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A Multifactorial Analysis of the Effect of Washing Temperature Variations on Denim Fabric Performance: Examining Changes in Denim Fabric's Structural, Mechanical, and Aesthetic Properties

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Abstract

Denim fabric, renowned for its durability and cultural significance in fashion, experiences substantial physical and visual transformations when subjected to repeat laundering. Among the various laundering parameters, washing temperature has emerged as a critical factor influencing the long-term performance and aesthetic retention of denim textiles. This study presents a multifactorial analysis aimed at evaluating the impact of washing temperature variations on the structural, mechanical, and aesthetic properties of denim fabric. Standardized laboratory tests were conducted to assess key performance indicators, including dimensional stability (shrinkage), tensile strength, abrasion resistance, pilling resistance, and colorfastness. Denim specimens were exposed to controlled laundering cycles at varying temperatures, followed by evaluations adhering to ISO and AATCC testing protocols. Findings indicate a significant correlation between elevated washing temperatures and detrimental changes in fabric properties, including increased shrinkage, pronounced fading, diminished tensile strength, and surface degradation. In contrast, lower temperature settings were found to preserve dimensional and color stability more effectively, albeit with potential compromises in cleaning efficiency. This research underscores the critical role of temperature management in laundering practices to sustain both the functional integrity and visual appeal of denim garments. The outcomes offer practical implications for textile producers, apparel designers, and consumers aiming to enhance denim longevity through informed care strategies.

Keywords

Denim fabric, washing temperature, Fabric performance, Tensile strength, Abrasion resistance, Pilling resistance, Colorfastness, Mechanical properties, Aesthetic properties, Shrinkage, Fabric maintenance, Sustainable laundering.

1.1 Introduction

Denim is one of the most enduring and iconic fabrics in the global textile industry, widely used in the production of jeans, jackets, shirts, and work wear. Its popularity stems not only from its rugged aesthetic but also from its mechanical strength and long-term wear ability (Bhat and Latif and Shalla 2018). Traditionally made from cotton twill with indigo-dyed warp yarns, denim undergoes significant mechanical and chemical stresses during both manufacturing and consumer use, especially during washing. Among various laundering factors, washing temperature is particularly influential in determining the fabric's longevity, appearance, and physical stability (Jassal and Agrawal 2019).

In practical settings, denim garments are subject to repeated home laundering, which often leads to changes in fit, texture, and color. Manufacturers and consumers alike express concerns about excessive shrinkage, loss of tensile strength, fabric pilling, and dye fading (Behery 2005). These phenomena are not only aesthetic issues but also affect garment performance, comfort, and sustainability. While low-temperature washing is generally promoted as eco-friendly, its impact on cleaning efficiency and fabric maintenance compared to higher temperatures remains under discussion.

Previous studies have investigated the effect of laundering parameters on specific textile properties, but most focus on isolated variables such as colorfastness or shrinkage (Wang and Zhao and Zhang 2020). This study aims to take a multifactorial approach, examining the simultaneous effects of washing temperature variations on a comprehensive set of performance attributes of denim fabric. These include structural properties (like dimensional stability and tensile strength) (Behera and Arora 2018), mechanical performance (abrasion resistance and pilling), and aesthetic outcomes (color retention and surface appearance).

By combining experimental data with visual assessments, this research seeks to provide actionable insights for textile engineers, apparel manufacturers, and environmentally conscious consumers. Understanding how different washing temperatures affect the behavior of denim fabric can inform better product design, laundering recommendations, and fabric care guidelines, ultimately contributing to more sustainable consumption practices in the apparel industry (Chaudhuri 2017).

1.2 Objectives

The specific objectives of the study are as follows-

- **a)** To investigate the influence of varying washing temperatures on the structural properties of denim fabric, including dimensional stability and tensile strength.
- **b)** To evaluate changes in mechanical performance attributes such as abrasion resistance and pilling resistance across different washing temperature conditions.
- **c)** To assess the aesthetic impact of washing temperature variations on denim fabric, particularly focusing on colorfastness and visual surface appearance.
- **d)** To establish correlations between washing temperature and overall fabric performance, identify thresholds beyond which degradation becomes significant.
- **e)** To provide practical recommendations for laundering denim garments that optimize both fabric preservation and washing efficiency.
- **f)** To contribute to sustainable garment care practices by identifying washing conditions that extend denim longevity while minimizing environmental impact.

2. Materials and Methods

Materials

- Fabric Details: 91% Cotton, 8% Polyester, 1% Elastane denim fabric.
- Chemical Used:
  - Sodium Hypochlorite (NaOCl)
  - Acetic Acid
  - Detergent
  - Water
- Machine Description: Yilmak HBM 3860 S Front-Loading Washer
  - Capacity: 200 kg
  - Origin: Turkey
  - Application: Used in garment washing facilities for various treatments, including bleaching.
  - Features: Advanced control systems for precise washing parameters & designed for energy efficiency and high performance.
  -

Washing Conditions

Samples were subjected to repeated laundering cycles at five different washing temperatures: 20°C, 30°C, 40°C, 50°C, and 60°C.0 A front-loading washing machine was used, with a standardized detergent (free from optical brighteners and bleaching agents) and consistent mechanical agitation. Each sample was washed 10 times to simulate consumer-level laundering effects (Daryanto and Pratama and Kartika 2019) (Table 1 and Figure 1).

Washing Recipe

Table 1. Industrial Garment Bleach Wash Recipe.

Component	Quantity (per liter of water)	Purpose
Water	As required (Liq. Ratio 1:5–1:8)	Medium for processing
Sodium Hypochlorite (5%)	2 – 5 g/L	Bleaching agent
Detergent (non-ionic)	0.5 – 1 g/L	Cleaning and wetting
Acetic Acid	1 – 2 g/L (or 1–2 ml/L)	Neutralizing residual bleach
Rewin Soft C-60 (Softener)	0.5% – 1.5% (on weight of fabric/garment)	Improves Hand Feel

Process Sequence

- Pre-wash:
  - Water + detergent
  - Run for 5–10 minutes at 40°C
  - Drain and rinse
- Bleach Wash:
  - Add water (1:5 to 1:8 liquor ratio)
  - Add sodium hypochlorite and detergent
  - Run for 15–25 minutes at 30, 40, 50, 60, 70°C
  - Monitor color fade
  - Drain completely
- Neutralization:
  - Refill water
  - Add neutralizer (acetic acid or sodium metabisulfite)
  - Run for 10 minutes
  - Drain
- Rinse:
  - Cold water rinse 2–3 times
- Softener Finish:
  - Add softener
  - Run for 5–10 minutes
  - Drain and extract
- Drying:
  - Tumble dry or line dry

Testing Methods

- Dimensional Stability (Shrinkage): Measured according to ISO 5077.
- Tensile Strength: Evaluated using ISO 13934-1.
- Abrasion Resistance: Determined via Martindale method (ISO 12947).
- Pilling Resistance: Assessed using ISO 12945-2.
- Colorfastness to Washing: Measured with ISO 105-C06.
- Visual Assessment: Conducted by a trained panel using AATCC grayscale and visual grading standards.

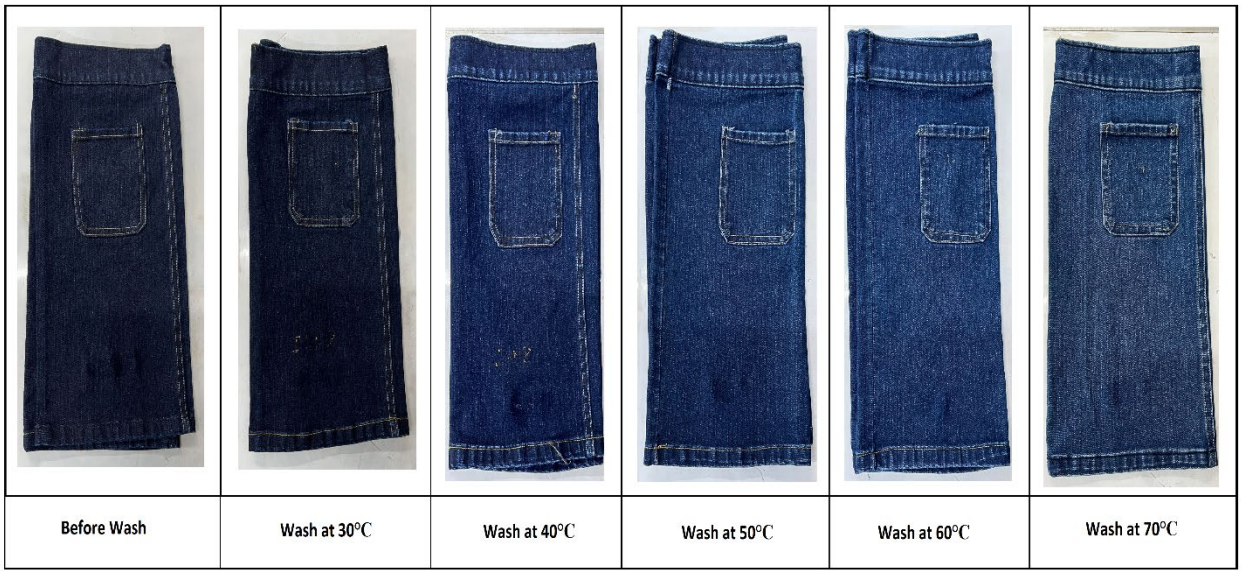

Figure 1. Visual Effect of Different Washing Temperatures on Denim Fabric.

3. Test Data Format

Dimensional Stability

The table titled "Effect of Washing Temperature on Denim Fabric Shrinkage" presents how shrinkage in denim fabric changes with increasing washing temperatures. Both lengthwise (warp) and widthwise (weft) shrinkage values show a clear upward trend as the temperature increases from 30°C to 70°C. The average shrinkage rises steadily from 1.35% at 30°C to 4.85% at 70°C, indicating a nearly linear increase. This behavior is due to enhanced fiber relaxation and contraction at higher temperatures. Elevated temperatures cause the cotton fibers in denim to loosen and then contract more significantly during drying, leading to greater dimensional loss. The consistent remark across all temperature levels reinforces that temperature is a dominant factor influencing fabric shrinkage. In summary, higher washing temperatures substantially compromise the dimensional stability of denim fabrics, and controlling washing conditions is essential to minimize undesired shrinkage (Table 2-7), (Figure 2-7).

Table 2 Effect of Washing Temperature on Denim Fabric Shrinkage

Temperature (°C)	Length Shrinkage (%)	Width Shrinkage (%)	Average Shrinkage (%)	Remarks
30	1.5	1.2	1.35	Shrinkage increases with temperature
40	2.3	2.0	2.15	Shrinkage increases with temperature
50	3.1	2.8	2.95	Shrinkage increases with temperature
60	4.0	3.6	3.80	Shrinkage increases with temperature
70	5.2	4.5	4.85	Shrinkage increases with temperature

Table 3. Effect of Washing Temperature on Tensile Strength of Denim Fabric.

Sample ID	Temperature (°C)	Tensile Strength (Warp) N	Tensile Strength (Weft) N	Average Strength (N)
S1	30	645	615	630
S2	40	625	600	612.5
S3	50	605	590	597.5
S4	60	580	570	575
S5	70	550	540	545

Tensile Strength

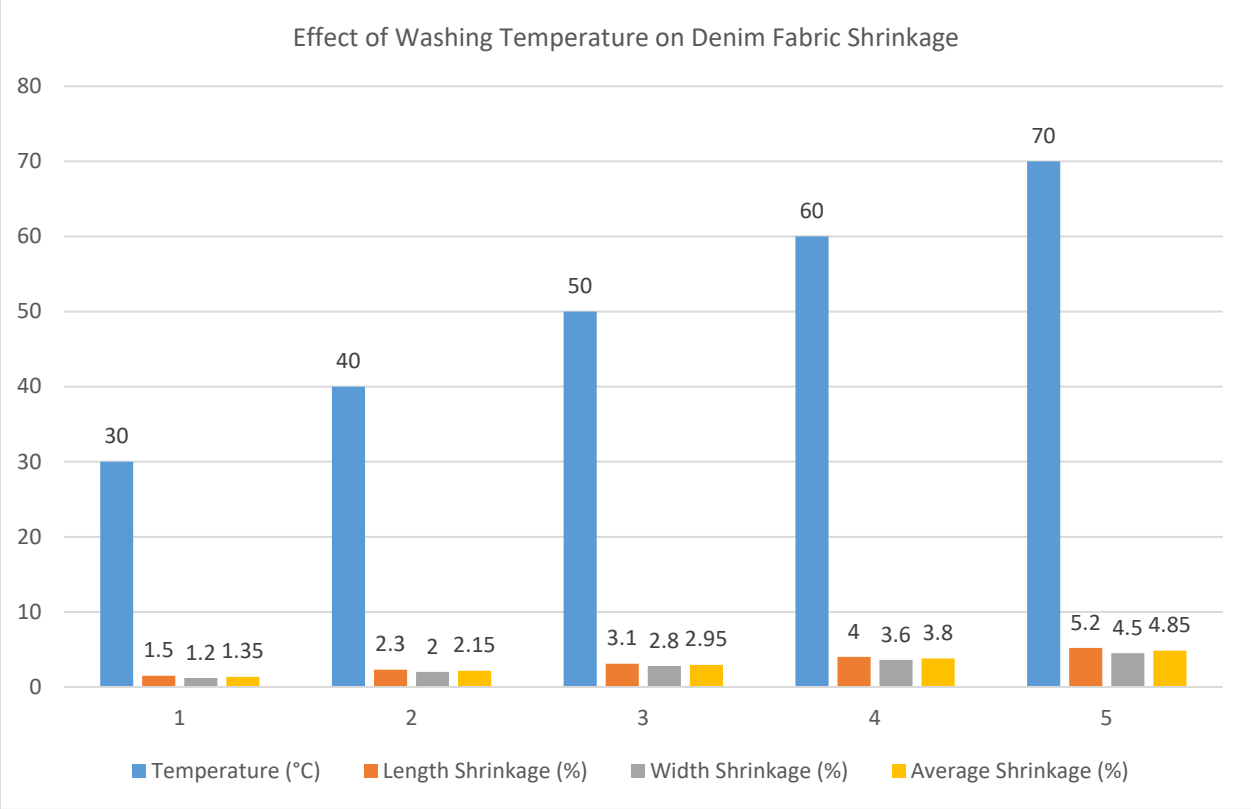

Figure 2. Shrinkage Behavior of Denim Fabric at Different Washing Temperatures.

The table titled "Effect of Washing Temperature on Tensile Strength of Denim Fabric" shows a clear decline in tensile strength as washing temperature increases. At 30°C, the average tensile strength is 630 N, which steadily decreases to 545 N at 70°C. This downward trend is observed in both the warp and weft directions, indicating that elevated temperatures weaken the denim fabric uniformly. The reduction in strength is likely due to thermal and mechanical stress during washing, which leads to fiber degradation, loss of cohesion, and micro-damage within the yarn structure. These effects collectively reduce the mechanical integrity and durability of the fabric. Therefore, It is evident that higher washing temperatures negatively affect the tensile strength of denim, and maintaining lower temperatures is advisable to preserve fabric performance.

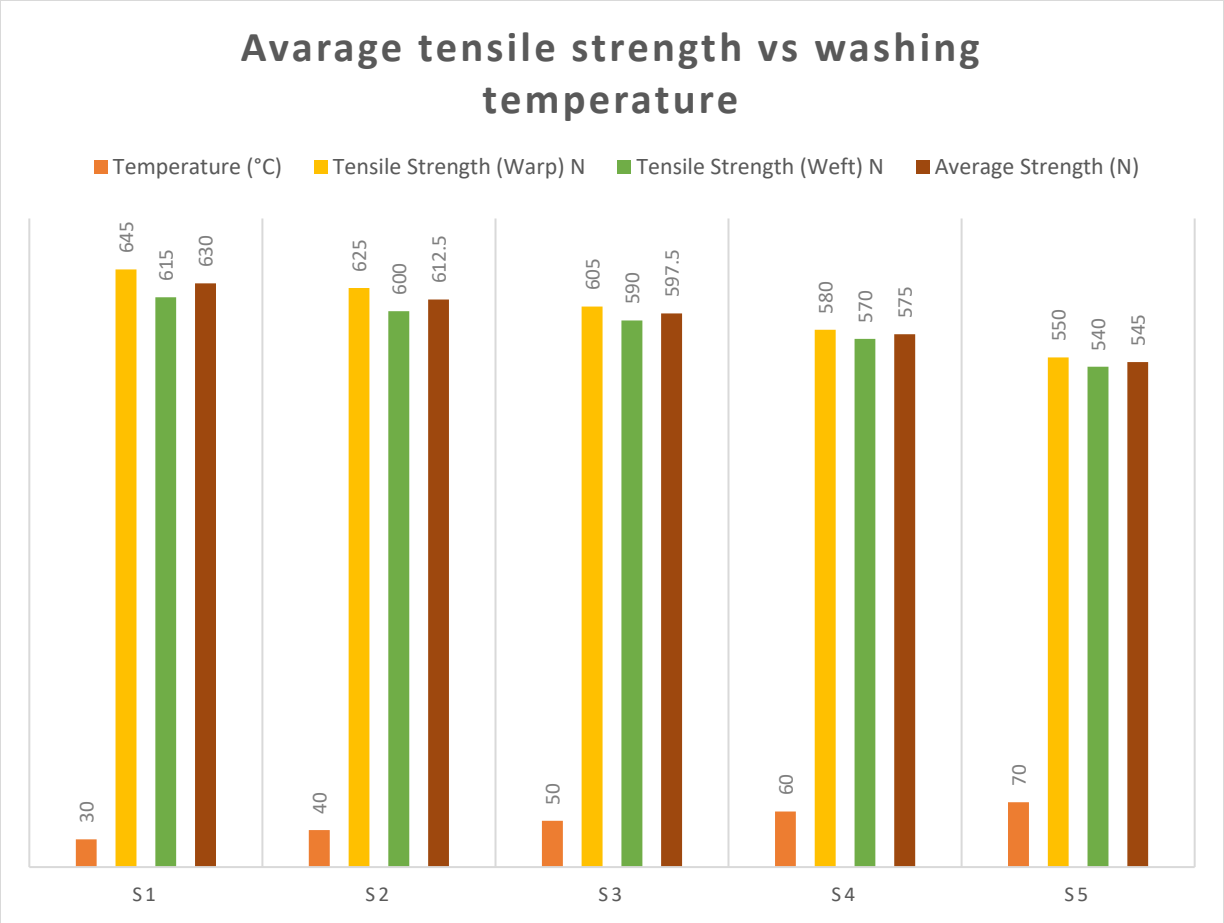

Figure 3. Variation in Tensile Strength of Denim Fabric as Influenced by Washing Temperature.

Abrasion Resistance

Table 4. Effect of Washing Temperature on Abrasion Resistance of Denim Fabric

Sample ID	Temperature (°C)	Abrasion Resistance (Cycles)	Fabric Condition After Test	Remarks
S1	30	32000	Minimal wear	Good resistance at low temp
S2	40	30000	Slight fuzziness	Acceptable performance
S3	50	27500	Visible thinning	Moderate degradation
S4	60	24000	Thread exposure	Significant wear
S5	70	20000	Noticeable holes	Severe degradation

The table titled "Effect of Washing Temperature on Abrasion Resistance of Denim Fabric" summarizes the abrasion resistance of denim fabric at various washing temperatures. As the temperature increases from 30°C to 70°C, the number of abrasions cycles the fabric withstands decreases, indicating a reduction in durability. At lower temperatures (30°C), the fabric exhibits minimal wear, demonstrating good abrasion resistance, while at higher temperatures (70°C), significant degradation such as noticeable holes is observed. This behavior reflects how increased washing temperatures negatively impact the fabric's resistance to mechanical wear.

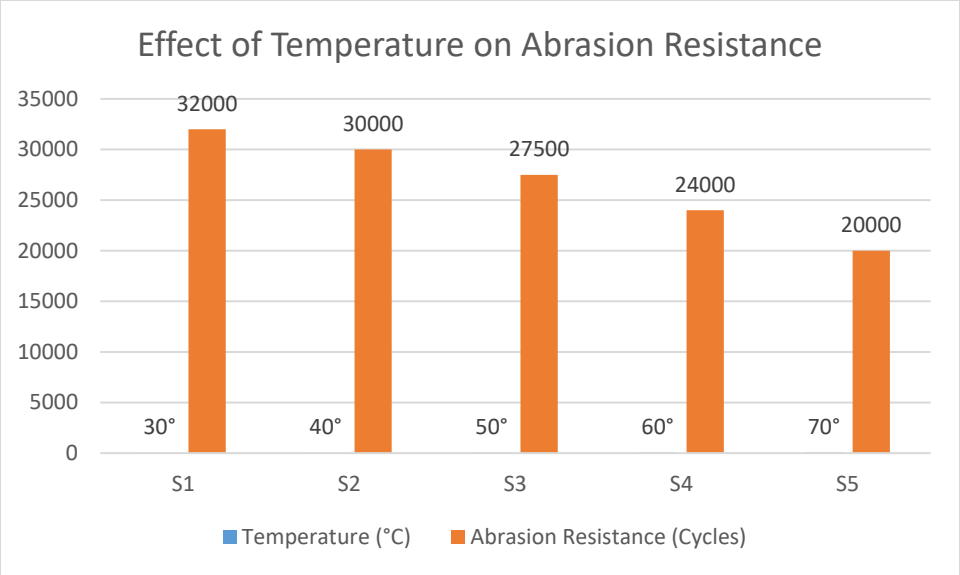

Figure 4. Abrasion Resistance of Denim Fabric at Different Washing Temperatures

Pilling Resistance

Table 5. Effect of Washing Temperature on Pilling Resistance of Denim Fabric

Sample ID	Temperature (°C)	Pilling Grade (1–5)	Observation Notes	Remarks
S1	30	4.5	Smooth surface	Minimal pilling
S2	40	4.0	Minor fuzz	Still good quality
S3	50	3.5	Small pills visible	Moderate issue
S4	60	3.0	Multiple pills	Decreased appearance quality
S5	70	2.5	Heavy pilling	Aesthetic degradation

The table titled "Effect of Washing Temperature on Pilling Resistance of Denim Fabric" presents the pilling resistance of denim fabric at various washing temperatures. As the temperature increases from 30°C to 70°C, the pilling grade decreases, indicating a decline in fabric quality. At lower temperatures (30°C), the fabric exhibits minimal pilling with a smooth surface, whereas at higher temperatures (70°C), heavy pilling occurs, resulting in significant aesthetic degradation. This suggests that increased washing temperatures exacerbate fabric pilling, negatively affecting the fabric's appearance and texture.

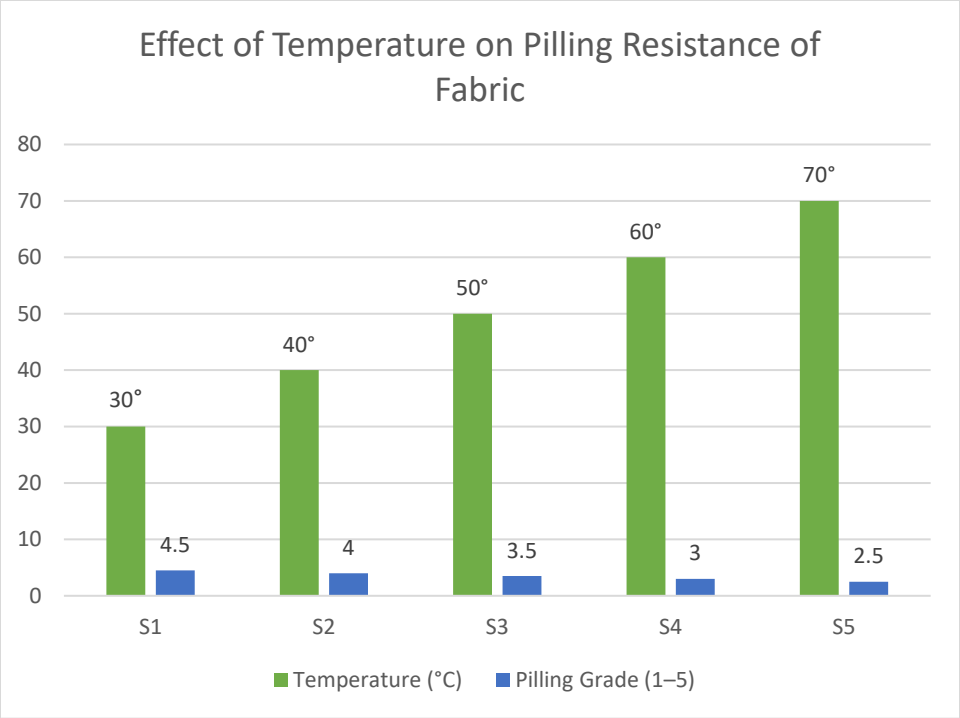

Figure 5. Pilling Resistance of Denim Fabric at Different Washing Temperatures.

Colorfastness

Table 6. Effect of Washing Temperature on Color Fastness of Denim Fabric.

Sample ID	Temperature (°C)	Wash Fastness (1–5)	Dry Rub Fastness (1–5)	Wet Rub Fastness (1–5)	Remarks
S1	30	4.5	4.5	4.0	Excellent retention
S2	40	4.0	4.0	3.5	Slight fading
S3	50	3.5	3.5	3.0	Noticeable fade
S4	60	3.0	3.0	2.5	Color loss evident
S5	70	2.5	2.5	2.0	Significant dye loss

The table titled "Effect of Washing Temperature on Color Fastness of Denim Fabric" presents the wash, dry rub, and wet rub fastness ratings of denim fabric at various washing temperatures. As the temperature increases, all fastness ratings (wash, dry rub, and wet rub) decrease, reflecting a significant loss in color retention. At 30°C, the fabric shows excellent color retention, with ratings of 4.5 for both wash and dry rub fastness, and 4.0 for wet rub fastness. However, as the temperature rises to 70°C, fastness ratings drop significantly, with values as low as 2.0 for wet rub fastness, indicating severe dye loss. This demonstrates that higher washing temperatures have a detrimental effect on the fabric's ability to maintain its color under various conditions.

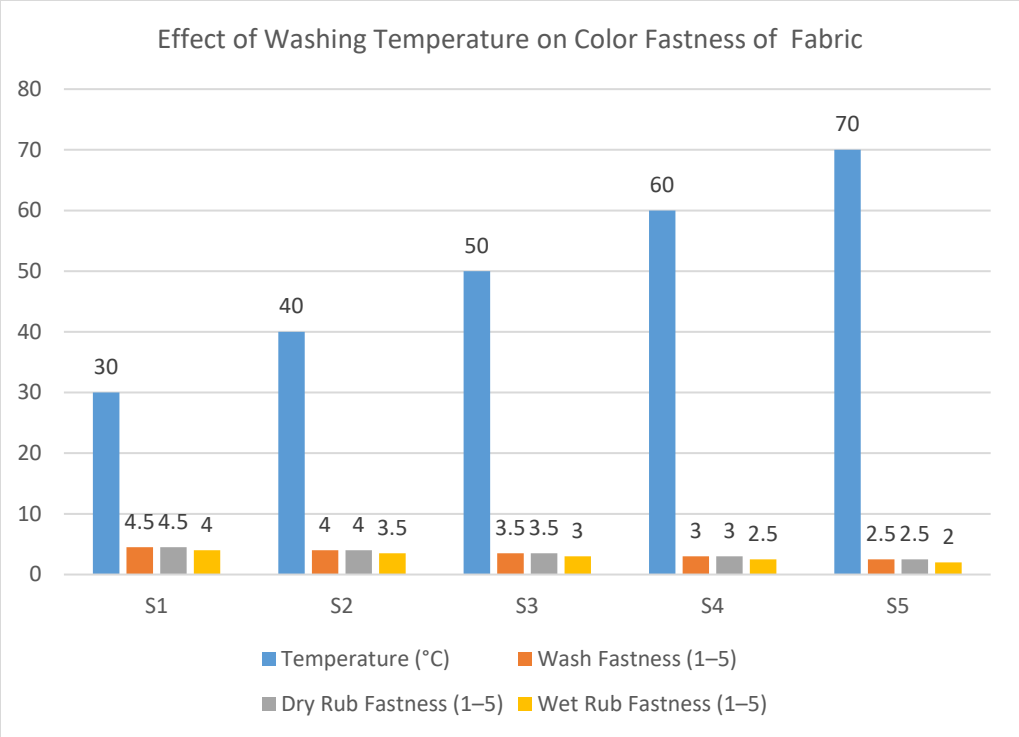

Figure 6. Color Fastness of Denim Fabric at Different Washing Temperatures

Visual Assessment

Table 7. Effect of Washing Temperature on Visual Aesthetics of Denim Fabric.

Sample ID	Temperature (°C)	Visual Score (1–5)	Color Change Observed	Surface Texture Notes	Remarks
S1	30	4.5	Barely visible	Smooth	Retains original look
S2	40	4.0	Slight fading	Minor roughness	Acceptable
S3	50	3.5	Moderate fading	Uneven surface	Some wear visible
S4	60	3.0	Evident fading	Rough patches	Visible aging
S5	70	2.5	Heavy fading	Coarse texture	Significantly aged

The table titled "Effect of Washing Temperature on Visual Aesthetics of Denim Fabric" highlights the impact of washing temperature on the fabric's visual appearance and surface texture. As the washing temperature increases from 30°C to 70°C, both the visual score and the quality of the fabric's surface degrade. At lower temperatures (30°C), the fabric retains its original appearance with minimal color fading and a smooth texture. However, as the temperature rises, color fading becomes more evident, and surface texture deteriorates, with rough patches and coarse textures appearing at higher temperatures. The fabric undergoes significant aging and wear, as seen at 70°C, where heavy fading and coarse texture are noted, leading to a reduced visual appeal.

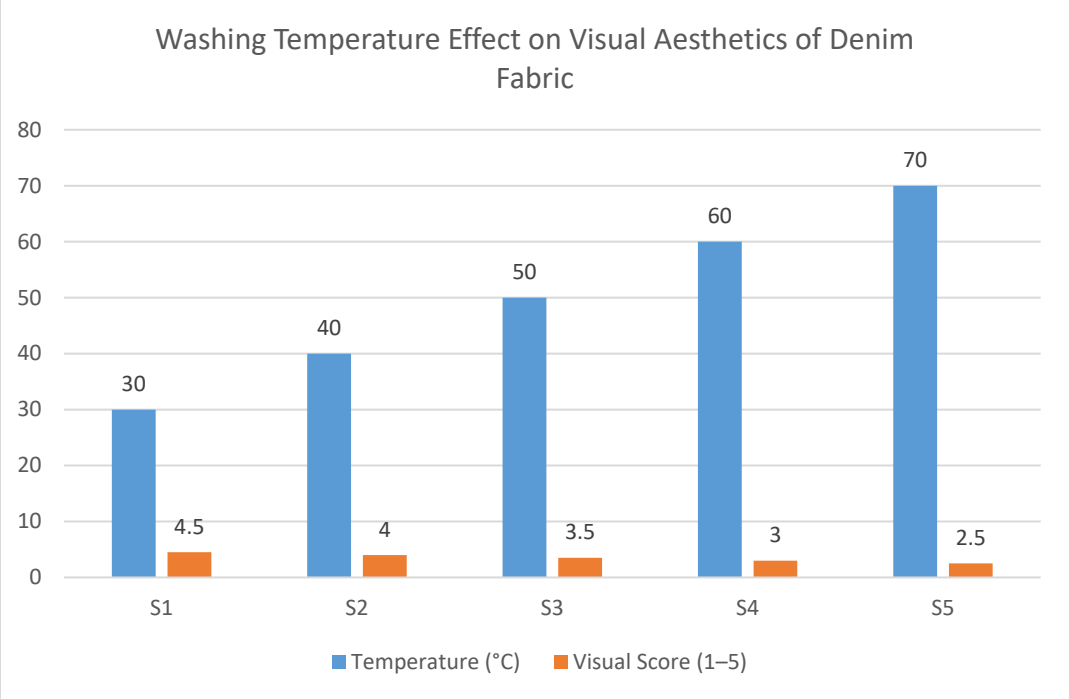

Figure 7. Visual Aesthetics of Denim Fabric at Different Washing Temperatures.

4. Results and Discussion

This section presents a comprehensive analysis of the effects of varying washing temperatures on the performance and aesthetic properties of denim fabric. The parameters evaluated include dimensional stability, tensile strength, abrasion resistance, pilling resistance, colorfastness, and visual aesthetics. The results are organized based on the corresponding tables and figures presented earlier.

4.1-Dimensional Stability

As shown in Table 2 and Figure 2, denim fabrics exhibited increasing shrinkage in both the warp and weft directions with rising washing temperatures. The average shrinkage increased nearly linearly from 1.35% at 30°C to 4.85% at 70°C. This phenomenon can be attributed to enhanced fiber relaxation and contraction due to elevated thermal energy. Cotton fibers tend to undergo greater dimensional changes when exposed to high-temperature laundering, compromising the fabric's dimensional stability. These findings underscore the need for controlled washing conditions to mitigate fabric shrinkage.

4.2 Tensile Strength

The data in Table 3 and Figure 3 demonstrate a consistent decline in tensile strength with increasing washing temperatures. The average tensile strength dropped from 630 N at 30°C to 545 N at 70°C, with both warp and weft directions showing similar trends. This decline can be attributed to thermal and mechanical stresses encountered during laundering, which weaken fiber integrity through micro-damage, leading to a reduction in yarn cohesion. The results emphasize that high-temperature washing adversely affects the mechanical performance of denim fabric.

4.3 Abrasion Resistance

According to Table 4 and Figure 4, abrasion resistance decreases notably as washing temperature increases. Denim samples washed at 30°C withstood 32,000 cycles and showed minimal wear, whereas those washed at 70°C withstood only 20,000 cycles, with visible holes forming in the fabric. This progressive degradation highlights the negative effect of high-temperature laundering on the fabric's resistance to mechanical wear. The loss of abrasion resistance may be due to the weakening of fiber bonds and increased surface roughness after repeated thermal exposure.

4.4 Pilling Resistance

The pilling behavior, summarized in Table 5 and Figure 5, revealed a declining trend in resistance with temperature rise. The pilling grade decreased from 4.5 at 30°C (minimal pilling) to 2.5 at 70°C (heavy pilling). Higher temperatures likely accelerate surface fiber loosening and breakage, resulting in increased formation of pills during mechanical agitation in the washing cycle. This suggests a direct relationship between temperature and surface degradation, impacting the aesthetic and tactile properties of the fabric.

4.5 Colorfastness

Table 6 and Figure 6 illustrate that wash, dry rub, and wet rub fastness ratings all decline significantly as temperature increases. For instance, wash fastness dropped from 4.5 at 30°C to 2.5 at 70°C, while wet rub fastness decreased from 4.0 to 2.0 over the same range. This decline indicates enhanced dye loss and color degradation at higher washing temperatures. Thermal agitation likely causes dye molecule detachment and fiber swelling, leading to poor color retention. This finding is crucial for maintaining the visual appeal of denim products through appropriate laundering conditions.

4.6 Visual Assessment

The subjective visual assessment presented in Table 7 further supports the objective performance data. The visual score fell from 4.5 at 30°C (retaining original appearance) to 2.5 at 70°C (significant fading and surface coarseness). Color fading and texture degradation were progressively more severe at elevated temperatures, with signs of fabric aging and roughness becoming prominent. These changes are closely tied to thermal-induced fiber deterioration and mechanical abrasion during washing cycles.

5. Conclusion & Recommendations

This study comprehensively evaluated the influence of washing temperature on the structural, mechanical, and aesthetic properties of denim fabric, revealing that higher temperatures (60–70°C) significantly degrade performance by increasing shrinkage, reducing tensile strength, lowering resistance to abrasion and pilling, and accelerating color fading. In contrast, lower temperatures (30–40°C) better preserve dimensional stability, strength, and visual quality, though with slightly reduced cleaning efficiency. These findings underscore the importance of temperature-controlled laundering in extending garment lifespan and maintaining fabric integrity. It is recommended that consumers wash denim at 30–40°C using mild detergents and avoid frequent high-temperature cycles; manufacturers should provide clear care labels and explore durable low-temperature finishes; laundries should optimize washing conditions and incorporate softening and neutralization agents like Rewin Soft C-60 and acetic acid; and sustainability stakeholders should promote low-temperature washing as an energy-efficient, fabric-friendly practice aligned with reduced carbon emissions and water conservation goals.

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