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Development of a Sustainable Fiber-Padded Hanger Design for Reducing Hanger-Induced Shoulder Deformation and Appearance Loss in Wool Knitted Jackets

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Abstract

In this study, the performance of novel fiber-wrapped hanger designs developed using recycled polyester nonwoven strips was investigated to reduce hanger-induced deformation in women's knitted jackets produced from an 80% Merino wool/20% polyamide blend during retail display and storage conditions. Hangers with fiber-wrapping thicknesses of 5, 10, 15, 20, and 25 mm were developed and compared with a conventional retail hanger and two commercial hanger models (KA3800 and KA3900). Shoulder angle change, mass distribution, fabric elongation, fabric recovery, seam-line deformation, and wrinkle appearance were evaluated as performance parameters. All experiments were conducted with five replicates, and the obtained data were analyzed using one-way analysis of variance (ANOVA). The results demonstrated that fiber wrapping significantly improved load distribution in the shoulder area and reduced deformation-related defects. In particular, the 20 mm and 25 mm fiber-wrapped hangers exhibited the lowest shoulder angle change and seam-line deformation, together with the highest recovery and wrinkle appearance ratings. The findings indicate that the proposed hanger designs provide an effective solution for preserving the dimensional stability and aesthetic appearance of wool-based knitted garments during long-term hanging storage and retail display.

Keywords

Knitted Jacket, Merino Wool, Hanger Design, Dimensional Stability, Wrinkle Appearance, Shoulder Deformation

1. Introduction

Wool-based knit outerwear products are widely preferred in the apparel industry due to their superior thermal comfort, elasticity, bulkiness, and aesthetic appearance. Particularly in 80% Merino wool/20% polyamide blended knitted structures, wool fibers exhibit excellent elastic recovery and shape retention properties owing to their natural crimp. Concurrently, polyamide fibers improve the mechanical strength, abrasion resistance, and wear performance of the fabric.

Knitted fabrics are susceptible to permanent elongation and dimensional changes under long-term loading and hanging storage conditions. This is primarily due to the high flexibility provided by their loop-based structures and the ability of individual loops to reposition under stress. During retail display processes where garments are suspended from hangers, the continuous transfer of the garment weight to the shoulder area causes distortion in loop geometry. This rearrangement behavior, driven by the high elasticity of the loop structure, results in local stress concentrations in the shoulder region and leads to permanent deformations over time. Recent studies on knitted fabric mechanics have revealed that the deformation behavior of knitted structures cannot be explained solely by fiber properties; loop topology, inter-loop contact mechanisms, and load transfer characteristics play a decisive role in the elastic recovery and dimensional stability performance of the fabric [1] [2]. Therefore, understanding the deformation mechanisms occurring during the use and storage of high-wool-content knitwear and developing solutions to minimize these deformations are of critical importance.

In retail stores, jackets and knitwear products are displayed on hangers for extended periods. During this process, the garment weight is continuously transferred to the shoulder area. In particular, narrow-shouldered plastic hangers transmit this load onto a limited contact area, causing sagging, bagging, and hanger marks along the shoulder line. Hangers currently utilized in the industry are mostly made of polypropylene (PP), polystyrene (PS), ABS plastic, or wood, and they focus solely on the load-bearing performance of the product itself. However, a significant portion of these hangers fails to provide load distribution compliant with human shoulder anatomy. It is well known that maintaining dimensional stability in garments is closely linked to the load transfer mechanism.

The hanger-induced deformation problem is particularly crucial for knitwear and knitted garments. Although knitted fabrics possess a higher elongation capacity compared to woven fabrics, they are subject to greater deformation under long-term loading. The literature indicates that the deformations occurring in knitted fabrics are related not only to tensile stresses but also to bending, compression, and inter-loop contact forces. Furthermore, it is stated that the three-dimensional deformation and curling behavior of knitted structures affect the overall form stability of the fabric [3] [4].

Although numerous studies exist regarding the dimensional stability, elongation-recovery behavior, and mechanical performance of knitted fabrics, research investigating the effect of hanger design on garment deformation remains quite

limited. Especially in wool-based knitted outerwear products, the effects of hanger contact area, shoulder support, and load distribution on shoulder sagging have not been sufficiently investigated. Existing studies show that wool knitted fabrics exhibit higher elastic recovery and compression resistance compared to cotton knits, and thus structural support elements are crucial in improving form retention performance [5] [6].

Within the scope of this study, the effects of standard retail hangers used in the industry versus newly developed lightweight and widened hanger designs containing fiber padding of various thicknesses on shoulder deformation and appearance loss were compared. The fiber padding application aimed to increase the contact area in the shoulder region, thereby reducing the load per unit area. By evaluating the effects of hanger types on shoulder sagging, bagging volume, changes in shoulder angle, seam line deformation, fabric elongation, recovery behavior, and wrinkle appearance, the objective was to determine the optimum hanger design for 80% wool/20% polyamide jackets.

2. Experimental Studies

2.1. Materials and Methods

In this study, a women's knit jacket manufactured from an 80% Merino wool and 20% polyamide fiber blend was used. The knit jacket was produced on a 12-gauge (E12) electronic flat knitting machine. The jacket features a Milano rib construction. In the production of the knit jacket, a two-ply Nm 28/2 yarn with a Z/S twist direction, consisting of 80% Merino wool and 20% polyamide, was utilized. The average twist value of the blended yarn was 620 turns/meter (tpm), the average fineness of the wool fibers was approximately 19.5 μm, and the fiber length ranged between 65 and 75 mm. The polyamide (PA 6.6) fibers had a linear density of 1.7 dtex, a breaking strength of 14.5 cN/tex, and an elongation at break of 17.8%.

The weight of the knitted fabric used was determined to be 385 g/m^2, with a thickness of 2.85 mm. The fabric structure contained an average of 14 wales/cm in the horizontal direction and 20 courses/cm in the vertical direction, resulting in a total stitch density of approximately 280 stitches/cm^2. The average loop length was measured at 4.10 mm.

The knit jackets used in the experiments were size M (size 38), and their average weight was measured as 640 g ± 10 g. The shoulder width of the jackets was 39 cm, the back length was 61 cm, and the sleeve length was 58 cm. The technical specifications and details regarding the product are displayed in **Figure 1**.

The experimental groups in the study were established based on the hanger type and fiber wrapping thickness (**Figure 2**). The fiber wrapping material used in the developed hanger designs was obtained through the mechanical recycling of polyester-based fabric wastes, which were generated during garment production and remained unutilized in warehouses. The resulting recycled fibers were converted into a nonwoven structure using the needle-punching method and subsequently applied as a wrapping layer on the shoulder region of the hangers. The developed

nonwoven strips consisted of 100% mechanically recycled post-industrial polyester waste, providing a zero-virgin-plastic padding alternative. Furthermore, the developed padded hangers are designed to be fully reusable in retail cycles and recyclable at their end-of-life. Different experimental groups were created by varying the fiber wrapping thickness to 5, 10, 15, 20, and 25 mm (Table 1).



Figure 1. General views (front, back, side, 45˚ angle, and bottom) and technical specifications of the 80% Merino wool/20% polyamide knitted women's jacket on a conventional retail hanger.

Table 1. Hanger experimental groups.

Group	Hanger Type	Base Shoulder Thickness (cm)	Fiber Padding Thickness (mm)	Objective/Purpose
G1	ST 1001 knitwear hanger	3.5 - 4	0	Standard control
G2	ST 1001 + fiber wrapping	3.5 - 4	5	Low padding
G3	ST 1001 + fiber wrapping	3.5 - 4	10	Medium-low padding
G4	ST 1001 + fiber wrapping	3.5 - 4	15	Medium padding
G5	ST 1001 + fiber wrapping	3.5 - 4	20	High padding
G6	ST 1001 + fiber wrapping	3.5 - 4	25	Very high padding
G7	KA 3800 jacket hanger	5.5 - 7	0	Sector-wide hanger comparison
G8	KA 3900 jacket/coat hanger	7	0	Widest standard hanger comparison

Considering that the garment weight is transferred to the shoulder regions via the hanger under retail display conditions, a load of approximately 3.1 N is applied to each shoulder area. This state of loading can lead to shoulder sagging, hanger marks, and bagging over time, particularly in knitted structures. In this study, the specimens were conditioned for 24 hours at a temperature of 20˚C ± 2˚C and a relative humidity of 65% ± 4%, in accordance with the International Organization for Standardization ISO 139 standard for the conditioning of textile materials. The knit jackets were utilized to compare the shoulder sagging and deformation performance of standard retail hangers against the newly developed hanger designs containing fiber padding of various thicknesses.

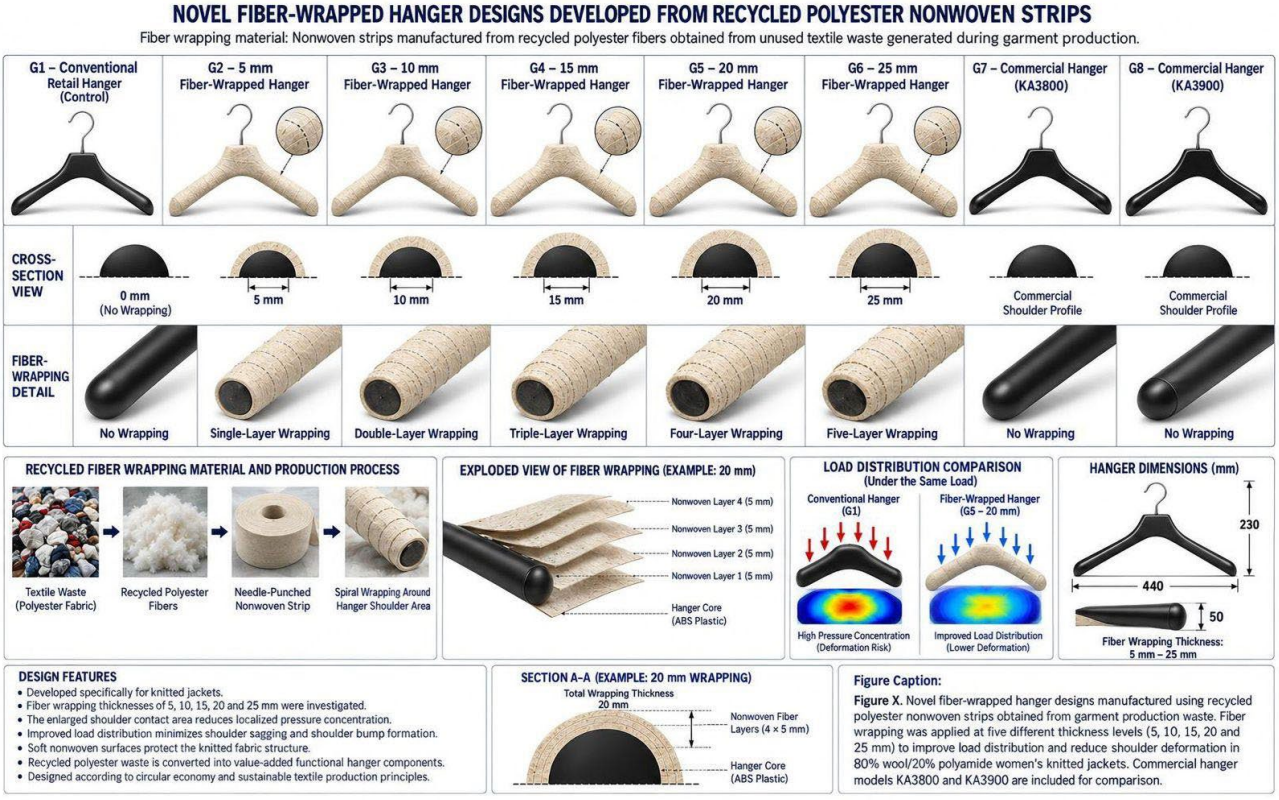


Figure 2. Fiber-wrapped hanger designs of various thicknesses developed using recycled polyester nonwoven strips, and reference hanger models.

The experimental groups in the study were established based on the hanger type and fiber wrapping thickness (**Figure 1**). The fiber wrapping material used in the developed hanger designs was obtained through the mechanical recycling of polyester-based fabric wastes, which were generated during garment production and remained unutilized in warehouses. The resulting recycled fibers were converted into a nonwoven structure using the needle-punching method and subsequently applied as a wrapping layer on the shoulder region of the hangers. Different experimental groups were created by varying the fiber wrapping thickness to 5, 10, 15, 20, and 25 mm (**Table 1**).

Owing to the developed nonwoven fiber wrapping layer, the contact area between the hanger and the garment was increased, thereby distributing the point loads occurring in the shoulder region over a wider surface and reducing stress concentrations. Consequently, this study aimed to limit the impact of hanger-induced load transfer on the knitted fabric structure, thereby minimizing changes in shoulder angle, shoulder sagging, fabric elongation, seam line deformation, and wrinkle formation in the 80% wool/20% polyamide knit jackets. Furthermore, it aimed to develop a sustainable product by utilizing recycled textile waste as a functional component. The developed fiber-wrapped hangers were evaluated by comparing them with a standard knitwear hanger widely used in the industry, as well as with the KA3800 and KA3900 commercial hanger models.

2.2. Deformation Measurements and Statistical Analysis

To determine the effects of the hanger designs on the performance of the knit jackets, parameters including shoulder angle change, load distribution index, hanger-induced elongation ratio, recovery ratio, seam-line deformation, and wrinkle appearance were evaluated.

Shoulder Angle Change (SAC)

The Shoulder Angle Change ($\Delta\theta$) parameter was utilized to quantitatively determine the geometric deformations occurring in the shoulder region. Rather than being a standard textile test method, the shoulder angle change was implemented as a specific geometric parameter developed to quantitatively assess hanger-induced shoulder deformation.

$$\Delta\theta = |\theta_t - \theta_0|$$

where:

- $\Delta\theta$: Shoulder angle change.
- θ_0: Initial shoulder angle.
- θ_t: Shoulder angle after the hanging duration.

Load Distribution Index (LDI)

To determine the intensity of the load applied by the hanger to the shoulder area, the mass distribution was calculated as follows:

$$LDI = W/A$$

where:

- W: Total weight of the knit jacket.
- A: Contact area between the hanger and the shoulder.

The hanger-garment contact area (A) was determined by measuring the geometric boundary of the hanger shoulder profile in contact with the internal seam line of the jacket, multiplied by the perimeter of the hanger cross-section at that region. A lower LDI value indicates that the load is distributed over a wider surface area, thereby minimizing the risk of localized shoulder deformation.

Hanging Elongation (HE, %)

The hanger-induced fabric elongation ratio HE (%) was calculated based on the dimensional change between the initial length (L_0) and the post-storage length (L_t) measured between reference points designated on the shoulder region (ASTM D5035-23):

$$HE(\%) = L_t - L_0/L_0 \times 100$$

where:

- HE (%) = Hanger-induced elongation ratio.
- L_0 = Initial shoulder length.
- L_t = Shoulder length after 30 days of hanging storage.

A decrease in elongation ratios denotes the performance and success of the hanger design in mitigating fabric deformation.

Hanging Recovery Ratio, HRR (%)

The recovery ratio was calculated to determine the extent to which the elongation induced during hanging storage was recovered after a relaxation period. To evaluate the shape-recovery performance of the fabric following hanger-induced deformation, the Hanging Recovery Ratio (Hanging Recovery Ratio, HRR) was computed. Initially, the baseline length (L_0) between specific reference points on the shoulder region was measured, followed by the storage of the specimens on hangers for 30 days. At the end of the storage period, the resulting elongated length (L_t) was recorded, and the specimens were allowed to relax for 24 hours under standard atmospheric conditions. The recovery ratio was determined using the post-relaxation length value (L_r):

$$HRR\ (\%) = L_t - L_r/L_t - L_0 \times 100$$

where:

- HRR (%): Hanging recovery ratio.
- L_0: Initial baseline length.
- L_t: Length after hanging storage.
- L_r: Length after the relaxation period.

Higher HRR values demonstrate that the knitted fabric structure can return to its initial form more effectively after hanger-induced deformation, exhibiting superior dimensional stability.

Seam-Line Deformation (SLD)

The Seam-Line Deformation (SLD) parameter was utilized to evaluate the structural stability of the seams in the shoulder region. The distance between designated reference points along the shoulder seam was measured before and after hanging storage. The dimensional change along the shoulder seam line was calculated using the following equation (ASTM D1683):

$$SLD\ (\%) = L_t - L_0/L_0 \times 100$$

- SLD (%) = Seam-line deformation.
- L_0 = Initial seam length.
- L_t = Seam length after hanging storage.

where L_0 is the initial seam length, and L_t is the seam length after hanging storage.

The equation was modified to accurately reflect the percentage increase in seam length following hanging storage, ensuring consistency with the positive values reported in the results.

Wrinkle Appearance

The wrinkle appearance of the garments was evaluated by a panel of five experts in compliance with the AATCC TM 128 standard. The evaluation was conducted using a 1 - 5 grading scale, where a grade of 1 represents a very poor appearance and a grade of 5 represents an excellent appearance. The final wrinkle appearance value for each specimen was determined by calculating the average of the scores assigned by the experts.

Statistical Analysis

The specimens were suspended on hangers for 30 days under controlled atmospheric conditions of 20˚C ± 2˚C and 65% ± 4% relative humidity. Eight distinct hanger experimental groups were established in the study. To ensure independent observations for the statistical analysis, a total of 40 identical knit jackets from the same production batch were randomly allocated, with five distinct jackets assigned exclusively to each hanger group (n = 5). No jacket was reused across different experimental groups. Statistical evaluation of the obtained data was conducted using the SPSS 26.0 software package.

The normality of the data distribution was verified using the Shapiro-Wilk test, and the homogeneity of variances was confirmed via Levene's test to justify the use of one-way ANOVA. One-way Analysis of Variance (One-way ANOVA) was applied to determine the effects of hanger types on the deformation parameters. For parameters where a significant difference was detected among the groups, the Tukey HSD post-hoc multiple comparison test was employed to identify the source of the variance. For all statistical analyses, the level of significance was set at a 95% confidence interval ($p < 0.05$).

3. Results and Discussion

3.1. Evaluation of Shoulder Angle Change (SAC) Results

According to the results of the shoulder angle change, the hanger type exerts a significant impact on the dimensional stability of the knit jackets (ANOVA, $p < 0.001$). The highest deformation was observed in the standard retail hanger (G1) at 8.14˚, whereas the shoulder angle change decreased progressively with increasing fiber wrapping thickness. The lowest values were obtained with the 20 mm and 25 mm fiber-wrapped hangers at 3.34˚ and 3.14˚, respectively (**Figure 3**).

The obtained results indicate that increasing the contact area in the shoulder region ensures a more homogeneous load distribution and mitigates localized stress concentrations within the knitted structure. This outcome aligns with previous studies reporting that the deformation behavior of knitted fabrics is directly linked to loop geometry and load transfer mechanisms [7]. Furthermore, it has been stated that the dimensional stability of knitted fabrics is significantly

influenced by structural parameters, and deformation can be minimized through appropriate support systems [8].

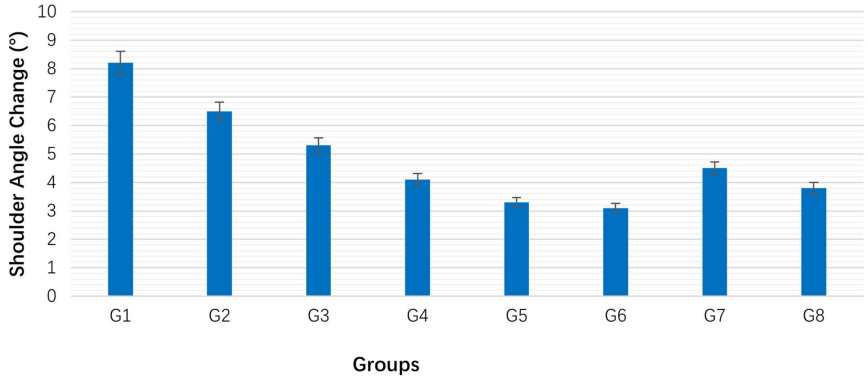


Figure 3. Shoulder angle change results.

Although the KA3800 and KA3900 commercial hangers exhibited lower deformation compared to the standard retail hanger, they displayed higher shoulder angle change values when compared to the newly developed fiber-wrapped hangers. This finding demonstrates that merely increasing the hanger width is insufficient; a soft and compressible support layer is also essential. Conclusively, the 20 mm fiber-wrapped hanger (G5) was identified as the optimum design in terms of both mitigating deformation and material efficiency.

Conclusively, the 20 mm fiber-wrapped hanger (G5) was identified as the optimum design for mitigating shoulder angle deformation. Although the 25 mm padding (G6) offered marginally lower SAC values, the 20 mm variant was selected as the optimum configuration based on a cost-performance and material-efficiency balance, as it minimizes recycled fiber consumption and manufacturing volume while achieving statistical parity in garment protection.

3.2. Evaluation of Load Distribution Index (LDI) Results

ANOVA results indicated that the hanger type exerted a statistically significant effect on the mass distribution across the shoulder region ($p < 0.001$). The highest mass distribution value was obtained with the standard retail hanger (G1; 18.62 g/cm^2), whereas this value decreased significantly with increasing fiber wrapping thickness. The lowest values were measured in the G5 (9.04 g/cm^2) and G6 (8.54 g/cm^2) groups (**Figure 4**).

These results demonstrate that the fiber wrapping application increases the shoulder contact area, thereby reducing the load per unit area. Mitigating stress concentrations in knitted fabrics contributes to limiting loop deformation and dimensional alterations [1] [4]. Although the commercial hangers (G7 and G8) exhibited a lower mass distribution compared to the standard hanger, they displayed higher values than the newly developed fiber-wrapped hangers. This case underscores that a more homogeneous load distribution plays a critical role in controlling deformation in wool/polyamide knit jackets.

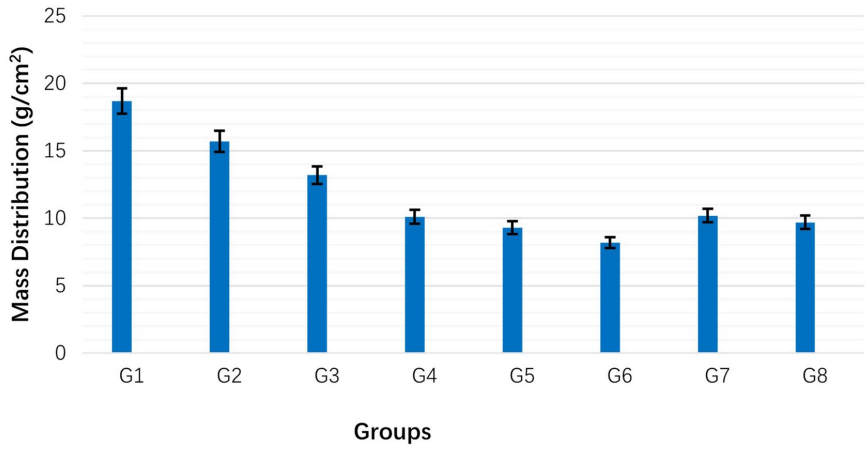


Figure 4. Load distribution index (LDI) results.

3.3. Hanging Elongation (%) Results

According to the fabric elongation ratio results, the hanger type was determined to have a statistically significant effect on the deformation behavior (ANOVA, $p < 0.001$). The highest elongation ratio was measured in the standard hanger (G1; 7.20%), whereas the elongation ratio decreased progressively with increasing fiber wrapping thickness. The lowest values were obtained in the G5 (3.26%) and G6 (3.06%) groups (Figure 5).

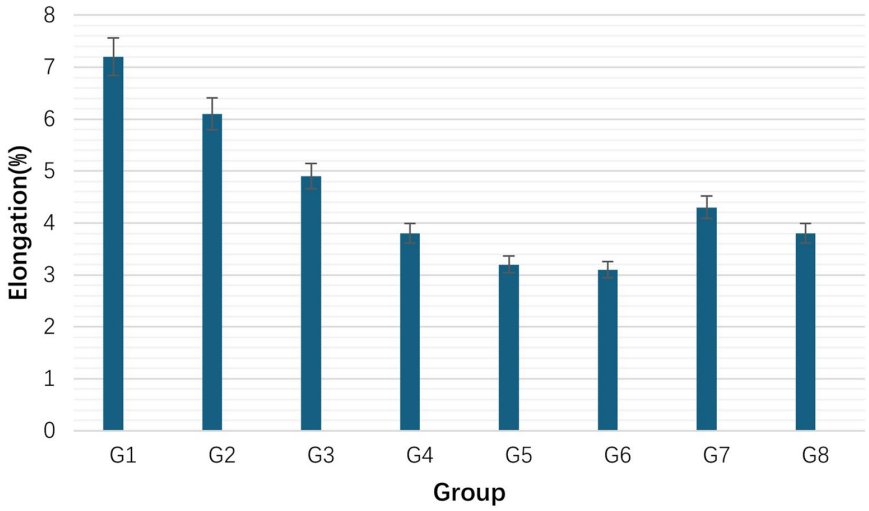


Figure 5. Hanging elongation (%) results.

These findings indicate that the fiber-wrapped hangers distribute the load in the shoulder region over a wider area, thereby minimizing loop deformation within the knitted fabric structure. The elongation behavior of wool-based knitted fabrics under long-term loading is associated with the viscoelastic properties of the fibers and alterations in loop geometry. By increasing the contact area, stress concentrations were mitigated, and the dimensional stability of the fabric was improved. Although the commercial hangers (G7 and G8) showed lower elongation ratios com-

pared to the standard hanger, they were not as effective as the developed fiber-wrapped hangers.

Conclusively, the 20 mm and 25 mm fiber-wrapped hangers significantly minimized the elongation occurring in the knitted structure, demonstrating the most successful performance in retaining the shape of the knit jackets.

3.4. Hanging Recovery Ratio (HRR, %) Results

According to the fabric recovery ratio results, the hanger type had a statistically significant effect on the elastic recovery performance of the knitted fabric (ANOVA, $p < 0.001$). The lowest recovery ratio was obtained with the standard retail hanger (G1, 69.40%), while the recovery ratio increased steadily with increasing fiber wrapping thickness.

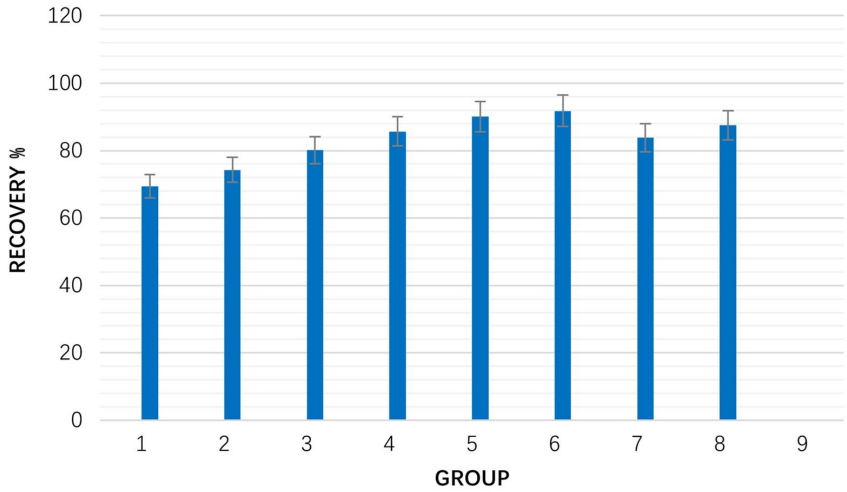


Figure 6. Hanging recovery ratio (HRR) results.

The highest recovery values were measured in the G5 (90.20%) and G6 (91.20%) groups, demonstrating that the deformations occurring in the knitted fabric structure of these groups could be largely recovered (**Figure 6**). The recovery behavior in wool-based knitted fabrics is closely related to the natural elasticity of the fibers and the ability of the loop structure to return to its initial geometry after loading. The concentration of the load within a narrow area on the shoulder region in the standard hanger increased loop deformation, thereby limiting the recovery capacity. Conversely, the fiber-wrapped hangers provided a more homogeneous load distribution by increasing the contact area, which minimized permanent deformations in the loop structure. While [1] reported that stress distribution plays a critical role in preserving loop geometry in knitted fabrics, [2] stated that dimensional stability and elastic recovery in knitted structures are directly influenced by the level of deformation within the fabric matrix. The commercial hangers (G7, 84.20% and G8, 87.20%) exhibited higher recovery performance compared to the standard hanger. However, the developed fiber-wrapped hangers, particularly at 20 mm and 25 mm thicknesses, yielded higher recovery ratios than the

commercial counterparts. Tukey's HSD post-hoc test revealed that while fiber-wrapped hangers performed significantly better than conventional and commercial models ($p < 0.05$), the difference between the 20 mm (G5) and 25 mm (G6) padding thicknesses was not statistically significant ($p > 0.05$). This outcome proves that not only the hanger width but also the soft and compressible support layer used in the shoulder region plays a vital role in mitigating deformation. Consequently, it was determined that the fiber-wrapped hanger designs significantly improved dimensional stability under long-term hanging storage conditions by preserving the garment form of the knit jackets.

3.5. Seam-Line Deformation % (SLD) Results

The seam-line deformation results showed that the hanger type had a statistically significant effect on the dimensional stability of the shoulder region (ANOVA, $p < 0.001$). The highest deformation ratio was identified in the standard retail hanger (G1, 4.16%), whereas a significant reduction in deformation values occurred with increasing fiber wrapping thickness. The lowest values were achieved in the G5 (1.36%) and G6 (1.20%) groups (Figure 7).

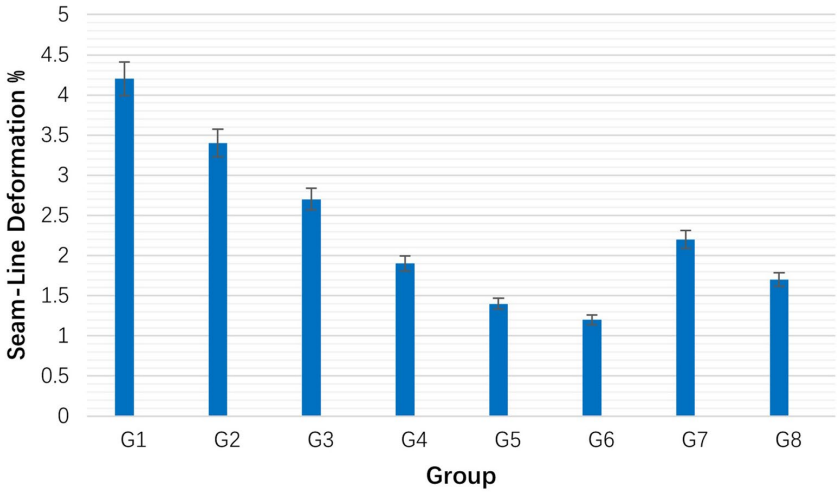


Figure 7. Seam-line deformation (SLD, %) results.

Seam-line deformation in wool-based knitted fabrics is directly associated with the viscoelastic behavior of the fibers and the rearrangement of the loop structure under load. Continuous stress concentrations occurring in the shoulder region during long-term hanging storage can lead to permanent structural modifications along the seam line. The developed fiber-wrapped hangers distribute the load over a wider area, thereby mitigating stress concentrations and enhancing the dimensional stability of the seam line. Similarly, it is well documented in the literature that the deformation behavior of wool knitted fabrics is significantly influenced by load distribution and structural fabric parameters [9]. Although the commercial hangers (G7 and G8) exhibited lower deformation compared to the standard retail hanger, they did not match the performance of the newly developed fiber-

wrapped hangers. These results indicate that a homogeneous distribution of the load across the shoulder area plays a critical role in preserving seam-line integrity in wool/polyamide knit jackets.

3.6. Wrinkle Appearance Rating Results

The wrinkle appearance results demonstrated that the hanger design exerted a statistically significant effect on the surface appearance of the knit jackets (ANOVA, $p < 0.001$). The lowest appearance rating was obtained with the standard retail hanger (G1, 2.20), whereas the appearance ratings increased progressively with increasing fiber wrapping thickness. The highest ratings were measured in the G5 (4.20) and G6 (4.30) groups (**Figure 8**).

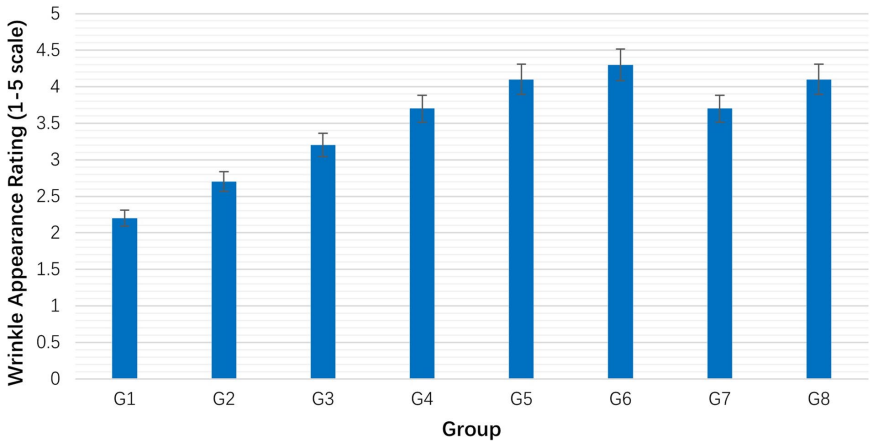


Figure 8. Wrinkle appearance rating results.

Wrinkle formation in wool-based knitted fabrics is fundamentally related to the natural elasticity of the fibers as well as the deformation behavior exhibited by the loop structure under loading conditions. Point loads generated in the shoulder region on standard hangers cause localized elongation along the course lines, resulting in wrinkling and form loss on the fabric surface. Conversely, the expansion of the shoulder contact area provided by the fiber-wrapped hangers allows the load to be distributed more homogeneously, thereby restricting loop deformation. Consequently, a smoother appearance is maintained on the fabric surface.

[10] reported that surface characteristics and knit construction significantly influence fabric performance in wool knits, emphasizing that the mechanical behavior of the knitted structure is directly linked to the garment's appearance properties. Similarly, studies conducted by [9] highlighted the robust relationship between fiber crimp, elastic recovery, and surface smoothness in Merino wool knitted fabrics. When the mode of load transfer to the fabric is altered, the preservation level of the loop geometry changes accordingly, which is directly reflected in the final wrinkle appearance rating.

Although the commercial hangers (G7 and G8) provided higher appearance ratings compared to the standard hanger, they fell short of the performance demon-

strated by the developed fiber-wrapped hangers. The results obtained, particularly in the G5 and G6 groups, show that the wrinkle appearance in wool/polyamide knit jackets depends not only on fiber characteristics but also on the hanger contact area and load distribution profile. Therefore, fiber-wrapped hangers can be considered an effective solution for preserving product appearance during retail display processes.

4. Conclusions and Recommendations

In this study, the effects of hanger designs padded with recycled polyester-based nonwoven fibers on hanger-induced deformations in wool-based knit jackets were investigated. The results demonstrated that the hanger design has a statistically significant effect on the dimensional stability and appearance characteristics of the shoulder region ($p < 0.001$).

The shoulder angle change, measured as 8.14˚ in the standard retail hanger, dropped to 3.34˚ and 3.14˚ for the 20 mm and 25 mm fiber-wrapped hangers, respectively. Similarly, the fabric elongation ratio decreased from 7.20% to a range of 3.26% - 3.06%, while the seam-line deformation regressed from 4.16% to levels of 1.36% - 1.20%. In contrast, the hanging recovery ratio increased from 69.40% to over 90%, and the wrinkle appearance rating reached up to 4.30 from an initial score of 2.20.

The findings indicate that the fiber support layer optimizes the load distribution across the shoulder region, reducing stress concentrations and thereby limiting permanent deformations within the knitted structure. It was determined that the fiber-wrapped hangers offer significant advantages over standard retail hangers, particularly in mitigating shoulder bagging, shoulder sagging, and appearance loss.

In conclusion, the 20 mm fiber-wrapped hanger design was identified as the overall optimum solution due to its superior cost-performance balance, effectively reducing material consumption while providing optimal protection against hanger-induced defects. It is anticipated that this sustainable design can be successfully implemented to control deformation during the retail display and storage processes of high-wool-content knitwear products.

Limitations of the Study and Future Recommendations

Although this study provides robust insights into preventing deformation in knitwear, certain limitations should be acknowledged. The experimental results are restricted to a single garment style (women's jacket), a specific fiber blend (80% Merino wool/20% polyamide), a single machine gauge (E12), and a fixed 30-day storage duration under controlled ambient conditions. Future studies are recommended to investigate the performance of the developed padded hangers on different knit structures, fiber compositions, and extended storage durations.

Author Contributions

Conceptualization: Koçak, D. and Ural, Ö.; Methodology: Koçak, D. and Ural, Ö.;

Validation: Koçak, D. and Ural, Ö.; Formal analysis: Koçak, D. and Ural, Ö.; Investigation: Koçak, D., Ural, Ö., Erdem, D., and Yıldırım, M.; Resources: Koçak, D., Ural, Ö., Erdem, D., and Yıldırım, M.; Data curation: Koçak, D., Ural, Ö., Erdem, D., and Yıldırım, M.; Writing—original draft preparation: Koçak, D. and Ural, Ö.; Writing—review and editing: Koçak, D. and Ural, Ö.; Visualization: Koçak, D. and Ural, Ö; Supervision: Koçak, D. and Ural, Ö.; Project administration: Koçak, D. and Ural, Ö.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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