand for long-lasting and durable textiles [5].

When the fibres migrate to the surface and cling to one another to form pills, the result is a hairy surface. Furthermore, foreign materials adhere to them and expand. If an external force is greater than the holding power of the fibre retaining the pill in place, the pill will come away from the surface. If not, Khoddami [6] states that it stays on the surface. Pilling is a serious problem for textile and clothing manufacturers as well as end users since it reduces the product's lifespan [7]. One of the consequences of fabric abrasion is the unsightly look of pilling, which can seriously compromise the fabric's viability for apparel. Fuzz creation, entanglement, its growth, and wear-off are the four stages in a pill's development [8]. Given that synthetic fibres. Since man-made fibres were developed and widely used in textiles, pilling has become an even more critical issue.

Woven textiles are manufactured for a variety of end uses, each with different performance requirements. The chemical and mechanical structures of woven fabric dictate its performance and, ultimately, whether it is suitable for a certain use. Textile material performance evaluation, regulatory compliance, and product quality assessment all depend on fabric testing. It provides information on the physical properties of the woven materials [9].

In recent years, a significant focus on sustainable textiles has resulted in the creation of materials with improved durability and decreased pilling. To help the manufacturers and consumers, textiles must be selected according to its performance and appearance for the end use. This study investigates the relationship between the number of washes and fabric pilling by examining changes in pilling resistance across various laundry cycles.

2. RESEARCH METHODOLOGY

Fabric samples in cotton and polyester with different weave construction were collected and determined for their pilling behaviour. The construction specifications of samples are given in Table 1.

Table 1. Construction specification of prepared specimens

Sample code	Fibre content	Weave structure	Mass (gsm)	Thread count	Linear density (warp x weft)
A1	Cotton-100%	Plain	105	135	11.23 x 12.45
A2	Cotton-100%	Basket	115	114	11.23 x 12.45
A3	Cotton-100%	Rib	136	153	11.23 x 12.45
A4	Cotton-100%	Twill	120	119	11.23 x 12.45
A5	Cotton-100%	Satin	112	105	11.23 x 12.45
B1	Cotton-40% Polyester-60%	Plain	117	113	11.23 x 14.52
B2	Cotton-40% Polyester-60%	Basket	122	102	11.23 x 14.52
B3	Cotton-40% Polyester-60%	Rib	132	98	11.23 x 14.52
B4	Cotton-40% Polyester-60%	Twill	125	115	11.23 x 14.52
B5	Cotton-40% Polyester-60%	Satin	115	105	11.23 x 14.52

Pilling behaviour of fabrics was evaluated following ASTM D 4970 [10]. using Martindale apparatus. The samples prepared by washing to remove impurities on their surface. These were conditioned for 4 hours prior to testing in a standard atmosphere of 21° ±1°C temperature and 65%±2% relative humidity [11].

The specimen from each group of fabrics were cut in circular with the diameter of 1.5 x 5.5 inches. It was ensured that no selvedge, creased or wrinkled area included in the specimen. The specimen was mounted on a circular disk covered with the felt in similar dimensions to the specimen. All the disks were placed into the holders. A weight of 3 kpa was added by applying the pressure, as per the instructions given in the test procedure. The apparatus was turned on and the given number of revolutions were allowed. The face of the specimen was rubbed against the same mounted fabric in a geometric configuration, such as a straight line that widens over time into an ellipse, before tracing the same figure once more under light pressure for a given number of revolutions. The specimens were evaluated at 50, 100, 150, 200 and 250 rubbing cycles and observed in relation to the specimen that was given no revolution. Following scale was used to report on the observed resistance to pilling (Table 2).

Table 2. Assessment scale of pilling

Scale	Indicator
5	No pilling
4	Minimal pilling
3	Moderate pilling
2	Significant pilling
1	Extreme pilling

The samples were washed following AATCC M6 [12] using a front-load machine with 0.1 grams per litre of standardized detergent. The agitation was kept at 45 rounds per minute at a temperature of 52°C for about 11 minutes. The wash cycle was followed by rinsing and spinning. The specimens were tumble dried at 65°C for about an hour. All specimens were given five washing cycles and evaluated for their pilling resistance at 0 wash, after the third wash and after the fifth wash.

3. RESULTS AND DISCUSSION

Three specimens from each group of fabrics were assessed for their pilling at 0-wash, 3rd wash and 5th wash intervals. Statistical analysis was performed using SPSS. The difference between the tested specimens following washing intervals at 0, 3, and wash was calculated using ANOVA. P-value of less than 0.05 was considered as significant (Table 3).

Table 3. Pilling assessment at various washing intervals

	0 wash					3rd wash					5th wash				
Sample	50 C	100 C	150 C	200 C	250 C	50 C	100 C	150 C	200 C	250 C	50C	100 C	150 C	200 C	250 C
A1	5	4	4	3	3	5	4	4	3	3	4	4	4	3	2
A2	5	4	3	3	2	5	4	3	2	2	4	3	2	2	2
A3	4	4	3	3	2	4	3	2	2	1	4	3	2	1	1
A4	5	4	4	3	3	4	3	3	3	2	4	3	3	2	2
A5	4	4	3	3	2	4	3	2	1	1	3	2	1	1	1
B1	5	4	3	3	2	5	4	3	3	3	5	4	4	3	3
B2	5	4	4	3	2	4	4	3	2	1	4	3	3	2	1
B3	5	4	4	4	2	4	3	3	2	2	4	3	3	2	2
B4	5	4	4	3	3	4	4	3	3	2	4	3	3	2	2
B5	4	4	3	3	2	4	3	2	2	1	4	3	2	1	1

It has been clearly observed from the obtained data that all samples gradually lost their performance after each washing and rubbing cycle. This indicates that rubbing accelerates pill formation on the surface of the fabrics. Among all the weaving types, the plain weave B1, made from a blend of cotton and polyester, retained its best appearance up to 5 washes, followed by sample A1, which was also a made following plain weave structure but from 100% cotton fibre. The plain weave B1, outperformed other fibres due to the combined qualities of the cotton and polyester fibres. Table 4 depicts that there is a significant difference among different weave types for their pilling behaviour. Polyester is a synthetic fibre that is resistant to abrasion and wear. The polyester-cotton combination increases the fabric's resilience, decreasing fibre breakage and, consequently, pilling.

Table 4. Statistical analysis of pilling at 0 wash

Source type	Different washes	Type III-Sum of Squares	df	Mean Square	F	p-value
Different wash intervals	Linear	75.56	1	75.56	62.05	0.01

The plain weave structure contributes to the fabric's durability. These fabrics are tightly woven, making them more resistant to surface abrasion than other weaves such as twill and satin. This tightness reduces fibre movement and its breakage, which helps to keep the fabric looking smooth for longer, as seen in both B1 and A1 samples. Fabric woven with insufficient yarn tension has an impact not only on fabric construction but also on fabric qualities. Plain weave is stronger than twill, but twill 2/1 is stronger than twill 2/2. It has high interlacement density that minimizes the fibre exposure to surface abrasion, resulting in fewer free fibres that can produce pills. It has been investigated that textile with long floats, such as satin, are more likely to display higher pilling levels due to the increased chance for yarns to snag on surfaces and suffer friction during use and laundry [13].

Table 5 indicates that there is a significant difference among tested fabrics after three washes. Even the best-performing specimen B1 started to pill after 200 rubbing cycles, which is consistent with the average fabric degradation.

Table 5. Statistical analysis of pilling at 3rd wash

Source type	Different washes	Type III-Sum of Squares	df	Mean Square	F	p-value
Different wash intervals	Linear	92.34	1	92.34	77.56	0.01

Washing introduces several forces, including agitation, water immersion, and detergent contact, all which damage fibres over time. Even strong fibres like polyester can begin to wear after several washes, resulting in pilling. The cotton fibres in the combination also contribute to pilling since they wear down faster than polyester. The friction that occurs during the use of the product and the hydrodynamic forces th at occur during laundery are the immediate sources that affect the pilling behaviour. Fibres migrate to the surface due to their mobility during use and washing, which is one of the indirect causes [14]. The polyester component improves the fabric's durability by adding strength and elasticity to the blend, allowing the cloth to tolerate more cycles without displaying major symptoms of pilling [15].

The satin weave performed the worst among all weaves, degrading significantly with each rubbing and washing cycle. One major cause for this poor performance is the presence of long floats in the satin weave. These long floats provide weak areas in the fabric because they are less firmly interlaced than in other weaves, such as plain weave (Table 6).

Table 6. Statistical analysis of pilling at 5th wash

Source type	Different washes	Type III-Sum of Squares	df	Mean Square	F	p-value
Different wash intervals	Linear	121.98	1	121.98	91.34	0.02

This open structure allows for increased yarn slippage, resulting in faster wear and tear, particularly when subjected to the mechanical stress from rubbing and laundering. In addition, the smooth and lustrous surface of the satin, makes it more susceptible to abrasion. The yarns in satin weave also tend to move more easily, reducing the fabric's durability and increasing the risk of damage over time. These structural properties make satin weave less durable in conditions such as washing and rubbing. It is crucial for fabrics to keep their performance even after repeated laundering. Washing is vital to remove contaminants from materials. Proper washing is crucial for optimal results. Improper execution might have a negative impact on

fabric performance [16]. Another reason is that an increased number of laundry cycles removed the lint from the fabric's surface, resulting in mass loss. Furthermore, the low-quality finishing treatments applied to these materials washed away from the surface during, diminishing their abrasive and tensile strength [17].
Recent research in this field has focused on several parameters that affect pilling performance.
Pilling is caused by two major factors, the type of yarn and the type of cloth. The loose structure of yarn and fibre helps to prevent the formation of fuzz and extra pills [8]. The two best ways to reduce pilling are to increase the denier of polyester and nylon strand or to crop out any projecting fibres through singeing. The former prevents or considerably reduces pilling. Cropping prevents pilling in highly tightly woven textiles, but loosely woven materials continue to pill because rubbing causes more threads to rise to the surface of the fabric, resulting in pills. Increasing the tensions that retain the fibres within the fabric helps to mitigate this effect, but if these forces are exceeded during use, the fabric may pill severely. Frictional forces between fibres can be increased by selecting the suitable yarn and fabric characteristics, as well as applying the appropriate chemical treatment [18, 19].
Researchers [20] investigated the mechanical elements that contribute to pilling in woven textiles, emphasizing the importance of yarn twist and weave pattern in preventing pilling. The compact fabric provides superior abrasion and pilling resistance due to its low hairiness and compact structure [21]. The weave of the cloth can affect its ability to pill. Two-layers form pills faster than one-layer due to their larger length. It has been observed that shorter threads improve fabric pilling performance [22]. Basket weave is the variation of plain weave in which two or more warp and weft threads are intertwined in a crisscross pattern. This structure resulted in a looser weave with greater flexibility and breathability, but it also makes the fabric more susceptible to yarn slippage and pilling due to the reduced number of interlacements [23]. Satin woven fabrics have lesser pilling resistance than twill and plain-woven fabrics [24, 25].
The findings on the pilling performance of various woven textiles after laundering and abrasion cycles are validated by several studies that examined the structural and material properties of fabrics under similar stress conditions [23]. The thin areas in the materials were unable to withstand the pressure produced by abraders. It was found that uneven yarns have inferior abrasion resistance because of their thick and thin portions [17].

4. CONCLUSION

The study shows that fabric pilling is greatly impacted by weave type and fibre composition. Tightly woven fabrics, such as plain and twill weaves, as well as polyester-based fabrics, are more durable after laundering. Satin and basket weaves, with fewer interlacement points, were more susceptible to pilling and abrasion. These findings highlight the role of weave structure and fibre blend in improving fabric performance.

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