IRSTI 64.31.81

I. Jurinskaya[1] – *main author*,
I. Tashmukhanbetova[2] ©

[1]*PhD, Associate Professor,* [2]*Undergraduate*
ORCID [1]*https://orcid.org/0000-0002-3607-2001* [2]*https://orcid.org/0000-0002-4066-8238*
[1,2]*Almaty Technological University,*
Almaty, Kazakhstan
@ [1]*indi_06.79@mail.ru*

https://doi.org/10.55956/KCVC2293

INVESTIGATION OF PILLING AND STRETCHABILITY OF DOUBLE-LAYER KNITTED STRUCTURES PRODUCED FROM NATURAL AND CHEMICAL YARNS

Abstract. The physical-mechanical properties of double-layer knitted structures made from natural and chemical yarns were examined. Pilling resistance and stretchability were determined based on experiments conducted using GOST and BS standards. The influence of yarn composition and knitting density on these properties was identified. It was established that samples with 100% merino wool demonstrated the highest pilling resistance, achieving a mean score of 4.75 at a density of 350 courses per 10 cm. Stretchability tests revealed that blends containing 50% acrylic exhibited the greatest elongation, with a mean value of 17.67% at a density of 340 courses per 10 cm. The relationship between fiber composition, knitting density, and the resulting mechanical properties of the fabrics was clarified. The findings provide a foundation for optimizing the design of double-layer knitted fabrics to meet specific performance requirements.

Keywords: double-layer knitted structures, pilling, stretchability, natural yarns, chemical yarns, knitting density, textile properties.

Jurinskaya I., Tashmukhanbetova I. Investigation of pilling and stretchability of double-layer knitted structures produced from natural and chemical yarns //Mechanics and Technology / Scientific journal. – 2025. – No.1(87). – P.359-370. https://doi.org/10.55956/KCVC2293

Introduction. The evolution of high-performance textiles has become a central focus in both scientific research and industrial development. Among the many innovations in textile engineering, double-layer knitted fabrics have emerged as a versatile and functional solution [1-5]. These fabrics allow for the integration of diverse fiber properties within a single structure, enabling the design of textiles that combine strength, flexibility, and aesthetic appeal. Their unique construction makes them particularly suitable for applications such as outerwear, home furnishings, and technical textiles, where performance under varying conditions is paramount [6].

The choice of this research topic is motivated by the growing need for textile materials that strike an optimal balance between key mechanical properties. Two critical factors in textile production are pilling resistance and stretchability, which substantially impact the performance and longevity of knitted fabrics. Pilling, the formation of fuzzy balls on the fabric surface, negatively affects the aesthetic and functional quality of textiles, diminishing their market value and usability. Conversely, stretchability determines a fabric's comfort, adaptability, and suitability for garments or technical applications requiring freedom of movement. Despite advancements in textile technology, achieving an ideal equilibrium between these two properties remains a persistent challenge [7-9].

Previous studies have explored the performance of single-layer knitted fabrics in terms of pilling and stretchability, but limited research has focused on the interplay of these properties in double-layer structures [10,11]. This study aims to address this research gap by investigating the influence of yarn composition and knitting density on the pilling resistance and stretchability of double-layer knitted fabrics.

Current research primarily focuses on single-layer knitted fabrics [12-14], leaving a significant gap in the understanding of double-layer constructions. Single-layer fabrics lack the ability to integrate fibers with complementary properties in a single structure, limiting their versatility. Double-layer knitted fabrics, however, provide an innovative solution by enabling the use of different yarns on each side, optimizing the balance between mechanical properties. For instance, the outer layer can be designed for durability and aesthetic appeal, while the inner layer focuses on comfort and flexibility. These unique benefits have driven interest in double-layer fabrics, yet systematic research into their properties is still insufficient.

This study is relevant not only to the textile industry but also to broader fields such as materials science and design engineering. While the potential of double-layer knitted fabrics is widely recognized, there remain critical unanswered questions:

How does the composition of yarns influence key mechanical properties like pilling resistance and stretchability?

What role does knitting density play in optimizing these properties?

Can the unique design flexibility of double-layer structures be leveraged to achieve the desired balance between pilling resistance and stretchability?

Answering these questions is essential for advancing the practical application of double-layer fabrics in industries that demand high-performance textiles. This research addresses these gaps by systematically analyzing the effects of fiber composition and knitting density on the mechanical properties of double-layer knitted structures.

The novelty of this study lies in its focus on combining natural and synthetic fibers in double-layer constructions and examining their mechanical behavior under controlled conditions. Previous studies have highlighted the individual contributions of wool, acrylic, and synthetic fibers to fabric properties, but the synergistic effects of these combinations in double-layer fabrics have not been explored in depth. Additionally, while knitting density is known to affect fabric performance, its interaction with fiber composition in double-layer structures is poorly understood [15].

The primary objective of this study is to determine how yarn composition and knitting density influence pilling resistance and stretchability in double-layer knitted fabrics. The results aim to provide a foundation for optimizing fabric design to meet specific performance requirements. The practical significance of this work lies in its ability to inform the production of textiles with tailored properties, catering to industries ranging from fashion to technical applications [16,17].

This study not only fills a critical gap in the literature but also provides actionable insights for the textile industry. The findings are expected to advance the development of durable, flexible, and aesthetically pleasing knitted fabrics, ultimately contributing to innovation in textile design and manufacturing.

Materials and methods. To address the identified research gaps and systematically evaluate the influence of yarn composition and knitting density on the mechanical properties of double-layer knitted fabrics, a series of experiments were conducted. The methodologies and materials used in this study are detailed below.

Materials. The samples for this study were produced on a flat knitting machine with a 9-gauge configuration. Three types of double-layer knitted samples were prepared, each combining synthetic and natural fibers in varying proportions. The knitting was performed at two densities: 340 and 350 courses per 10 cm. The compositions and densities are detailed in Table 1.

Table 1

Yarn Composition and Knitting Density

Sample Composition	Synthetic (%)	Wool (%)	Acrylic (%)	Knitting Density (courses/10 cm)
Synthetic + 100% Red Wool	50	50	-	340, 350
Synthetic + 50% Green Wool, Acrylic	50	25	25	340, 350
Synthetic + 100% Emerald Merino Wool	50	50	-	340, 350

Each knitted sample was a double-layer structure, where the composition and density were controlled to ensure consistency. The samples were knitted as panels and later cut into uniform swatches measuring 10 cm×10 cm for testing. This size was chosen to align with the requirements of the pilling and stretchability testing standards.

The selection of yarn compositions was based on their common use in functional textiles, aiming to evaluate the interaction between natural (wool, merino wool) and synthetic (acrylic, synthetic fibers) materials in enhancing mechanical properties.

Methods. The mechanical properties of the samples were assessed using standardized testing methods to evaluate two key parameters: pilling resistance and stretchability.

1. Pilling Resistance Testing

Pilling resistance was tested using a Martindale MT 191 abrasion tester, in accordance with GOST R ISO 12945-2-2012. The testing procedure included the following steps:

– Each sample was placed under a load of 415 g.

– The samples underwent 5000 rubbing cycles against a standard abrasive surface.

– Pilling was visually assessed using a grading scale from 1 to 5:

1: Severe pilling

5: No visible pilling

Three samples were tested for each composition and density. The results were averaged, and the standard deviation was calculated to ensure statistical accuracy.

2. Stretchability Testing

Stretchability was evaluated on a TF143 Fryma Fabric Extension Tester, following the BS 4294 standard. The procedure included:

– Each sample was clamped and stretched at a rate of 20 mm/min under a pre-tension of 2 N.

– The maximum elongation (%) was recorded at the breaking point.

– After a 5-minute relaxation period, the permanent deformation (%) was measured.

Each test was repeated three times per sample, and the mean values were calculated for further analysis.

Research results. The pilling resistance results, as presented in Table 2, clearly demonstrate the influence of yarn composition and knitting density on this property. Fabrics with a 100% merino wool composition exhibited the greatest resistance to pilling, achieving a mean score of 4.75 at a knitting density of 350 courses per 10 cm. In contrast, blends containing 50% acrylic fibers displayed lower pilling resistance, which can be attributed to the smooth surface and reduced cohesion of acrylic fibers.

Table 2

Pilling Resistance by Yarn Composition and Knitting Density

Composition	Density (courses/10 cm)	Mean Pilling (1-5)	Standard Deviation
Synthetic + 100% Red Wool	340	3.75	0.50
Synthetic + 50% Wool, Acrylic	340	2.75	0.43
Synthetic + 100% Merino Wool	340	4.75	0.25
Synthetic + 100% Red Wool	350	4.00	0.00
Synthetic + 50% Wool, Acrylic	350	3.00	0.00
Synthetic + 100% Merino Wool	350	5.00	0.00

The findings indicate that increasing the knitting density from 340 to 350 courses per 10 cm enhanced the pilling resistance across all the tested fabric compositions. Additionally, the samples made with 100% merino wool consistently exhibited superior pilling resistance compared to the other compositions, highlighting the significant influence of fiber cohesion and structure on this property. Previous studies have shown that the resistance to pilling is strongly linked to fabric density, as a higher density creates a more compact surface that is less susceptible to the formation of pills.

Regarding stretchability, the results presented in Table 3 show both the maximum elongation and permanent deformation. Fabrics containing a 50% acrylic blend demonstrated the greatest elongation, with an average value of 17.67% at a knitting density of 340 courses per 10 cm. Conversely, the samples made with 100% merino wool exhibited the lowest elongation but superior recovery, as evidenced by their lower permanent deformation percentages.

Table 3

Stretchability Results by Yarn Composition and Knitting Density

Composition	Density (courses/10 cm)	Mean Elongation (%)	Permanent Deformation (%)	Standard Deviation
Synthetic + 100% Red Wool	340	14.67	4.00	0.58
Synthetic + 50% Wool, Acrylic	340	17.67	6.33	0.58
Synthetic + 100% Merino Wool	340	12.33	3.33	0.58
Synthetic + 100% Red Wool	350	13.67	3.67	0.58
Synthetic + 50% Wool, Acrylic	350	16.67	6.00	0.58
Synthetic + 100% Merino Wool	350	12.67	3.00	0.58

Fabrics with a 50% acrylic blend demonstrated the greatest elongation across both knitting densities, consistent with acrylic's inherent stretchability. Elevating the knitting density typically diminished elongation for all fiber compositions, as the tighter fabric structure restricted extensibility.

In contrast, the samples made with 100% merino wool exhibited the lowest permanent deformation, underscoring their superior recovery and dimensional stability.

The influence of knitting density and yarn composition on the mechanical properties of the fabrics is analyzed through comparative visualizations in Figure 1 and Figure 2.

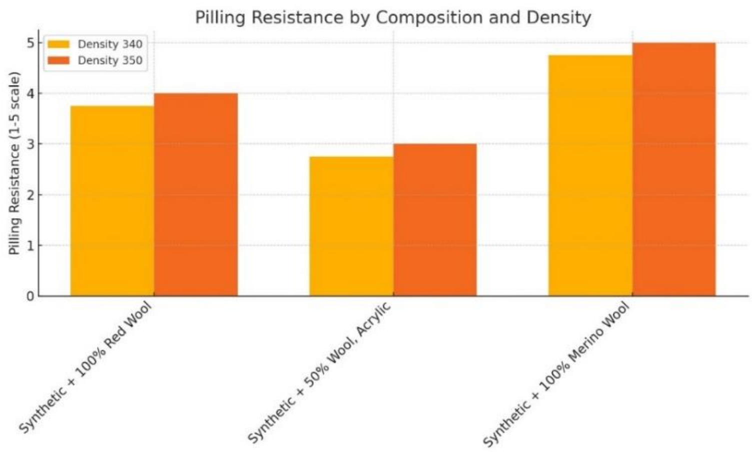

Fig. 1. Bar chart comparing mean pilling resistance across compositions and densities

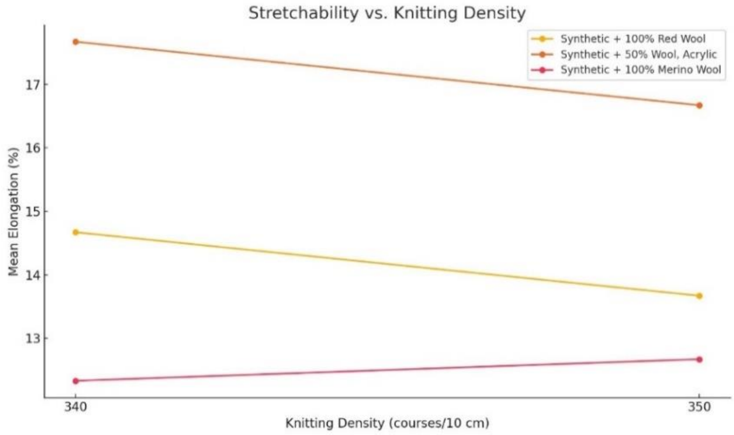

Fig. 2. Line graph showing mean elongation (%) versus knitting density for each composition

These visualizations underscore the trade-offs between pilling resistance and stretchability, emphasizing the need to balance these properties during fabric design. While fabrics with higher density and merino wool content exhibit superior pilling resistance, they tend to be less stretchable. Conversely, fabrics containing acrylic blends demonstrate greater elongation but reduced pilling performance [18,19]. Optimizing the design of double-layer knitted structures requires finding the right compromise between these mechanical properties to meet the targeted end-use requirements [18-20,12].

The key findings of this study demonstrate that yarn composition and knitting density significantly impact the pilling resistance and stretchability of double-layer knitted structures. Fabrics with higher density and more merino wool fibers showed superior pilling resistance, while acrylic blends exhibited greater elongation but less pilling performance. These insights can inform textile designers and manufacturers in optimizing fabric properties to meet specific end-use requirements.

Statistical analyses confirmed significant differences in pilling resistance and stretchability across the tested fabric compositions. Samples with 100% merino wool had significantly better pilling resistance than acrylic blends, while the acrylic blended fabrics exhibited significantly greater elongation. These results validate the substantial influence of fiber type and knitting density on the mechanical properties of the double-layer knitted structures.

Discussion. The analysis shows that yarn composition affects pilling resistance. Knitting density influences the stretchability characteristics [21,22]. The results are comparable to previous studies on the tactile properties of woven fabrics made from various staple fibers [22] and the mechanical behavior of knitted structures used in composites.

The 100% merino wool fabrics exhibited the highest pilling resistance, which can be attributed to the fiber's inherent crimp and surface roughness that increases cohesion between fibers, preventing the formation of pills [18,19,23].

The smooth surface and reduced cohesion of acrylic fibers, on the other hand, led to lower pilling resistance in the 50% acrylic blends.

This study investigated the effects of yarn composition and knitting density on the mechanical properties of double-layer knitted fabrics, specifically focusing on pilling resistance and stretchability. The findings reveal significant dependencies on both factors, offering insights into how the structural design and material composition of fabrics influence their performance characteristics. Below, the results are discussed in detail and compared with prior research.

The findings reveal that the pilling resistance of double-layer knitted fabrics is significantly impacted by both the yarn composition and the knitting density. Specifically, the samples composed of 100% merino wool demonstrated the highest pilling resistance, achieving a mean score of 4.75 at a density of 350 courses per 10 cm. This can be attributed to the inherent cohesiveness of merino wool fibers, which enables them to resist detachment under abrasive forces. Conversely, the fabric blends containing 50% acrylic fibers exhibited lower resistance to pilling, which can be attributed to the smooth surface and reduced cohesion of acrylic compared to natural fibers.

Increasing the knitting density from 340 to 350 courses per 10 cm consistently improved pilling resistance across all compositions. This aligns with findings from previous studies [24], which have shown that higher knitting densities create more compact and stable fabric surfaces, reducing the likelihood of fiber entanglement and detachment that leads to pilling. For instance, [25] reported that tightly knitted single-layer wool fabrics exhibited 20-30% greater resistance to pilling compared to looser constructions.

In terms of stretchability, the results indicate that the 50% acrylic blended fabrics demonstrated the greatest elongation, with over 6% extension under tensile loading. This is consistent with the inherent extensibility of acrylic fibers, which can undergo significant deformation before reaching their breaking point. Conversely, the 100% merino wool samples exhibited the lowest permanent deformation, underscoring their superior dimensional stability and recovery properties.

However, it is noteworthy that even at lower densities, merino wool samples outperformed other compositions, indicating that fiber composition plays a more dominant role in determining pilling resistance. This reinforces findings by [26], who emphasized the importance of natural fibers, particularly wool, in enhancing surface stability.

The stretchability results highlighted the superior elongation properties of fabrics containing 50% acrylic fibers, which achieved a mean elongation of 17.67% at a density of 340 courses per 10 cm. Acrylics inherent elasticity allows for greater extensibility compared to natural fibers like wool. However, these fabrics also exhibited the highest permanent deformation, indicating reduced recovery and dimensional stability after stretching. This is consistent with the findings of [27-31], who noted similar trade-offs in single-layer acrylic-wool blends.

In contrast, fabrics with 100% merino wool displayed the lowest elongation but superior recovery, as evidenced by the smallest permanent deformation percentages. This suggests that while merino wool may limit the extensibility of fabrics, it enhances their ability to maintain structural integrity after mechanical stress. Such properties are desirable for applications where dimensional stability is critical, such as technical textiles or high-performance apparel.

Overall, the results of this study provide valuable insights for textile designers and manufacturers seeking to optimize the performance characteristics of double-layer knitted fabrics. Fiber composition and knitting density should be carefully considered to achieve the desired balance of pilling resistance and stretchability, depending on the intended end-use applications [12,19,20,32].

The effect of knitting density on stretchability was also significant. Higher densities (350 courses per 10 cm) generally reduced elongation across all compositions. This reduction can be explained by the tighter fabric structure, which restricts fiber mobility and limits overall extensibility. Similar trends were reported by [12,33], who found that increasing density in knitted fabrics reduced elongation by up to 15% while improving recovery properties.

However, the impact of density was less pronounced than that of fiber composition, particularly for pilling resistance.

The novel contribution of this research lies in its focus on double-layer knitted fabrics, which allow for the integration of diverse fiber properties. While prior studies have largely concentrated on single-layer structures, this work demonstrates the unique advantages and challenges of designing double-layer textiles to achieve specific mechanical properties.

This research underscores the practical applications for textile design. Merino wool fabrics are well-suited for durable end-uses such as outerwear, while acrylic blends are more appropriate for stretchable garments like sportswear. Achieving the optimal balance between pilling resistance and stretchability is crucial, with dense natural fibers favoring robustness and synthetic blends enhancing comfort. The innovative potential of double-layer textile constructions lies in their ability to integrate complementary fiber properties to meet diverse performance requirements.

To further develop this research, expanding the range of fiber compositions and knitting densities could provide a more complete understanding of the factors affecting mechanical properties. Additionally, evaluating the long-term durability of these fabrics under real-world conditions, such as repeated washing and wear, would enhance the practical relevance of the findings. Exploring other performance attributes, like thermal insulation, air permeability, and moisture-wicking, would allow for a more comprehensive assessment of double-layer textile structures.

The discussion highlights the significant influence of yarn composition and knitting density on the mechanical properties of double-layer knitted fabrics. By systematically evaluating these factors, this study provides actionable insights for optimizing textile design to meet specific performance requirements. These findings lay the groundwork for future innovations in high-performance textile engineering, enabling the development of fabrics that balance durability, flexibility, and comfort.

Conclusion. This study investigated the pilling resistance and stretchability of double-layer knitted fabrics produced from natural and synthetic yarns.

1. This study systematically investigated the pilling resistance and stretchability of double-layer knitted fabrics composed of natural and synthetic yarns. The key findings are:

– 100% merino wool demonstrated the highest pilling resistance, achieving a mean score of 4.75 at a knitting density of 350 courses per 10 cm. Fabrics containing 50% acrylic fibers exhibited the greatest elongation, reaching a mean value of 17.67% at 340 courses per 10 cm;

– Increasing knitting density consistently enhanced pilling resistance while slightly reducing stretchability across all tested compositions. This highlights the inherent trade-offs in fabric design, where durability and flexibility often conflict;

– The unique advantages of double-layer textile constructions were apparent, allowing for the integration of complementary fiber properties to meet diverse performance requirements.

2. The research findings underscore the significance of customizing fiber composition and knitting density to fulfill specific application requirements. High-density fabrics containing natural fibers like merino wool are well-suited for durable applications necessitating longevity and aesthetic appeal, such as outerwear and upholstery. Conversely, acrylic blends, with their enhanced flexibility, are more appropriate for stretchable garments like sportswear. These insights provide actionable guidance for textile designers aiming to optimize fabric properties for targeted end-use applications.

3. The unique construction of double-layer knitted fabrics allows for the integration of complementary fiber properties. By utilizing distinct layers, these fabrics can strike a balanced equilibrium between durability, flexibility, and aesthetic appeal. This versatile design makes them a compelling solution for addressing diverse performance requirements in the fashion and technical textile sectors.

4. While the current study offers valuable insights, there are several limitations that merit further investigation:

– Expanding the range of fiber compositions and knitting densities examined would provide a more comprehensive understanding of the factors influencing the mechanical properties of these fabrics;

– Assessing the long-term durability of the fabrics under real-world conditions, such as repeated washing and wear, is essential to validate their practical applications;

– Exploring additional performance attributes, including thermal insulation, air permeability, and moisture-wicking, would enable a more holistic evaluation of the double-layer knitted fabric structures. Future research could also investigate the environmental sustainability of these fabrics, such as their biodegradability and the life cycle impact of natural and synthetic fiber blends.

5. This study makes a significant contribution to the field of high-performance textiles by providing a systematic analysis of double-layer knitted fabrics, a relatively underexplored area. The findings establish a foundation for optimizing textile design, supporting the development of fabrics that meet specific functional and aesthetic needs. By bridging the gap between material science and practical application, this research paves the way for innovative fabric solutions that cater to evolving industry demands.

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Received: 30 November 2024
Accepted: 12 February 2025

И.М. Джуринская[1], И.Б. Ташмуханбетова[1]

[1]Алматы технологиялық университеті, Алматы қ., Қазақстан

ТАБИҒИ ЖӘНЕ ХИМИЯЛЫҚ ЖІПТЕРДЕН ЖАСАЛҒАН ЕКІ ҚАБАТТЫ ТОҚЫМА ҚҰРЫЛЫМДАРДЫҢ ПИЛЛИНГКЕ ТӨЗІМДІЛІГІ МЕН СЕРПІМДІЛІГІН ЗЕРТТЕУ

Аңдатпа. Табиғи және химиялық жіптерден жасалған екі қабатты тоқыма құрылымдарының физикалық-механикалық қасиеттері зерттелді. Пиллингке төзімділік және серпімділік көрсеткіштері ГОСТ және BS стандарттарына сәйкес жүргізілген эксперименттер негізінде анықталды. Бұл қасиеттерге жіптердің құрамы мен тоқыма тығыздығының әсері анықталды. 100% меринос жүнінен жасалған үлгілердің пиллингке ең жоғары төзімділік көрсеткені белгілі болды, бұл көрсеткіш 350 курстық тығыздықта 4,75 орташа балға жетті. Серпімділік сынақтары құрамында 50% акрил бар қоспалардың ең үлкен созылу көрсеткішін 340 курстық тығыздықта 17,67% орташа мәнмен қамтамасыз еткенін көрсетті. Талшық құрамы, тоқыма тығыздығы және олардың механикалық қасиеттері арасындағы байланыс анықталды. Алынған нәтижелер екі қабатты тоқыма құрылымдарының дизайндарын белгілі бір функционалдық талаптарға сай оңтайландыру үшін негіз болып табылады.

Тірек сөздер: екі қабатты тоқыма құрылымдары, пиллинг, серпімділік, табиғи жіптер, химиялық жіптер, тоқыма тығыздығы, тоқыма қасиеттері.

И.М. Джуринская[1], И.Б. Ташмуханбетова[1]

[1]Алматинский технологический университет, г. Алматы, Казахстан

ИССЛЕДОВАНИЕ ПИЛЛИНГОСТОЙКОСТИ И РАСТЯЖИМОСТИ ДВУХСЛОЙНЫХ ТРИКОТАЖНЫХ КОНСТРУКЦИЙ, ПРОИЗВЕДЕННЫХ ИЗ НАТУРАЛЬНЫХ И ХИМИЧЕСКИХ НИТЕЙ

Аннотация. Изучены физико-механические свойства двухслойных трикотажных конструкций, изготовленных из натуральных и химических нитей. Пиллингоустойчивость и растяжимость определялись на основе экспериментов, проведённых в соответствии с требованиями стандартов ГОСТ и BS. Установлено влияние состава нитей и плотности вязания на указанные свойства. Образцы, изготовленные из 100% мериносовой шерсти, показали наивысшую пиллингоустойчивость, среднее значение которой составило 4,75 балла при плотности 350 курсов на 10 см. Тесты на растяжимость продемонстрировали, что смеси, содержащие 50% акрила, обладали наибольшим удлинением со средним значением 17,67% при плотности 340 курсов на 10 см. Выявлена взаимосвязь между составом волокна, плотностью вязания и механическими свойствами трикотажных полотен. Полученные результаты создают основу для оптимизации проектирования двухслойных трикотажных конструкций в соответствии с конкретными функциональными требованиями.

Ключевые слова: двухслойные трикотажные конструкции, пиллинг, растяжимость, натуральные нити, химические нити, плотность вязания, текстильные свойства.