INFLUENCE OF PRELOADING PARAMETERS ON THE MECHANICAL PROPERTIES OF VISCOSE YARN

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This study investigates the influence of controlled preload magnitude and duration on the mechanical properties of 15 tex viscose yarn. A central composite experimental design was used to examine how preload parameters (preload magnitude and duration) affect the breaking force, tenacity, and breaking elongation of the yarn. The results show that preload magnitude is the dominant factor governing yarn behavior, whereas preload duration has only a minor effect. Moderate intermediate preloading (preload magnitude, F_n = 84.8 cN/thread, for a preload duration of T_n = 2.0 hours) increased the yarn's breaking force and tenacity by approximately 30–34% compared with the unloaded state. This improvement is attributed to increased fiber alignment and structural consolidation within the yarn. However, the enhanced mechanical properties were accompanied by a reduction of approximately 24% in breaking elongation, indicating decreased extensibility. These findings demonstrate that preload application can be used as a practical process parameter to tailor yarn performance for textile applications, particularly where higher mechanical properties are required, such as in knitting. The outcomes provide useful guidance for optimizing yarn preparation and improving the mechanical reliability of viscose-based textile products.

Keywords: viscose yarn, knitting, breaking force, tenacity, elongation, mechanical properties

Introduction

Viscose (rayon), also known as regenerated cellulose, accounts for the dominant share of man-made cellulosic fiber (MMCF) and is among the most widely used MMCFs. It is highly valued for its softness, breathability, and versatility, accounting for approximately 80% of global MMCF production. In 2024, worldwide viscose production reached approximately 6.7 million tonnes, accounting for nearly 6% of global fiber production [1]. Produced primarily from wood pulp and increasingly from recycled textile waste, viscose combines the comfort and moisture-management characteristics of natural fibers with the processing efficiency of synthetic materials. In parallel, growing sustainability initiatives have intensified research into eco-responsible viscose production and recycling technologies, reinforcing its role as a key material in the transition toward circular textile systems [2-4]. Viscose fabrics are widely used in apparel applications due to their smooth handle, high moisture absorbency, and excellent drape, all of which contribute to favorable thermal–physiological comfort. Compared with most synthetic fibers, viscose exhibits greater hygroscopicity and breathability, supporting thermal regulation during wear. However, viscose fibers are also sensitive to moisture and mechanical loading, which may adversely affect their dimensional stability, tensile strength, and elongation behavior [5].

Yarn composition, count, and physico-mechanical properties are key factors influencing knitting performance and the quality of final knitted products. Yarn selection also depends on end-use requirements, fabric design, machine type, and gauge. Therefore, appropriate yarn selection based on its properties is essential for achieving desired product performance and application-specific functionality [6]. During yarn processing and knitting, yarns are subjected to repeated tensile stresses that can lead to structural damage or changes in mechanical properties. Consequently, their mechanical performance is commonly assessed by breaking force and elongation, as variations in these parameters may disrupt loop formation during knitting, impair knitting efficiency, and compromise fabric uniformity [7-10]. Viscose yarns are widely used in the production of knitted fabrics, ranging from lightweight fashion garments to functional textiles [11,12]. Their inherent flexibility and extensibility facilitate the formation of a variety of knit structures, which strongly affect the mechanical properties, dimensional stability, and comfort of the final product. In addition, blending viscose with other fibers, such as cotton or polyester, is also frequently used to enhance durability while retaining desirable tactile properties [8].

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Yarns exhibit pronounced viscoelastic behavior under mechanical loading, meaning that when stresses below the breaking limit are applied and subsequently removed, recovery of the original length is often incomplete and time-dependent. The extent of elastic and plastic deformation is governed by the magnitude and duration of the applied load, as well as the relaxation time, making these factors important for understanding yarn performance during knitting processes [13]. Consequently, the mechanical response of yarns to tensioning, preloading, and relaxation significantly influences final fabric properties, including elongation, breaking strength, and long-term dimensional stability [14]. Building on this, the novelty of the present study lies in the systematic investigation of how preload magnitude and preload duration affect the mechanical behavior of commercially produced 15 tex viscose yarn. Specifically, the study evaluates breaking force, tenacity, and breaking elongation under varying preload conditions. The objective is to identify optimal preloading parameters that minimize structural damage to the yarn, improve loop formation and uniformity during knitting, and ultimately enhance the overall performance and durability of viscose knitted fabrics.

Materials and methods

Materials

This study investigated a 15 tex viscose yarn. The yarn is commercially available and widely used in knitting production.

Methods

The yarn was conditioned under standard atmospheric conditions in accordance with ISO 139:2005 [15], at a temperature of 20 ± 2 °C and a relative humidity of 65 ± 4%. The breaking force, tenacity, breaking elongation, and breaking time were tested in accordance with ISO 2062:2012 [16] and ISO 6939:1988 [17]. The values given are the mean of fifty measurements for the yarn samples before preloading and twenty-five measurements for the yarn samples after preloading.

The mechanical properties were tested using a constant-rate-of-extension tensile testing machine, RT-250, equipped with flat-faced gripping jaws. Straight yarn specimens were mounted under a pre-tension of 0.5 cN/tex to eliminate slack without inducing measurable extension. The distance between the clamps was set to 100 mm, and the crosshead speed was adjusted to 80 mm/min to achieve an average breaking time of approximately 20 seconds.

The experimental data were processed statistically. The Shapiro–Wilk test was used to assess the normality of the primary mechanical characteristics of the yarn.

Experimental planning

The study was designed according to an orthogonal central composite experimental plan (K_{o2}). Two parameters were selected as controlled factors:

- preload magnitude, F_n (x_1), cN/thread,
- preload duration, T_n (x_2), hours.

The factors and their variation levels of the yarn are shown in Table 1.

Table 1. The levels of the factors for the viscose yarn

No	Factors		Levels of variation			Variation
			-1	0	+1	step
1	Preload magnitude	F_n (x_1), cN/thread	28.3	84.8	141.3	56.5
2	Preload duration	T_n (x_2), hour	0.5	2.0	3.5	1.5

The sample preparation followed the methodology described in the paper [14]. The required number of yarn specimens was prepared and mounted as loops (Figure 1a) on a rack-type relaxometer (Figure 1b). The preload magnitude (F_n, x_1) was applied to the yarn, corresponding to 10%, 30%, and 50% of the initial breaking force (F_o), which has levels of variation -1, 0, and +1 or 28.3 cN/thread, 84.8 cN/thread, and 141.3 cN/thread, respectively. For this purpose, the yarn length was fixed at 80 cm, forming loops of 40 cm. After five days of conditioning, the loops were cut into four equal segments and subsequently tested to failure using a tensile testing machine.

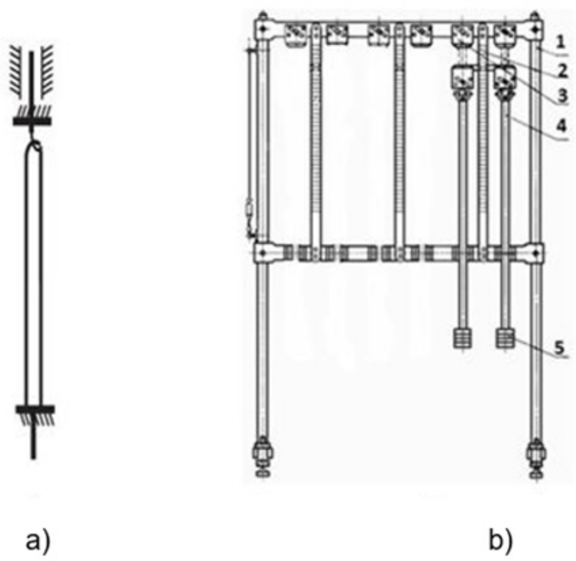

Figure 1. The yarn samples as loops (a) and "rack" relaxometer (b): 1 - stand, 2 - ruler, 3 - clamps, 4 - hanger, 5 – load [14]

Results and discussion

The mechanical properties of the yarn before planning

Table 2 presents the descriptive statistics and results of the normality test for the measured mechanical properties of viscose yarn: breaking force (F_o), tenacity (F_{eo}), breaking elongation (E_o), and breaking time (t_o).

Statistical analysis of the experimental data was performed to determine whether it followed a normal distribution using the Shapiro-Wilk test. The histograms of the normal distribution (*p*-value > α, α = 0.001) with maximum cases (n) for the values for breaking force (F_o), tenacity (F_{eo}), breaking elongation (E_o), and breaking time (t_o) are shown in Figure 2.

Table 2. The main initial mechanical properties of the viscose yarn, tested with the Shapiro-Wilk test

Parameter	The characteristics (significance level α=0.001)			
	F_o, cN	F_{eo}, cN/tex	E_o, %	t_o, s
Average	282.73	18.84	3.34	27.33
P-value	0.009	0.009	0.036	0.005
W-value	0.94	0.94	0.95	0.93
Median	287.6	19.15	3.40	27.25
Standard deviation σ	18.78	1.26	0.60	3.32
Coefficient variation CV, %	6.64	6.64	17.97	12.16

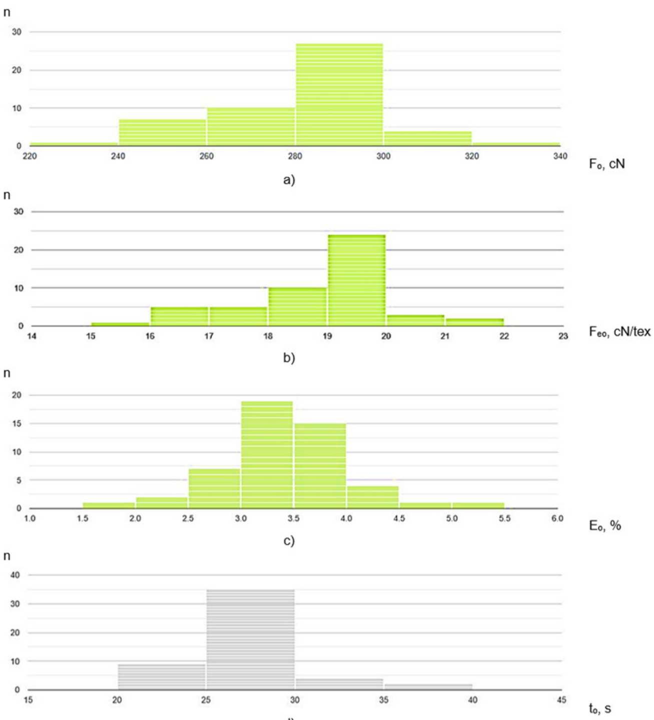

Figure 2. The histogram of the normal distribution of the initial mechanical properties of viscose yarn: a) breaking force (F_o), b) tenacity (F_{eo}), c) breaking elongation (E_o), d) breaking time (to)

The average values indicate that the yarn has an initial breaking force (F_o) of 282.73 cN and a corresponding tenacity (F_{eo}) of 18.84 cN/tex. The average breaking elongation (E_o) is 3.34%, while the average breaking time (t_o) is 27.33 seconds (Table 2). The median values are similar to the averages across all parameters, suggesting that the data distributions are relatively symmetric.

Normality of the data was tested using the Shapiro–Wilk test. The W-values ranged from 0.93 to 0.95, indicating that the datasets are reasonably close to a normal distribution, as presented in Figure 2. However, the p-values for all parameters exceed the α=0.001 threshold, so the null hypothesis (H_0) of normality is accepted. The difference between the sample values and the normal distribution is not statistically significant. A non-significant result can prove that the null assumption cannot be rejected.

The variability of the parameters was measured using the standard deviation and coefficient of variation (CV). The initial breaking force (F_o) and tenacity (F_{eo}) show relatively low variability (CV = 6.64%), indicating a stable breaking force. Conversely, the breaking elongation (E_o) shows much higher variability (CV = 17.97%), meaning that deformation behavior is less uniform than strength. The breaking time (to) also shows moderate variability (CV = 12.16%).

Overall, these results imply that viscose yarn exhibits a consistent breaking force, whereas elongation and fracture time are more affected by structural and material irregularities. This aligns with the viscoelastic nature of regenerated cellulose fibers, where deformation mechanisms tend to be more variable than fracture strength.

Table 3 presents the experimental planning matrix and the corresponding results obtained by varying the preload magnitude (F_n, x_1) and preload duration (T_n, x_2) to evaluate their influence on the yarn's mechanical properties.

Table 3. Planning matrix and research results for yarns after preload

No	Matrix		The mechanical properties of the yarn		
	x_1 (F_n)	x_2 (T_n)	F_p, cN	F_{ep}, cN/tex	E_p, %
1	+	+	350.11±9.50	23.34±0.63	1.73±0.39
2	−	+	372.33±6.96	24.82±0.46	3.56±0.22
3	+	−	343.29±12.42	22.89±0.83	1.97±0.31
4	−	−	386.09±17.62	25.74±1.17	3.34±0.54
5	+	0	354.20±7.71	23.61±0.51	2.02±0.26
6	−	0	392.80±12.22	26.19±0.81	3.53±0.28
7	0	+	385.11±27.80	25.67±1.85	3.46±0.39
8	0	−	343.77±26.04	22.92±1.74	2.89±0.47

The process of yarn deformation and destruction is as follows. When the yarn is stretched, the tension in the fibers increases, causing defects in the fiber structure to develop into cracks, which ultimately result in fiber breakage. During yarn stretching, the weakest fibers break first, shifting stresses to other fibers and causing new ruptures in the more stretched fibers. Breaking some fibers reduces the mutual pressure, friction, and adhesion between them, so the fibers often slide past each other rather than break. In some cases, sharply thinned areas, known as necks, may form in certain fibers due to structural changes in the polymer material that makes up the fibers. Fiber deformation is often linked to the presence of amorphous regions – disordered areas – in the polymer, as well as the fibrillar nature of the fibers and macrodefects in their structure. Along the fiber's length, there are thinned and thickened sections, with cracks forming between them that can lead to fiber breakage [18].

Breaking force of the yarn after the preload

Based on the experimental results and the evaluated significance of the regression coefficients, a second-order polynomial model in coded form was developed to describe the yarn breaking force (F_p):

$$Y\{F_p, cN\} = 367.52 - 16.26\,x_1 + 2.54\,x_1^2 - 8.08 \cdot x_2^2 \qquad (1)$$

The validity of the obtained model was verified by comparing the calculated Fisher coefficient (F_c) with the tabulated value (F_t) at p = 0.95, confirming that $F_c < F_t$.

Using equation (1), which describes the breaking force (F_p) of the viscose yarn, Figure 3 presents the relationship between the yarn breaking force after preload (F_p) and the preload magnitude (F_n, x_1) as well as the preload duration (T_n, x_2).

The coded and actual experimental values for preload magnitude (F_n, x_1) and preload duration (T_n, x_2) are presented in Table 4.

Table 4. The coded and actual experimental values for preload magnitude (F_n, x_1) and preload duration (T_n, x_2)

Factors	The coded and actual experimental values								
	-1.00	-0.75	-0.50	-0.25	0.00	0.25	0.50	0.75	1.00
F_n, cN (x_1)	28.3	42.4	56.6	70.7	84.8	98.9	113.1	127.2	141.3
T_n, hour (x_2)	0.50	0.88	1.26	1.64	2.02	2.40	2.78	3.16	3.54

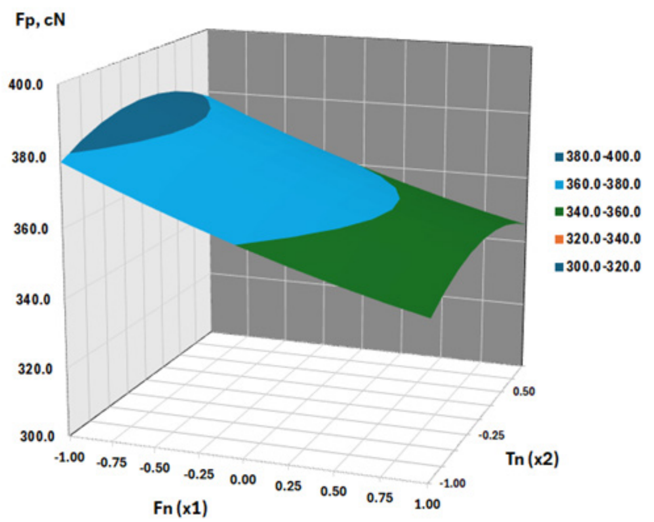

Figure 3. The relationship between the breaking force after preload (F_p), the preload magnitude (F_n, x_1), and the preload duration (T_n, x_2)

The breaking force of the viscose yarn increased after a preload was applied. At an intermediate preload level of the preload magnitude (F_n = 84.8 cN/thread, x_1 = 0) and preload duration (T_n = 2.0 hours, x_2 =0), the breaking force (F_p) was approximately 30.0% higher than that of the yarn before preload (F_o). This suggests that moderate preloading improves the mechanical performance of viscose yarn, most likely by reducing structural irregularities and promoting better fiber alignment within the yarn.

Figure 3 shows that the breaking force of viscose yarn after preload (F_p) is influenced more strongly by the magnitude of the applied preload (F_n, x_1) rather than by its duration (T_n, x_2). When the preload magnitude (F_n) was increased from 28.3 cN/thread (10% of the initial breaking force (F_o)) to 141.3 cN/thread (50% of the initial breaking force (F_o)), and the preload duration (T_n) was varied from 0.5 hours to 3.5 hours, the resulting breaking force after preload (F_p) values ranged from 345.4 to 386.7 cN.

Specifically, increasing the preload magnitude (F_n, x_1) from 28.3 cN/thread to 141.3 cN/thread (a 5-fold increase) caused an 8.7% decrease in breaking force across all preload durations (T_n, x_2). In contrast, extending the preload duration (T_n, x_2) from 0.5 to 3.5 hours resulted in only a 2.2% reduction in breaking force after preload (F_p). These results confirmed that, for viscose yarns, preload magnitude is the dominant factor affecting tensile strength, while preload duration plays a comparatively minor role.

Tenacity of the yarn after the preload

Using the experimental results and the significance of the regression coefficients, a second-order polynomial model in coded form was created to describe the tenacity (F_{ep}):

$$Y\{F_{ep}, cN/tex\} = 25.00 - 1.13\,x_1 + 0.18\,x_1^2 - 0.60 \cdot x_2^2 \qquad (2)$$

The validity of the obtained model was verified by comparing the calculated Fisher coefficient (F_c) with the tabulated value (F_t) at p = 0.95, confirming that $F_c < F_t$.

Equation (2) was used to determine the tenacity after preload (F_{ep}) of the viscose yarn, and Figure 4 shows how the tenacity after preload (F_{ep}) varies with the preload magnitude (F_n, x_1) and preload duration (T_n, x_2).

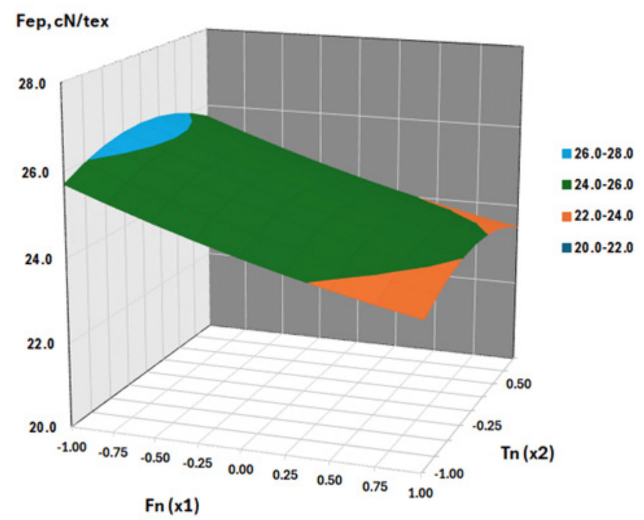

Figure 4. The relationship between tenacity after preload (F_{ep}), the preload magnitude (F_n, x_1), and the preload duration (T_n, x_2)

Figure 4 shows that the tenacity of viscose yarn after preload (F_{ep}) follows the same overall trend as the breaking force after preload (F_p). It is primarily influenced by the magnitude of the applied preload (F_n, x_1), whereas the preload duration (T_n, x_2) has a comparatively minor effect. When the preload magnitude (F_n) was increased from 28.3 cN/thread (10% of the initial breaking force (F_o)) to 141.3 cN/thread (50% of the initial breaking force (F_o)), and the preload duration (T_n) was varied from 0.5 hours to 3.5 hours, the resulting tenacity after preload (F_{ep}) values ranged from 23.45 to 26.31 cN/tex. Similar to the breaking force, the tenacity of the viscose yarn (F_{ep}) increased following preload application. At an intermediate preload magnitude level (F_n = 84.8 cN/thread, or x_1 = 0) and a preload duration (T_n = 2.0 hours, or x_2 =0), the tenacity after preload was approximately 33.7% higher than that of the yarn prior to preloading. This confirms that moderate preload conditions improve the load-bearing capacity of viscose yarns, likely by enhancing fiber alignment and redistributing internal stresses within the yarn structure.

Breaking elongation of the yarn after the preload

Based on the experimental results and emphasizing the significance of the regression coefficients, a second-order equation was developed in coded variables to describe the yarn's breaking elongation (E_p):

$$Y\{E_p, \%\} = 2.70 - 0.64\,x_1 - 0.43 \cdot x_1^2 - 0.09 \cdot x_2^2 \quad (3)$$

The validity of the obtained model was verified by comparing the calculated Fisher coefficient (F_c) with the tabulated value (F_t) at p = 0.95, confirming that $F_c < F_t$.

Figure 5 illustrates the variation in breaking elongation after preload (E_p), calculated from equation (3), as a function of the preload magnitude (F_n, x_1) and the preload duration (T_n, x_2).

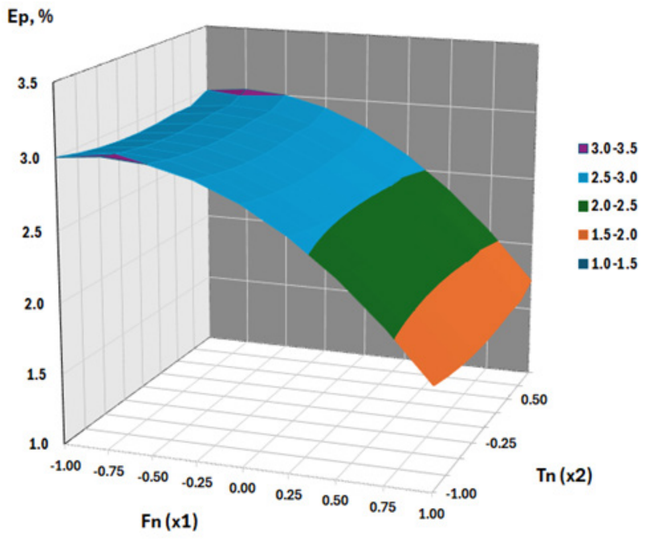

Figure 5. The relationship between breaking elongation after preload (E_p), the preload magnitude (F_n, x_1), and the preload duration (T_n, x_2)

The breaking elongation after preload (E_p) of the viscose yarn decreased after the application of a preload. At intermediate preload levels (F_n = 84.8 cN/thread, x_1 = 0; T_n = 2.0 hours, x_2 = 0), the breaking elongation after preload was approximately 23.7% lower compared to the yarn before preloading. As the preload magnitude (F_n) was increased from 28.3 cN/thread (10% of the initial breaking force (F_o)) to 141.3 cN/thread (50% of the initial breaking force (F_o)), and the preload duration (T_n) was varied from 0.5 hours to 3.5 hours, the resulting breaking elongation after preload (E_p) of the yarn ranged from 1.63 to 3.03 %.

As shown in Figure 5, the breaking elongation after preload (E_p) is predominantly influenced by the magnitude of the applied preload (F_n, x_1) rather than the duration of its application (T_n, x_2). Specifically, increasing the preload from 28.3 cN/thread to 141.3 cN/thread (a fivefold increase) led to a 43.5% reduction in breaking elongation across all tested preload durations. In contrast, extending the preload duration from 0.5 to 3.5 hours resulted in only a minor 3.7% decrease in breaking elongation after preload.

The reduction in elongation at higher preload magnitudes can be explained by structural changes within the yarn. Under higher tensile loading, the fibers become more aligned and compacted along the yarn axis, while fiber crimp and internal structural irregularities are reduced. As a result, the yarn structure becomes more oriented and less capable of further extension during subsequent tensile loading. In addition, higher preload levels may induce partial plastic deformation and reduce the mobility of fibers within the yarn structure, limiting their ability to rearrange during stretching. Consequently, the yarn exhibits lower extensibility and reduced breaking elongation after preloading.

These findings indicate that the yarn's elongation behavior is highly sensitive to the magnitude of the applied preload, while the duration of preloading has a comparatively limited effect.

Conclusion

The results of this study highlight the essential role of preload magnitude in affecting the mechanical properties of 15 tex viscose yarn. Moderate preloading at an intermediate level of preload magnitude (F_n = 84.8 cN/thread) and preload duration (T_n = 2.0 hours) resulted in a substantial improvement in breaking force and tenacity, with increases of approximately 30–34% after preloading. This enhancement is likely associated with improved fiber alignment and a reduction in structural irregularities within the yarn. At the same time, breaking elongation decreased by approximately 24%, indicating a trade-off between increased strength and reduced extensibility.

These findings suggest that precise regulation of the preload magnitude may be an effective strategy to enhance yarn strength and tenacity during textile manufacturing, whereas preload duration appears to be a secondary factor with minimal impact. Integrating these insights into yarn processing and quality assurance practices can optimize yarn performance in knitting operations, thereby facilitating the production of fabrics with more uniform mechanical properties. The ultimate objective of optimizing preloading parameters is to minimize structural damage to the yarn, improve loop formation and loop uniformity during knitting, and consequently enhance the performance, dimensional stability, and durability of viscose knitted fabrics.

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Izvod

UTICAJ PARAMETARA PREDOPTEREĆENJA NA MEHANIČKA SVOJSTVA VISKOZNE PREĐE

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Ova studija istražuje uticaj kontrolisane veličine predopterećenja i njenog trajanja na mehanička svojstva 15 teks viskoznog prediva. Primenjen je centralni kompozitni eksperimentalni plan kako bi se ispitalo kako parametri predopterećenja (veličina i trajanje) utiču na prekidnu silu, istrajnost i prekidno istezanje posle predopterećenja. Rezultati pokazuju da je veličina predopterećenja dominantan faktor koji reguliše ponašanje prediva, dok trajanje predopterećenja ima samo mali efekat. Umereno srednje predopterećenje (veličina predopterećenja, F_n = 84.8 cN/nit za trajanje predopterećenja T_n = 2.0 sati) povećalo je silu i relativna prekidna sila prediva za približno 30–34% u poređenju sa neopterećenim stanjem. Ovo poboljšanje se pripisuje povećanom poravnanju vlakana i strukturnoj konsolidaciji unutar prediva. Međutim, poboljšane mehaničke osobine su praćene smanjenjem od oko 24% u prekidnom istezanju, što ukazuje na smanjenu rastezljivost. Ovi nalazi pokazuju da se aplikacija za predopterećenje može koristiti kao praktični parametar procesa za prilagođavanje performansi prediva za njenu primenu u tekstilu, posebno tamo gde su potrebna veća mehanička svojstva, kao što je pletenje. Rezultati pružaju korisne smernice za optimizaciju pripreme prediva i poboljšanje mehaničke pouzdanosti tekstilnih proizvoda na bazi viskoze.

Ključne reči: viskozna pređa, pletenje, prekidna sila, istrajnost, izduženje, mehanička svojstva