# Investigation of the Pilling Behavior of Natural, Regenerated Cellulose and their Blends of Knitted Fabrics with Different Softeners

R.A.D.C.P. Wijerathna
*Textile and Apparel Engineering*
*University of Moratuwa*
Moratuwa, Sri Lanka
181054B@uom.lk

A.D.M.P. Priyadarshani
*Textile and Apparel Engineering*
*University of Moratuwa*
Moratuwa, Sri Lanka
181036X@uom.lk

G.K. Nandasiri
*Textile and Apparel Engineering*
*University of Moratuwa*
Moratuwa, Sri Lanka
gayanin@uom.lk

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*A. Introduction*

The evolution of textiles from basic protection to advanced functionality has led to higher expectations for modern garments, encompassing swimwear, sportswear, and more. While fabric softeners enhance softness by reducing friction and creating a smooth texture, controlling pilling is vital. Pilling, small fiber balls on fabric, is particularly concerning in cellulose-based knitted fabrics. This issue stems from fibers' flexibility and low strength. Innovative methods, including modifying fibers, yarns, constructions, and finishes, target anti-pilling improvement. Softeners, commonly used as finishing agents, affect pilling differently based on type, concentration, and application. Some enhance resistance by reducing fuzziness and boosting fiber cohesion, while others reduce resistance by increasing fiber mobility. Balancing softness and pilling resistance require thorough testing to ensure textile quality aligns with end-user expectations This research will help the textile industry to understand how softeners affect the pilling behavior of cellulose knitted fabrics. Therefore, it's important for textile manufacturers to consider the potential impact of softeners on pilling when developing textile products, and to use appropriate techniques to minimize the pilling effect.

*B. Literature review*

Pilling, the formation of undesirable spherical masses on fabric surfaces due to fiber entanglement, has long been a concern in the textile industry. Although rarely addressed before 1950, it now poses a significant challenge that affects fabric appearance and comfort [1]. Pilling is particularly prevalent in fabrics made from spun yarns of staple fibers, and it arises from abrasion during washing and wearing, prompting textile manufacturers to diligently manage and measure this phenomenon [2]. Research conducted on cellulose fabrics reveals the intricate nature of pilling behavior, shaped by diverse variables such as yarn type, processing methods, and conditions of use. Schindler's investigation, for instance, contends that cotton and rayon fabrics tend to shed pills more readily due to the breakable nature of their fibers [2]. However, a study by Nilgün et al. counters this notion, underscoring the potential of specific processing techniques and enzymatic treatments to mitigate pilling tendencies effectively [3].

Central to understanding pilling behavior is the intrinsic character of cellulose fibers. Fiber length and strength play pivotal roles; shorter and weaker fibers exhibit heightened pilling, while longer and more robust fibers tend to generate fewer pills [4]. Fiber orientation within fabric structures also influences pilling, with fabrics featuring unidirectional fiber alignment, such as knits, being more susceptible due to localized stress and friction. Conversely, woven fabrics or those with randomized fiber orientation demonstrate enhanced pilling resistance.

The role of yarn type is crucial, as it significantly impacts fabric pilling. Fabrics spun from open-end yarns commonly exhibit superior pilling resistance compared to those from ring-spun yarns. Moreover, finer yarns, boasting higher twist factors, experience reduced pilling, and fabrics constructed from plied yarns tend to outperform single-yarn fabrics due to enhanced binding and reduced hairiness [5].

Fabric structure is another pivotal factor. Stitch length inversely affects pilling resistance, with shorter stitches resulting in tighter, more resilient structures. Additionally, the impact of fabric finishing processes and surface modifications on pilling behavior cannot be underestimated, as they influence the propensity for fiber entanglement and subsequent pilling formation [6].

Addressing the challenge of pilling, fabric softeners emerge as a noteworthy solution. Diverse classes of softeners, such as cationic, anionic, non-ionic, silicone, and amphoteric variants, offer unique benefits. Cationic softeners, known for their positively charged groups, augment fabric pliability and water absorption. Anionic counterparts improve wettability and antistatic properties. Non-ionic options, lacking charge, necessitate specific application methods. Silicone-based softeners, particularly those with amino-functionalized structures, contribute to fabric softness and lubrication. Amphoteric softeners stand out for their enhanced antistatic and hydrophilic attributes [2].

Empirical evidence confirms that proper utilization of softeners can notably enhance pilling resistance. Fabrics treated with silicone or nano silicone softeners exhibit marked reductions in pilling [7]. Notably, the effectiveness of softeners is intertwined with the crystallinity of fibers; certain fabric types, like Tencel, benefit more from softener applications due to their inherent smoothness [8].

To conclude, the intricate interplay of variables, encompassing fiber characteristics, yarn type, fabric structure, and softener application, collectively determines pilling behavior in cellulose fabrics. Rigorous attention to these factors, coupled with strategic use of appropriate softeners, holds the promise of elevating fabric quality, enhancing comfort, and bolstering visual appeal.

## C. Materials and Methods

The selected regenerated yarns were viscose, modal, tencel, and bamboo and the selected natural cellulose yarns were cotton and combed cotton. A collection of knitted fabrics was manufactured as mentioned in Table I, using those selected yarns, which have been specifically ring-spun to possess the same yarn count of 40 Ne. In addition to that spandex yarns were having the same yarn count of 22 Dtex.

TABLE I. FABRIC COMPOSITION

| *No.* | *Fabric type* | *CPI* | *WPI* |
|---|---|---|---|
| 1 | 95/5 Combed Cotton / Spandex | 65 | 43 |
| 2 | 95/5 Modal / Spandex | 64 | 45 |
| 3 | 95/5 Tencel/ Spandex | 65 | 44 |
| 4 | 95/5 Viscose/ Spandex | 66 | 45 |
| 5 | 60/35/5 Tencel / Modal / Spandex | 68 | 42 |
| 6 | 60/35/5 Bamboo / Cotton / Spandex | 64 | 41 |
| 7 | 60/35/5 Tencel / Viscose / Spandex | 65 | 41 |
| 8 | 60/35/5 Tencel / Cotton / Spandex | 68 | 43 |

These fabrics were produced as single jersey fabrics using a 28 gauge and 30-inch diameter with a single jersey machine. To ensure consistency in the results, the fabrics were knitted with the same fabric parameters, such as 150 gsm, and 2.80 mm stitch length. This controlled approach will provide a solid foundation for comparing the various fabrics produced.

Given that the fabrics under investigation are of cellulosic origin and have a white shade, a bleaching process was applied without the addition of any dyeing chemicals to the dye bath. The dye profiles were adjusted slightly in accordance with the specific characteristics of each fabric type.

Table II shows the softeners selected for this study include cationic, silicone, and non-ionic softeners. These softeners were applied to the fabric samples using the mini padder machine, with varying concentrations of 20g/L, 40g/L, and 60g/L for each softener. This will provide a range of data for analysis and comparison of the effectiveness of the softeners at different concentrations.

After the application of softeners, the fabrics were dried using the mini stenter machine and then conditioned in standard atmospheric conditions at 20 ± 2°C temperature and 65 ± 4% relative humidity for 24 hours. This conditioning process is essential in order to ensure that the fabrics are stable and have reached a consistent state before testing.

TABLE II. TYPES OF SOFTENERS

| *No.* | *Softener title* | *Softener type* | *Appearance* | *Chemical character* |
|---|---|---|---|---|
| 1 | Daysoft SLC NEW | Cationic | White – yellowish thick liquid | Fatty quaternized product |
| 2 | Desil 125 NEW | Silicone | Colourless – light white liquid | Micro-emulsion of modified amino-siloxane |
| 3 | Daysoft WS HP | Non-ionic | White paste | Fatty acid condensation |

The pilling behavior of the fabrics with and without softeners was studied in accordance with the ISO 12945-2:2000 standard, "Textiles - Determination of fabric propensity to surface fuzzing and to pilling - Part 2: Modified Martindale method." This standard provides a standardized method for evaluating the pilling behavior of fabrics and is widely used in the textile industry. The pilling behavior of the fabrics was assessed using a pilling assessment viewer machine under D65 daylight conditions. This assessment was conducted after different numbers of revolutions (500, 1000, 2000) in a Martindale abrasion and pilling tester. The fabric samples were graded according to a 1 to 5 scale, where 1 represents the worst pilling and 5 represents the best pilling. For fixed revolutions in Martindale and Pilling tester machine, three samples were tested for each combination of fabric type, softener type, and concentration of softeners. As an example, for 1000 revolutions, three samples were tested from 95/5 Cotton / Spandex fabric which is treated with 40g/L silicone softeners. And also, three samples from each fabric type were tested without softener conditions. This ensured that the results are representative of the entire sample population and provided a good indication of the pilling behavior of the fabrics with and without softeners. Through analysis of the results of the pilling test, the optimal softener type and concentration for each fabric type can be predicted and identified prior to bulk production in the industry.

## D. Results and Discussion

In the comprehensive analysis of different fabric compositions, their response to various softeners, and the impact of concentration and revolution levels on pilling resistance, a nuanced understanding emerges. When examining the 95/5 Combed Cotton / Spandex fabric, it becomes evident that both the Daysoft SLC cationic and Daysoft WSHP nonionic softeners showcase a commendable edge over the Desil silicone softener in terms of pilling resistance. A notable observation is that the Daysoft SLC softener consistently achieved the highest pilling grade at both 500 and 1000 revolutions, with no discernible variation across different concentration levels. However, as the revolution count reached 2000, it became apparent that a concentration of 60 g/L was the most effective in bolstering pilling resistance compared to concentrations of 20 g/L and 40g/L. Transitioning to the 95/5 Modal / Spandex fabric, a surprising outcome emerged when treated with the Daysoft cationic softener. In this scenario, there was an unexpected lack of discernible impact on fabric pilling behavior for both 500 and 1000 revolutions. Strikingly, the pilling grades with and without the softener were found to be comparable, indicating that the Daysoft cationic softener exhibited little influence on the fabric's pilling resistance in this specific context. In sharp contrast, the application of the Desil softener showcased its potential in reducing pilling resistance for the 95/5 Modal / Spandex fabric. Moreover, as the revolution count escalated, the fabric's pilling resistance displayed a distinct diminishing trend. Shifting focus to the 95/5 Tencel / Spandex fabric, a comprehensive examination revealed consistent behavior between the untreated fabric and fabric treated with the Daysoft SLC cationic softener at concentrations of 20 g/L and 60 g/L for 500 and 1000 revolutions. As revolution levels surged, pilling grades experienced a notable decline due to the additional force exerted during the testing process, resulting in the formation of an increased number of pill balls. Remarkably, the Desil silicone softener showcased lower pilling resistance compared to the other two softeners.

As the analysis extends to the 95/5 Viscose / Spandex fabric, it becomes evident that the fabric's pilling resistance dwindled as the revolution count escalated. Interestingly, the Desil silicone softener, applied at a concentration of 20 g/L, exhibited better pilling resistance at 500 revolutions compared to the other two softeners. Conversely, both the Daysoft SLC cationic and Daysoft WSHP nonionic softeners displayed comparable effects on the fabric's pilling resistance. These softeners seemed to exhibit a more subdued impact on the Tencel/Spandex blend, thereby yielding relatively consistent levels of pilling resistance.

The examination extends to the 60/35/5 Tencel / Modal / Spandex fabric, where the untreated fabric surprisingly showcased better pilling resistance than its treated counterparts. The Daysoft SLC cationic softener, upon application, demonstrated a consistent pilling grade across 500, 1000, and 2000 revolutions, with the exception of the 60 g/L concentration at 2000 revolutions. This particular outcome implies that while the Daysoft SLC softener exhibited limited impact on bolstering pilling resistance, its performance was sensitive to specific concentration and revolution parameters. In contrast, the Desil silicone softener exhibited a different pattern of impact on the fabric. Meanwhile, the Daysoft WSHP non-ionic softener, particularly at a concentration of 60 g/L and for 1000 revolutions, emerged as a standout performer in terms of pilling resistance.

As the exploration delves into the 60/35/5 Bamboo / Cotton / Spandex fabric, an intriguing revelation emerges: the pilling grade of the untreated fabric consistently decreases as the number of revolutions in the Martindale machine increases. In terms of the applied softeners, the Daysoft SLC cationic softener exhibits consistent effects across its various concentrations when subjected to escalating revolutions. In contrast, the Desil silicone softener, in conjunction with this fabric, showcases varied impacts dependent on the concentration employed. Meanwhile, the Daysoft WSHP non-ionic softener's pilling resistance remains relatively consistent across revolution levels and concentrations, save for a notable instance at 1000 revolutions and a 20 g/L concentration.When scrutinizing the 60/35/5 Tencel / Viscose / Spandex fabric, untreated fabric emerges as the frontrunner in terms of pilling resistance, maintaining consistent results across different revolutions. Notably, the Daysoft SLC cationic and Daysoft WSHP non-ionic softeners showcase similar patterns of reduced pilling resistance with increasing revolutions.The examination extends to the 60/35/5 Tencel / Cotton / Spandex fabric, revealing that the Desil silicone softener and untreated fabric exhibit similar pilling grades for 500 and 1000 revolutions. However, deviations become apparent for higher concentrations and revolutions. The Daysoft SLC cationic softener showcases a declining pilling resistance trend with escalating revolutions, notably pronounced at a 60 g/L concentration.

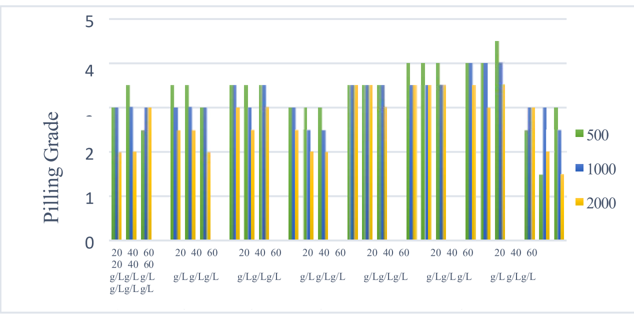


Fig.1. Comparison of pilling grades for Daysoft SLC - Cationic softener

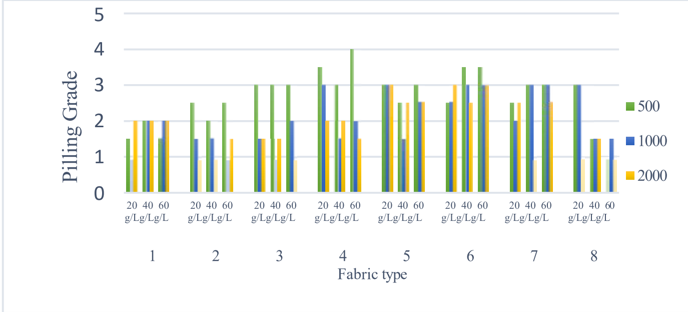


Fig.2. Comparison of pilling grades for Desil 125 NEW - Silicone softener

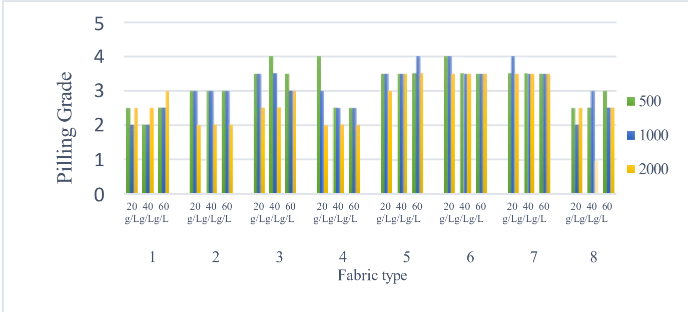


Fig. 3. Comparison of pilling grades for Daysoft WS HP - Nonionic softener

Fig. 1, Fig. 2, and Fig. 3 illustrate a comparative analysis of pilling grades among three different softeners: Daysoft cationic, Desil silicone, and Daysoft non-ionic softeners. The numerical values along the x-axis correspond to the corresponding fabric types as outlined in Table I.

## *E. Conclusion*

The type and concentration of softeners play a crucial role in determining the resistance of fabric to pilling. In this context, the performance of Daysoft SLC NEW and Daysoft WS-HP softeners has been found to surpass that of Desill-silicone based on the specific composition of the fabric and the number of revolutions undergone. By carefully selecting the appropriate softener type and concentration, it becomes possible to achieve improved fabric quality, heightened customer satisfaction, and increased durability of the end product. This underscores the importance of optimizing the choice and amount of softener used in order to enhance overall fabric properties and ensure a higher level of product performance.

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