Research Article

Directional Interaction Of Sewing Thread Linear Density And Fabric Orientation On Seam Performance Of Lightweight Cotton Interlock Fabrics

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Abstract

Seam performance plays a critical role in the durability of knitted garments, particularly in lightweight fabrics. The margin between seam failure and fabric rupture is minimal. This study is to understand the interaction between sewing thread linear density and fabric direction on seam strength and seam efficiency of a lightweight cotton interlock fabric. Seams were constructed using a superimposed seam with stitch class 401 at a stitch density of 12 stitches per inch, using polyester sewing threads of 40 Tex and 60 Tex. Seam performance was evaluated in both wale and course directions and interpreted in relation to the fabric's structural and mechanical properties, including tensile and tear strength. A two-factor factorial design was adopted, and statistical analysis was performed using two-way ANOVA with interaction and interaction-based linear regression. Results reveal a significant interaction between thread linear density and fabric direction. Increasing thread linear density improved seam strength and seam efficiency in the wale direction, whereas it had the opposite effect in the course direction. The findings highlight the importance of direction-specific seam engineering for lightweight knitted garment manufacturing.

Keywords Seam strength; Seam efficiency; Lightweight knitted fabric; Fabric direction; Sewing thread linear density; Interlock fabric.

1. Introduction

Seam performance is an important factor in garment durability and service life as garments experience continuous mechanical loading during wear and laundering. In many apparel applications, seam failure may occur before fabric rupture, making seam strength and seam efficiency important considerations during seam engineering and seam parameter selection [1]. However, in lightweight knitted fabrics, seam failure commonly initiates at the seam line due to localized fabric damage and stress concentration caused by sewing, rather than failure of the sewing thread itself. In knitted fabrics, seam engineering is more challenging due to their high extensibility, loop mobility, and direction-dependent structural behavior, which increases sensitivity to seam parameters and further complicates seam engineering [2].

The mechanical response of knitted fabrics varies with fabric orientation due to differences in loop alignment. Wale and course directions exhibit different tensile strength, elongation, and deformation. Especially for interlock knitted fabric, which is a weft-knitted fabric, extensibility is greater in the course direction. These mechanical properties have been mentioned in numerous studies, but the implications for seam performance are not established at the same level [3].

Available research is mostly focused on individual sewing parameters like stitch class, seam type, stitches per inch (SPI), sewing thread linear density (Tex), sewing needle, and their influence on seam performance. However, seam performance along the fabric direction has not been sufficiently explored [4].

Lightweight knitted garments are versatile, as they can be worn all year round and can be used as a layering in winter. Suitable for innerwear, t-shirts, infant and kids wear, as they are breathable and give comfort [5]. Lightweight cotton interlock fabrics are also widely used in garments worn by adolescents, including T-shirts, school uniforms, sportswear, and casual apparel. Improving seam performance in these garments contributes to durability and comfort during the frequent physical activities associated with adolescence. Unlike woven fabrics, existing studies on seam performance are mainly focused on medium to heavy-weight knitted fabrics. This higher fabric weight provides greater structural stability, which may partially mask the sewing induced damage [6]. In contrast, lightweight knitted fabrics have limited load-bearing capacity, resulting in localized damage during wear and laundering. Despite this, research on the seam performance of lightweight knitted garments that explicitly considers fabric direction remains

limited. Another important parameter to consider is the sewing thread linear density, as it must provide sufficient reinforcement without damaging the fabric, which directly affects seam performance [7].
Moreover, seam performance depends not only on sewing parameters and fabric orientation but also on fabric mechanical properties, like tensile and tear strength, as these factors influence load transfer at the seam line, especially in lightweight knitted garments. Relatively few studies compare seam performance with baseline mechanical properties of the fabric.
Based on this, there is a clear research gap in understanding how the sewing thread linear density interacts with fabric orientation to influence seam strength and seam efficiency in lightweight knitted fabrics. To address this gap, a controlled experiment treating fabric direction as the primary variable, along with fabric linear density, examines seam strength and efficiency in relation to fabric mechanical properties.

2. Literature Review

Previous studies on knitted seam performance have established that sewing parameters such as stitch class, stitch density, and sewing thread linear density influence seam strength and seam efficiency [4]. Sewing thread linear density provides reinforcement at the seam line; however, in lightweight knitted fabrics, excessive thread mass may increase sewing-induced fabric damage, limiting seam efficiency [3]. Chainstitch constructions, particularly stitch class 401, are commonly employed in knitwear due to their extensibility and ability to accommodate fabric deformation during loading [8]. Stitch density also affects seam integrity, with moderate values such as 12 stitches per inch (SPI) widely adopted in industry to balance seam stability and fabric preservation [9]. Despite these findings, limited studies have systematically examined how sewing thread linear density interacts with fabric direction in lightweight knitted fabrics. Although seam performance has been widely studied for knitted apparel, very few studies have discussed its importance in garments frequently worn by adolescents, where durability and wearer comfort are important quality considerations.

3. Materials and Methods

3.1 Fabric testing for structural and mechanical properties

The fabric used in this study was 100% cotton knitted interlock sourced from Tirupur, India. Fabric structural parameters, such as GSM, yarn count, and wale and course counts, were determined to establish a baseline for interpreting seam performance. These parameters directly influence loop geometry and load distribution in knitted fabrics, which affects seam behavior during tensile loading. Similarly, fabric mechanical parameters were determined to establish the directional mechanical limits of the fabric, and tensile and tear strength tests were conducted. Both structural and mechanical parameter tests were conducted using ASTM test methods. For every test, five specimens were tested in each direction, and mean values were calculated and reported.

3.2 Sewing Parameters and Seam Preparation

All seams were prepared in controlled conditions to effectively isolate the effects of sewing thread linear density and fabric direction. A superimposed seam (SS) was created using a double-thread chainstitch (401) with a stitch density of 12 stitches per inch (SPI). This superimposed seam was selected because it is most used and represents the most basic seam structure, allowing for direct load transfer across the seam line. Stitch class 401 was selected because it is widely used in knitted garment construction and provides sufficient extensibility to accommodate loop deformation. Sewing was carried out using a needle size Nm 75 to minimize yarn damage in the knitted structure, and 100% polyester sewing thread with linear densities of 40 Tex and 60 Tex was used. A constant seam allowance of 10 mm was maintained for all specimens. A stitch density of 12 SPI was used as it is a commonly used industrial setting for lightweight knitted fabrics, providing adequate stitch integrity while avoiding excessive needle perforation that may induce fabric damage.
When the objective is to study the effects of selected factors, all other potentially influential variables should be held constant to avoid contradictions and to allow clear interpretation of both main and interaction effects [10]. Accordingly, in the present study, sewing parameters other than thread linear density and fabric direction were maintained at neutral, commonly used industry-standard levels to enable direct evaluation of seam strength behavior.
All seams were sewn in both wale and course directions of the fabric.

3.3 Experimental Design and Statistical Analysis

Seam efficiency (%) was calculated using the formula below in both wale and course directions.

$$\text{Seam Efficiency}(\%) = \left(\frac{\text{Seam Strength}}{\text{Fabric Strength}}\right) \times 100$$

A two-factor factorial experimental design was employed with:

- Factor A: Thread linear density (40 Tex, 60 Tex)
- Factor B: Fabric direction (wale, course)

A total of 20 seam specimens were tested. Five replicate specimens were tested for each combination of thread linear density and fabric direction, resulting in a 2 × 2 factorial design. Seam strength was measured, and seam efficiency was calculated. Statistical analyses were performed using specimen data (n = 20). A Two-way ANOVA with interaction was used to evaluate the effects of thread linear density, fabric direction, and their interaction. An interaction-based linear regression model was further developed to examine the moderating role of fabric direction using the Microsoft Excel Analysis ToolPak. Fabric direction, a categorical variable, was incorporated into the regression model using binary indicator coding (wale = 1, course = 0). An interaction term was constructed as the product of thread linear density and fabric direction to examine direction-dependent effects

Data visualization was performed using Python in the Google Colab cloud-based environment. The Matplotlib and Seaborn libraries were used to generate interaction plots and bar charts for comparative analysis of the relationship between thread linear density and fabric direction.

4. Results and discussion:

4.1 Fabric structural and mechanical parameters

As shown in Table 1, the fabric GSM is 135 g/m^2, with a yarn count of 36 Ne in both the wale and course directions, and the fabric has 42 Wales per inch (WPI) and 44 Courses per inch (CPI). The slightly higher CPI relative to the WPI indicates a compact horizontal-loop arrangement.

Table 1 Baseline Structural parameters of the fabric (mean of five specimens)

Parameter	Value
Fabric type	Cotton interlock
GSM	135
Yarn count (wale)	36 Ne
Yarn count (course)	36 Ne
Wales per inch (WPI)	42
Courses per inch (CPI)	44

Results in Table 2 confirm the directional nature of the interlock structure, with higher resistance in the wale.

Table 2 Baseline mechanical properties of the fabric (mean of five specimens)

Results	Wale direction	Course direction
Tensile strength (lbf)	58	50
Tear strength (lbf)	2	1.8

4.2 Directional Mechanical Response of the Cotton Interlock Fabric

Knitted interlock fabrics exhibit inherent direction-dependent mechanical behavior due to the orientation of loop pillars and intermeshing courses. The baseline mechanical results confirm this behavior, with the wale direction showing higher tensile and tear resistance than the course direction. Wale direction exhibits a tensile strength of 58.0 lbf, compared to 50.0 lbf in the course direction, indicating that vertical loop columns act as the primary load-bearing elements, whereas horizontal loop segments contribute less effectively under tensile loading [11].

These directional differences establish the mechanical boundary conditions within which seam performance must be interpreted. In lightweight knitted fabrics, where the margin between seam failure and fabric rupture is limited, seam strength and seam efficiency must be evaluated relative to the fabric's directional tensile capacity rather than as absolute values.

4.3 Seam Strength and Seam Efficiency

Seam strength and seam efficiency values for all sewing conditions are summarized in Table 3. Clear direction-dependent trends are evident. In the wale direction, seam strength significantly increased when sewing thread linear density was raised from 40 Tex to 60 Tex. This increase resulted in seam efficiency approaching the tensile strength of the fabric. This behavior indicates effective load transfer between the seam and the fabric structure when sufficient reinforcement is provided.

Table 3. Seam strength and seam efficiency (mean of five specimens per sample)

Thread linear density (Tex)	Fabric direction	Mean seam strength (lbf)	Fabric tensile strength (lbf)	Seam efficiency (%)
40	Wale	33.2	58	57.2
60	Wale	55.3	58	95.3
40	Course	39.5	50	79
60	Course	36.9	50	73.8

When examining in the course direction, increasing thread linear density resulted in a reduction in seam strength and seam efficiency. Though a higher Tex thread provides higher intrinsic strength, its effectiveness is limited by the lower tensile and tear resistance of the fabric in the course direction. Previous studies have shown that in knitted fabrics, seam performance is affected more by fabric damage than by thread strength when the fabric reinforcement is more than the structural capacity of the fabric [12,13].

Fig 1 illustrates the opposing trends in seam strength with thread linear density for the wale and course directions, while Fig 2 highlights the corresponding seam efficiency behavior

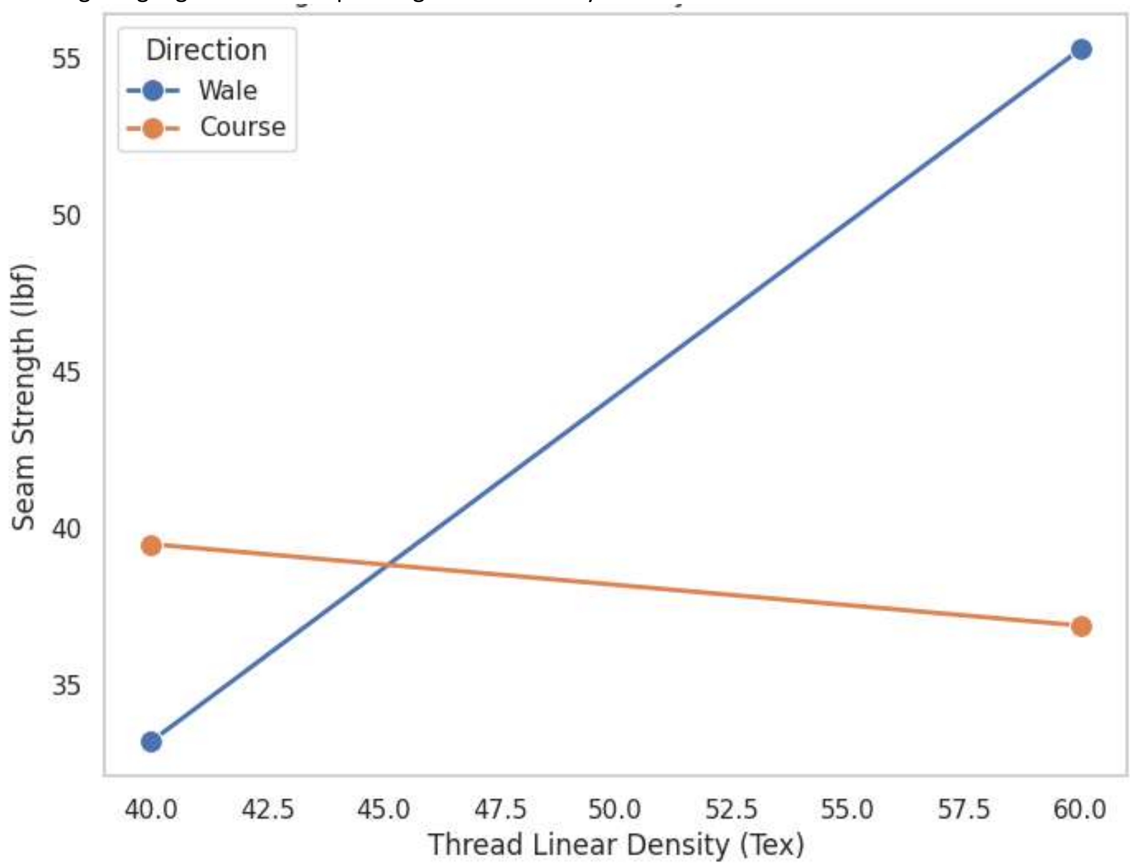

Fig 1 Effect of thread linear density on seam strength in wale and course directions

As shown in Fig 1, seam strength increases markedly with thread linear density in the wale direction, while a reduction is observed in the course direction, indicating direction-dependent trends in seam behavior.

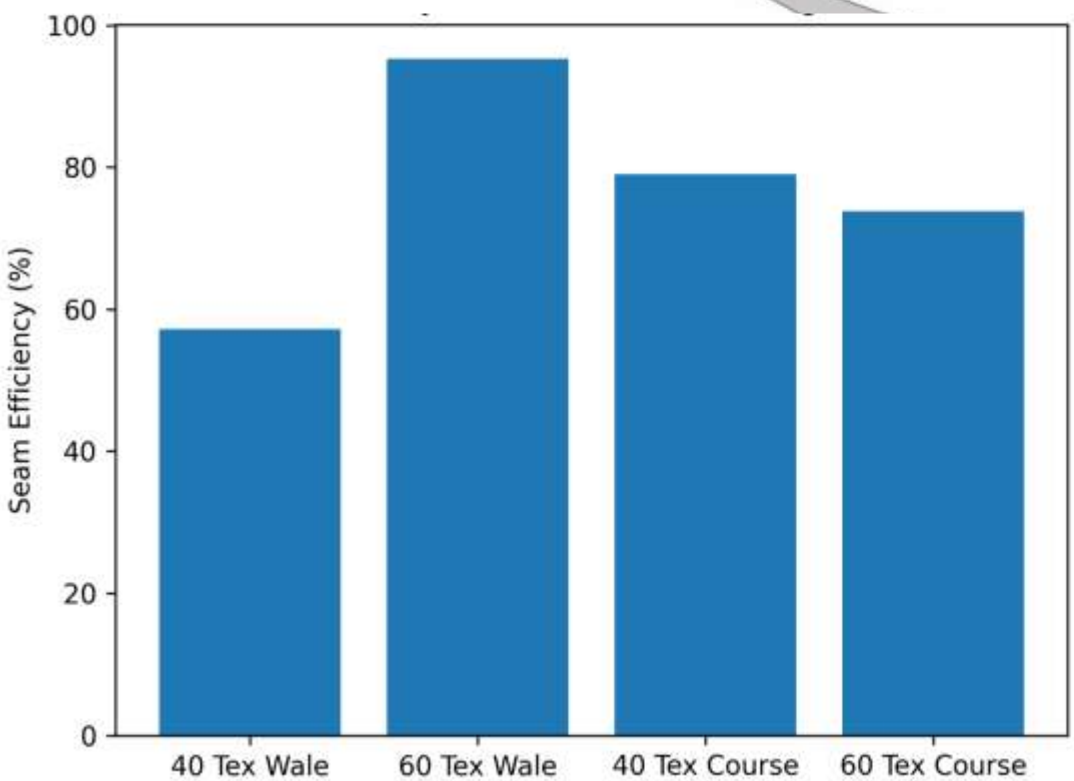

Fig 2 Seam efficiency under different sewing conditions.

Seams in the wale direction with 60 Tex thread approach the tensile strength limit of the fabric, whereas in the course direction exhibit reduced efficiency with increased thread linear density.

A clear directional contrast is observed in the effects of thread linear density. An increase in thread linear density from 40 Tex to 60 Tex resulted in a 66.5% increase in seam strength in the wale direction, whereas in the course direction, it caused a 6.6% reduction in seam strength. These opposing trends indicate that the effect of thread linear density on seam performance is strongly dependent on fabric orientation.

4.4 Two-way ANOVA

Results from the two-way ANOVA (Table 4) show that both thread linear density and fabric direction have a significant impact on seam strength ($p < 0.01$). More importantly, the interaction between thread linear density and fabric direction is highly significant ($p < 0.001$). This indicates that the effect of thread linear density on seam strength is greatly influenced by fabric orientation.

Table 4 Two-way ANOVA results for seam strength (based on 20 observations)

Source of variation	**Degrees of freedom**	**F-value**	**P-value**	Significance
Thread linear density (Tex)	1	9.84	0.006	Significant
Fabric direction	1	18.26	0.001	Significant
Tex × Direction	1	108.94	< 0.001	Highly significant
Error	16	–	–	–

The interaction plot shown in Fig 1 confirms this non-parallel behavior, which shows that seam strength increases sharply with thread linear density in the wale direction while decreasing in the course direction.

4.5 Interaction-Based Regression Analysis

An interaction-based regression analysis is conducted to further interpret the moderating role of fabric direction, and an interaction regression model was developed using specimen-level data. Fabric direction was dummy-coded (Course = 0, Wale = 1).

Table 5. Regression coefficients for the interaction model

Predictor	Coefficient	P-value
Intercept	44.7	< 0.001
Thread linear density (Tex)	−0.13	< 0.001
Fabric direction	−55.7	< 0.001
Tex × Direction	1.235	< 0.001
Regression Statistics		
Multiple R	0.999606127	
R Square	0.999212409	
Adjusted R Square	0.999064735	
Standard Error	0.264575131	
Observations	20	

The regression model showed a high R^2 of 0.99 and an adjusted R^2 of 0.98. whereas a base model without the interaction term showed substantially lower explanatory capability. This confirms that thread linear density alone cannot explain variations in seam strength without considering fabric orientation. The interaction coefficient highlights how the fabric structure affects the effectiveness of sewing-thread reinforcement, thereby supporting the ANOVA findings. The regression model is presented as an explanatory tool rather than as a universal predictive model.

4.6 Relationship Between Fabric Mechanical Properties and Seam Performance

The observed seam behavior is consistent with the mechanical properties of the fabric. In the wale direction, higher tensile and tear resistance provide a structurally stable seams that allows higher Tex thread to be effectively utilized, resulting in seam efficiencies approaching the fabric tensile limit. This indicates efficient load transfer across the seam line.

In the course direction, lower tensile and tear resistance combined with higher loop density (CPI = 44) increase susceptibility to localized damage during needle penetration. The use of heavier thread in this orientation increases thread volume and friction within the loop structure. This causes loop crowding and partial fiber damage during seam sewing. Thus, seam strength is reduced despite the higher strength of the thread. Previous studies have reported similar seam behavior in knitted fabrics [13,14].

4.7 Practical Implications for Sewing Optimization

From a garment manufacturing perspective, the results emphasize the importance of seam engineering and optimizing sewing parameters for lightweight knitted fabrics based on seam orientation. Seams in wale direction can accommodate higher thread linear densities to achieve near fabric-limited performance, whereas seams in course direction require more moderate thread sizes to minimize damage from sewing thread and to preserve seam efficiency. This direction-specific approach offers a practical framework for improving seam reliability without increasing material consumption or production complexity. These findings may also assist manufacturers producing lightweight knitted garments for adolescents, where repeated movement and frequent laundering require durable seam construction without compromising comfort.

5. Conclusion

This study demonstrates that seam performance in lightweight cotton interlock fabrics is governed by a strong interaction between sewing thread linear density and fabric orientation. Increasing thread linear density significantly enhances seam strength and efficiency in the wale direction, while producing the opposite effect in the course direction due to structural constraints associated with loop orientation and density. These findings establish that optimization of sewing parameters for knitted fabrics must be direction-specific rather than uniform. The conclusions are specific to lightweight cotton interlock fabrics stitched under the stated sewing conditions, and extension to other knitted structures should consider differences in fabric architecture and mechanical behavior. Future research may extend this work by examining additional stitch classes, stitch densities, and knitted structures. The findings may also support seam parameter selection for lightweight knitted garments commonly used by adolescents, contributing to improved garment durability and wearer comfort.

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Grammarly was used only for language refinement during manuscript preparation

Ethics Approval
This study does not involve human participants or animals. Ethical approval was not required.

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