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Chord method based differentiation of tensile curves zones in elastic core cotton spun yarns

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This study aims to distinguish different zones within the tensile curves of elastic core-spun yarns using the chord method and to predict the effect of the yarn count, Dorlastan® count, and Dorlastan® draft on the different zones of stress-strain curves. Yarn samples are prepared on industrial-scale spinning machines having different counts (100, 50, 33.33, and 25 tex), three elastane filaments count (156, 78, and 44 dtex), and a range of elastane drafts. The findings reveal a decreasing trend in the difference between the extreme points of the elastic zone, both in terms of elongation and strength, for all yarn counts. Furthermore, the results demonstrate a growing trend in the viscoelastic and viscoelastoplastic part on the shape of the stress-strain curves for yarns 100/156, 50/78, and 25/44 as the Dorlastan® draft and yarn count increase. Conversely, for yarns 33.33/78 and 33.33/25, the Dorlastan count emerges as a significant influencing factor. Statistical analysis reveals that the yarn count and the Dorlastan® draft exert a notable effect on the full course of the stress-strain curves of the elastic core spun yarns. These results provide valuable guidance for industry professionals in developing more durable and dimensionally stable denim fabrics.

Keywords: Chord method, Dorlastan®, Elastic core-spun yarn, Stress-strain curve, Tensile curves, Yarn count

1 Introduction

Elastic core spun yarn structure consists of two components: a continuous multifilament core encased in staple fibres, typically cotton. Cotton fibres remain the preferred choice for the sheath due to their excellent absorbency, breathability, and comfort properties, which are difficult to replicate with synthetic fibres. The cotton fibres covering the elastane core provide the necessary tactile aesthetics to the wearer along with thermo-physiological comfort while the elastane core—often made of Lycra®, Dorlastan®, or spandex®—provides stretch and recovery[1]. The elastane filament in the core simultaneously provides stretch and recovery properties, which provide the wearer with free movement even in tight-fitting garments[2-3]. Consequently, core-spun cotton yarns, with an elastane component in the core and cotton in the sheath, have become quite popular in the textile industry, especially in the denim sector[4-5], because of their enhanced comfort and performance compared to conventional ring-spun yarns. Moreover, elastic yarns are also widely used in hosiery, swimwear, sportswear, lace, and high-performance textiles due to their extensibility and elastic recovery[6]. Various spinning systems such as ring, rotor, friction, and air-jet have successfully produced elastic core-spun yarns[7], improving the strength, durability, and functional properties of fabrics[8].

Previous research has extensively explored the impact of physical parameters on the mechanical properties of elastic core-spun yarns. Su *et al.*[9] investigated the effects of the draw ratio and elastane feed-in angle on core-spun yarns' structure and performance, concluding that a higher feed-in angle improves core coverage and that a draw ratio of 3.5 enhances elastic recovery. Babaarslan[10] reported that elastane positioning has a direct effect on the properties, structure, and performance of core-spun yarns produced on a modified ring-spinning frame. Other studies[8,11-15] investigated the impact of elastane

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draft on tenacity, breaking elongation, and elastic recovery, highlighting its critical role in defining yarn behaviour. Haitham *et al.*[16] analysed the influence of yarn count, cross-section, and spandex ratio on the yield and breaking point of the stress-strain curves of woven fabrics using the Meridith method.

Most existing studies focus primarily on yarn tenacity and breaking elongation, representing only the tensile curve's terminal point. However, understanding the full shape of the stress-strain curve is more informative, as it provides insights into yarn behaviour under varying strain levels. Besides the yarn strength and breaking extension, additional parameters derived from stress-strain curves offer a comprehensive understanding of tensile performance[17].

The behaviour of the tensile curve of elastic core spun yarns is not only a function of the nature and structural arrangement of the constituent fibres in yarn. The variations of the yarn count, the twist factor, and the elastane draft also play a key role in defining the characteristics of the tensile curves of the elastic core spun yarns. Therefore, this study employs the chord method to delineate distinct zones within the tensile curves of the Dorlastan® core spun yarns. The effect of parameters like Dorlastan® draft, Dorlastan® count and yarn count on different zones of the tensile curves of the elastic core spun yarns is investigated and validated through statistical analysis.

2 Materials and Methods

2.1 Materials

Core-spun yarns consist of a two-element structure: a core and a sheath. In this study, Dorlastan® filament was used as the core, while cotton fibres served as the covering material. Table 1 presents the physical and mechanical properties of both components. To produce core-spun yarns with a uniform twist factor of 138, a ring-spinning frame was equipped with a specialised attachment enabling the automatic insertion of the Dorlastan® filament with different percentages at the break of the front drafting roller. This ensured consistent core placement within the drafted cotton fibres, resulting in elastic ring-spun yarns. A schematic illustration of the core-spinning attachment is shown in Fig. 1[18].

Dorlastan® counts of 156, 78, and 44 dtex were used as the core, paired with cotton sheath yarns of 100, 50, 33.33 and 25 tex. The resulting Dorlastan®core spun yarns were designated as 100/156, 50/78, 33,33/78, 33,33/44 and 25/44, respectively. The draft values of Dorlastan® used in this study are given in Table 2.

2.2 Methods

2.2.1 Tensile Test

The tensile properties of the Dorlastan® core spun yarns were assessed using a Lloyd-type dynamometer. A total of 50 specimens are used, with a specimen length of 500 mm. The testing speed was maintained with respect to the 20 ± 3 s of breaking time as specified in NFG 07-002 standard[19]. To ensure reproducibility, specific

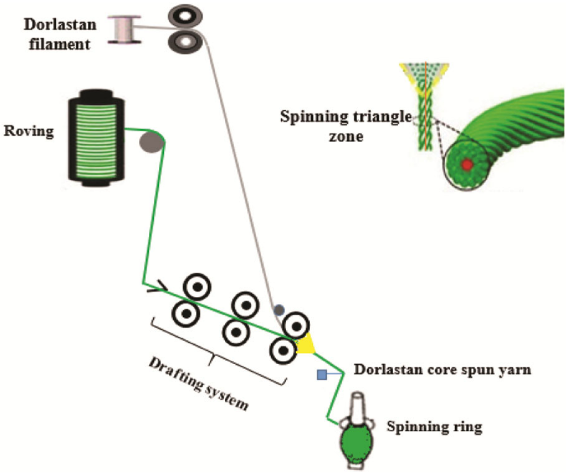


Fig. 1 — Principal of elastic core-spun yarn production[18]

Table 1 — Cotton fibre and Dorlastan® filaments properties

Cotton Fibre

Characteristic	Micronaire, µg/inch	Maturity	UHML, mm	Tenacity, cN/tex	Elongation, %
Mean value	4.06	0.9	29.67	29.26	8.36

Dorlastan® Filament

Count , dtex

156		78		44	
Characteristic	Mean value	Characteristic	Mean value	Characteristic	Mean value
Tenacity, cN	Extensibility %	Tenacity, cN	Extensibility, %	Tenacity, cN	Extensibility, %
175	510	115	500	55	480

Table 2 — Combinations of different ratios and draft values used

100			50			33.33			25		
Dorlastan® count, dtex	%	Draft	Dorlastan® Count, dtex	%	Draft	Dorlastan® Count, dtex	%	Draft	Dorlastan® count, dtex	%	Draft
	4.0	3.90		4.0	3.90	44	4.0	3.30		4	4.40
156	4.5	3.47	78	4.5	3.47		4.5	2.93	44	4.5	3.91
	5.0	3.12		5.0	3.12		5.0	2.64		5	3.52
	5.5	2.84		5.5	2.84		5.5	2.40		5.5	3.20
	6.0	2.60		6.0	2.60	78	6.0	3.90		6	2.93
	6.5	2.40		6.5	2.40		6.5	3.60		6.5	2.71
	7.0	2.23		7.0	2.23		7.0	3.34		7	2.51
	7.5	2.08		7.5	2.08		7.5	3.12		7.5	2.35
	8.0	1.95		8.0	1.95		8.0	2.93		8	2.20

Table 3 — Pretension values

					100/156				
Dorlastan® drafts	3.9	3.47	3.12	2.84	2.6	2.4	2.23	2.08	1.95
Pretension, cN/tex	0.7	0.65	0.64	0.6	0.54	0.52	0.5	0.48	0.43
					50 /78				
Dorlastan® drafts	3.9	3.47	3.12	2.84	2.6	2.4	2.23	2.08	1.95
Pretension, cN/tex	1.11	0.86	0.81	0.79	0.7	0.69	0.63	0.62	0.51
	33.33/44				33.33/78				
Dorlastan® drafts	3.3	2.93	2.64	2.4	3.9	3.6	3.34	3.12	2.93
Pretension, cN/tex	1.15	1.09	1.01	0.97	0.92	0.85	0.79	0.71	0.65
					25/44				
Dorlastan® drafts	4.4	3.91	3.52	3.2	2.93	2.71	2.51	2.35	2.2
Pretension, cN/tex	1.69	1.39	1.34	1.11	1.01	0.93	0.87	0.76	0.79

pretension values were applied to the elastic core spun yarns[20] (Table 3).

2.2.2 Chord Method

To assess the effect of Dorlastan® draft and yarn count on different zones of the stress-strain curves, the variation between the extreme points of each zone in terms of elongation and strength was calculated. The parameters ΔF_i and ΔE_i represent the variation in strength and elongation limiting each zone of the stress-strain curves[21]. The calculations are performed using Eqs. 1 and 2:

$$\Delta F_i(\%) = \frac{(F_{i+1} - F_i)}{F_4} \times 100 \quad (i = 1,2,3,4) \qquad \ldots (1)$$

$$\Delta \mathrm{E_i}(\%) = \frac{(\mathrm{E_{i+1}} - \mathrm{E_i})}{\mathrm{E_4}} \times 100 \quad (\mathrm{i} = 1,2,3,4) \qquad \ldots (2)$$

F_i and E_i (i=1, 2, 3, 4) are presented in Fig. 4. The zones were defined as indicated below::

Elastic zone: [F_1, F_2] and [E_1, E_2]

Visco-elastic zone: [F_2, F_3] and [E_2, E_3]

Visco-elastico-plastic zone: [F_3, F_4] and [E_3, E_4] where F_1 and E_1 refer to the pretension value and the corresponding extension, respectively.

2.2.3 Statistical Analysis

The influence of processing variables on the full stress-strain curve profile of elastic core-spun yarns was assessed through statistical analysis. The collected data were subjected to analysis of variance (ANOVA) to determine the significance of variations. All statistical analyses were conducted using Minitab Statistical Software (version 21.2, Minitab, 2022).

3 Results and Discussion

Figure 2 presents the mean curve of the tensile test for core-spun yarns 100/156, 50/78, 33.33/78, 33.33/44 and 25/44, corresponding to different Dorlastan® draft rates. These curves are the average of 50 tensile tests, plotted using the Meridith method[22].

The experimental results show a similar curve shape of the stress-strain curves for different Dorlastan® drafts across all tested yarns. The primary variation appears at the ultimate point, where

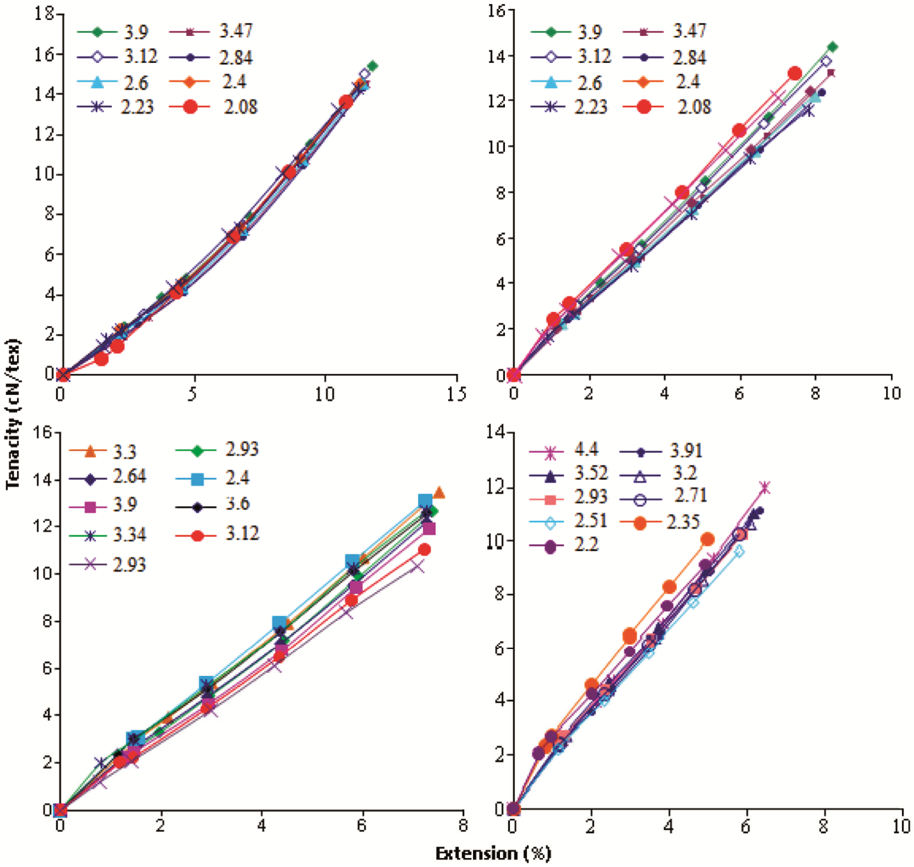


Fig. 2 — Tensile curves of Dorlastan® core-spun yarns (a) 100/156, (b) 50/78, (c) 33.33/78-33.33/44, and (d) 25/44

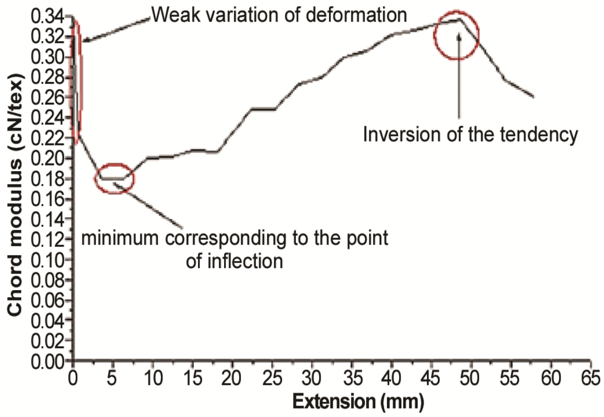


Fig. 3 — Chord modulus for the yarn 100/156 (Dorlastan® draft = 3.47)

breaking tenacity and elongation differ based on the Dorlastan® draft. Thus, distinguishing between different zones of the stress-strain curves using traditional methods proves challenging. To address this, the chord method[21] is employed to determine distinct tensile curve zones for studied yarns. Figure 3 illustrates the tenacity-deformation curve of yarn 100/156 with a Dorlastan® draft of 3.47.

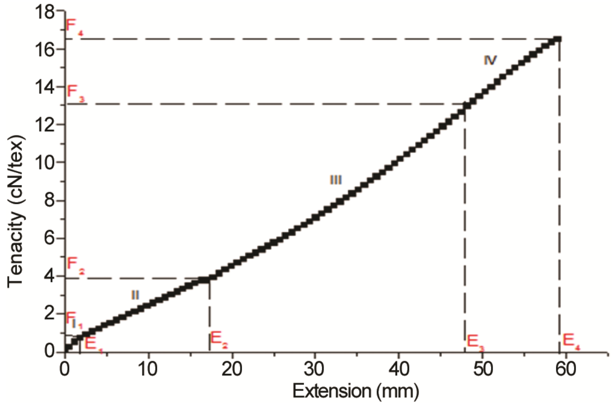


Fig. 4 — Tensile curve for yarn 100/156 (Dorlastan® draft = to 3.47)

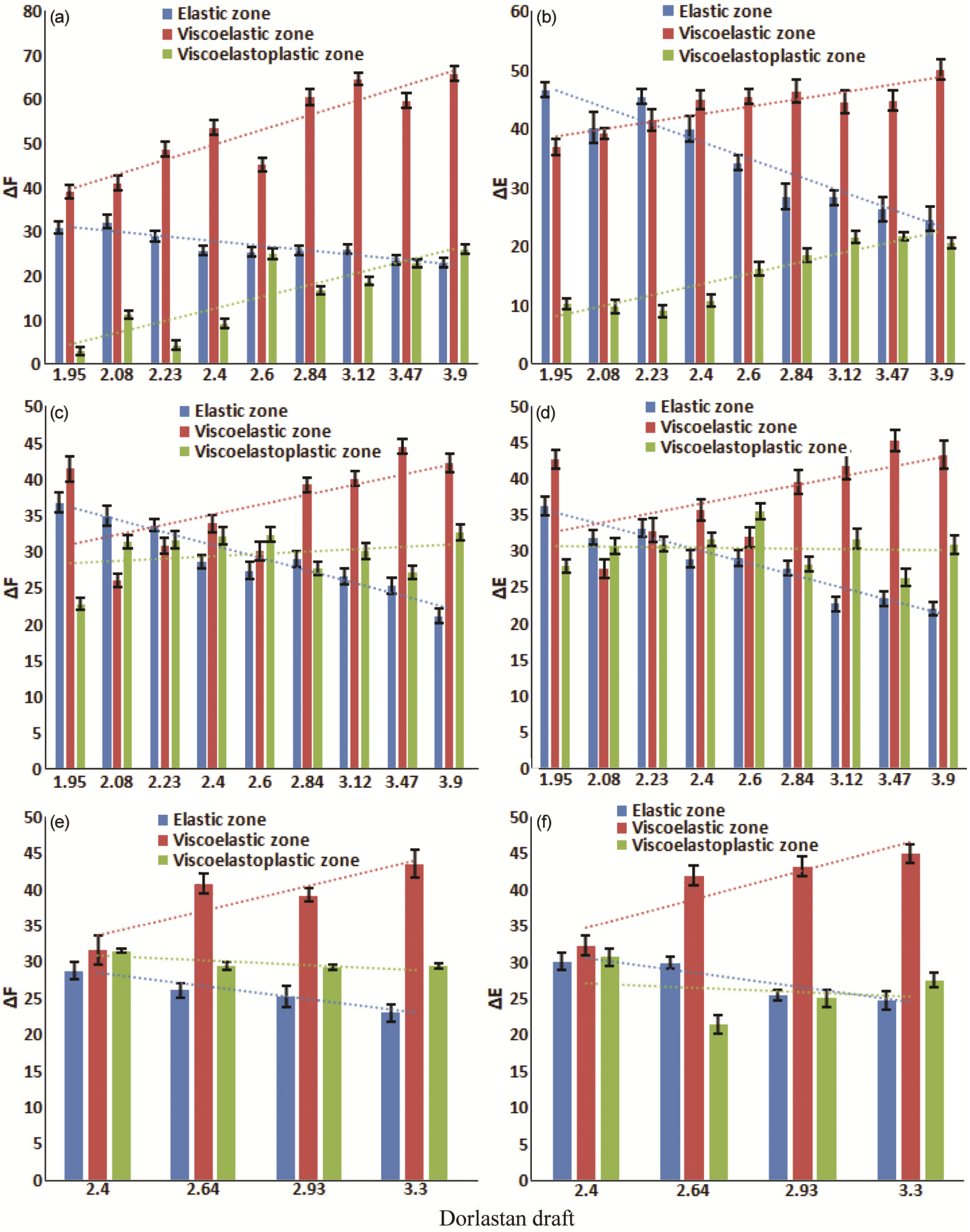
Figure 3 shows the presence of a zone for the weak variation of deformation, a minimum that corresponds to the inflection point that limits the elastic part of the tensile curve and a point of change of the tendency corresponding to the limit of the threshold of the constraint of the viscoelastoplastic part. Therefore, using the Chord method for the elastic core spun yarn 100/156, and for Dorlastan® draft equal to 3.47, four zones (I-IV) are carried out, as shown in Fig. 4.

- zone (I): a region of weak deformation corresponding to the pretension applied.
- zone (II): a linear elastic zone where recovery is total.
- zone (III): a non-linear viscoelastic deformation zone.
- zone (IV): a non-linear viscoelastoplastic zone exhibiting an exponential form.

The same method is applied to determine the different zones for yarns 100/156, 50/78, 33.33/78, 33.33/44 and 25/44 with different Dorlastan® drafts.

3.1 Effect of the Dorlastan® Draft

The variation of ΔE and ΔF *vs*. Dorlastan® draft for the elastic, viscoelastic and viscoelastoplastics zones of the Dorlastan® core spun yarns is shown in Fig. 5.



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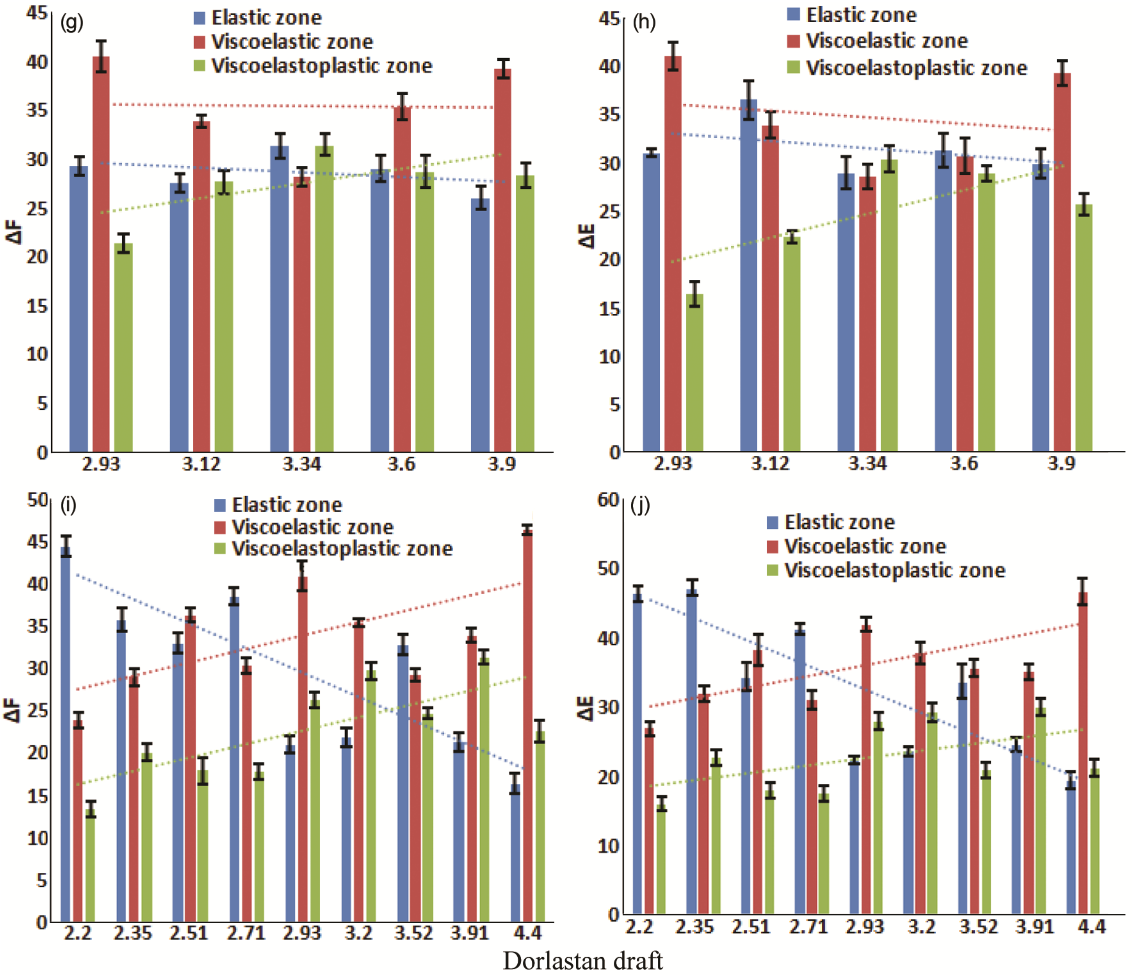

Fig. 5 — Variation of ΔF and ΔE *vs* Dorlastan® draft for different deformation zones (a and b) 100/156, (c and d) 50/78, (e and f) 33.33/78, (g and h) 33.33/44, and (i and j) 25/44

The results reveal a decreasing trend in the proportion of the elastic region within the overall stress-strain curve as the Dorlastan® draft increases. This may be attributed to the reduced core filament ratio after extensive drafting, leading to decreased elasticity. Consequently, the elastic region in the stress-strain curve decreases. Furthermore, the inherently inelastic cotton fibres forming the sheath contribute to restricting the overall stretchability of the yarns[23].

Figure 5 also demonstrates that the viscoelastic zone increases with Dorlastan® draft for yarns 100/156 [Fig. 5 (a) and (b)], 50/78 [Fig. 5 (c) and (d)], and 25/44 (Fig. 5 (i) and (j)]. This can be explained by the enhanced alignment of wrapping fibres around a more stretched core, reducing gaps between the core and sheath[11-12]. Thus, the elastic core spun yarns will be more stretched following the tensile test in the viscoelastic zone. Consequently, the relaxation between the morphological structures of the two materials will be established. Hence, the part of the viscoelastic zone increases. However, in yarns, 33.33/78 and 33.33/44, the effect of Dorlastan® count on the viscoelastic region differs. While the viscoelastic zone increases for yarn 33.33/78 with a higher elastane draft, it decreases for yarn 33.33/44, highlighting the influence of Dorlastan® count on viscoelastic deformation.

Furthermore, the viscoelastoplastic zone increases with higher Dorlastan® draft, particularly for yarns 100/156, 50/78, and 25/44. This trend is attributed to significant sheath fibre slippage supported by a well-stretched core towards the end of the tensile test. The impact of Dorlastan® count on viscoelastoplastic deformation is evident in yarns 33.33/78 and 33.33/44, reinforcing the importance of filament count in tensile behaviour. The confidence intervals of the experimental data confirm minimal errors, ensuring the reliability of the results.

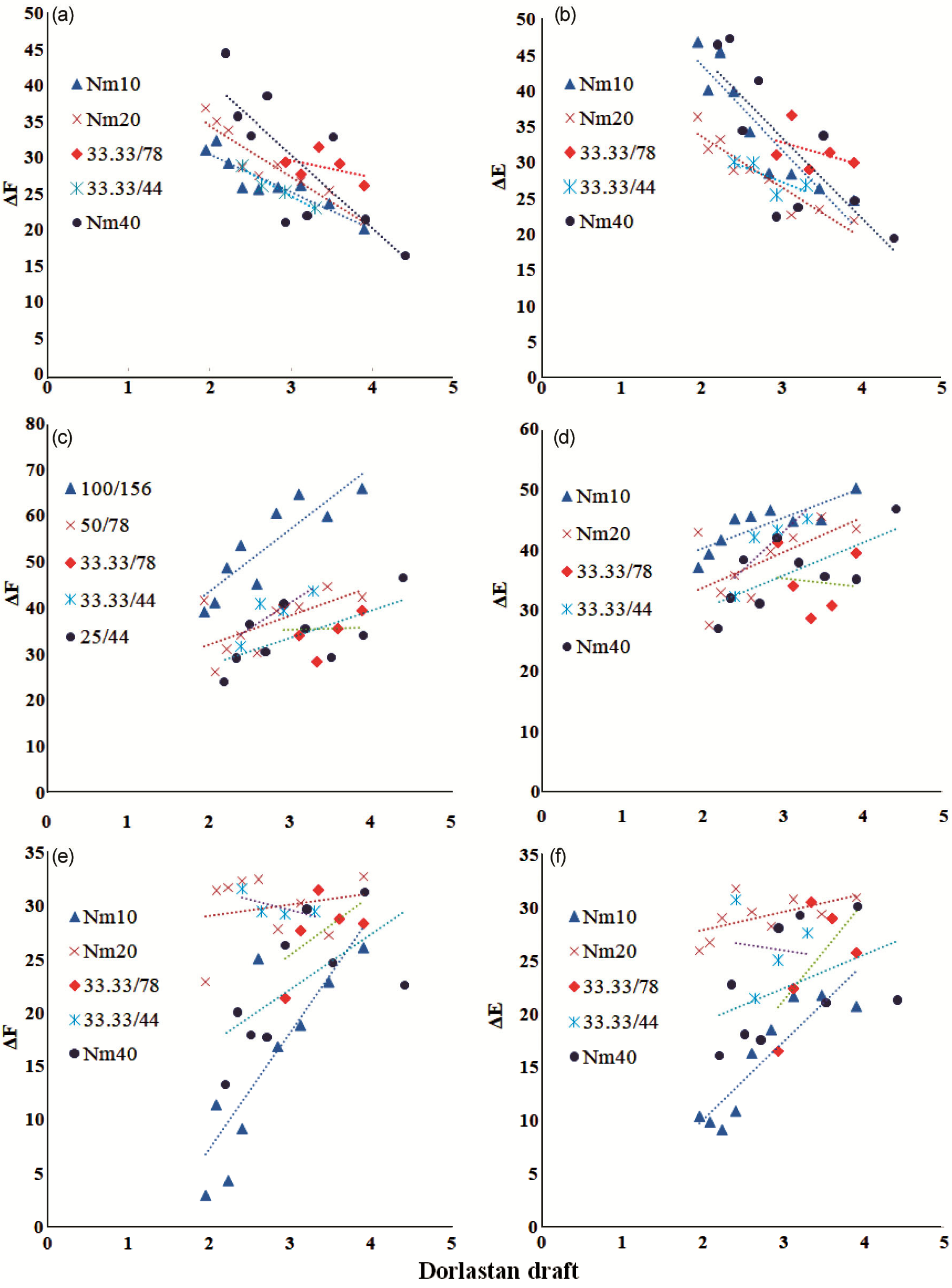

Fig. 6 — Variation of ΔF and ΔE *vs* Dorlastan® draft for (a) & (b) , (c) & (d) viscoelastic zone & viscoelastoplastic zone, and (e) & (f) of Dorlastan® core spun yarns

3.2 Effect of Yarn Count

To study the effect of the yarn count on the different deformation zones of the stress-strain curve, the variation in ΔE and ΔF for the elastic, viscoelastic and viscoelastoplastic zones is plotted as a function of the Dorlastan® draft (Fig. 6).

The results indicate a decreasing trend in viscoelastic deformation with finer yarns, while the

Table 4 — Statistical analysis of processing variables' impact on stress-strain curves of Dorlastan® core-spun yarns

Response	Processing variables	*p*-value	Fisher coefficient
Breaking elongation (%)	X_1: Dorlastan® draft	0.000*	43.91
	X_2 : Dorlastan® count, dtex	0.000*	39.8
	X_3 : yarn count, tex	0.000*	34.64
Tenacity, cN/tex	X_1: Dorlastan® draft	0.030*	16.32
	X_2 : Dorlastan® count, dtex	0.011*	19.98
	X_3 : yarn count, tex	0.385	6.25
$\Delta E_{\text{Elastic zone}}$	X_1: Dorlastan® draft	0.000*	41.91
	X_2 : Dorlastan® count, dtex	0.000*	8.47
	X_3 : yarn count, tex	0.000*	7.71
$\Delta F_{\text{Elastic zone}}$	X_1: Dorlastan® draft	0.000*	52.5
	X_2 : Dorlastan® count, dtex	0.018*	6.17
	X_3 : yarn count, tex	0.005*	9.18
$\Delta E_{\text{Viscoelastic zone}}$	X_1: Dorlastan® draft	0.000*	20.66
	X_2 : Dorlastan® count, dtex	0.007*	8.36
	X_3 : yarn count, tex	0.001*	9.18
$\Delta F_{\text{Viscoelastic zone}}$	X_1: Dorlastan® draft	0.000*	28.75
	X_2 : Dorlastan® count, dtex	0.319	2.88
	X_3 : yarn count, tex	0.027*	12.29
$\Delta E_{\text{Viscoelastoplastic zone}}$	X_1: Dorlastan® draft	0.001*	22.37
	X_2 : Dorlastan® count, dtex	0.144	1.51
	X_3 : yarn count, tex	0.037*	14.72
$\Delta F_{\text{Viscoelastoplastic zone}}$	X_1: Dorlastan® draft	0.000*	10.40
	X_2 : Dorlastan® count, dtex	0.220	6.44
	X_3 : yarn count, tex	0.070	1.8

*Statistically significant for p-value = 0.05

elastic and viscoelastoplastic zones exhibit an increasing trend. This behaviour suggests that finer yarns, with a lower sheath fibre content, exhibit higher elasticity and viscoplasticity. Conversely, coarser yarns, with more wrapping fibres, demonstrate increased viscoelasticity.

3.3 Statistical Analysis

To determine the statistical significance of Dorlastan® draft, Dorlastan® count, and yarn count on the tensile behaviour of core-spun yarns, an analysis of variance (ANOVA) is conducted.

Table 4 shows the degree of influence of processing parameters on the different zones of the tensile curve of the elastic core spun yarn.

The effect of the Dorlastan® draft, the Dorlastan® count, and yarn count on the breaking elongation, $\Delta E_{\text{Elastic zone}}$, $\Delta F_{\text{Elastic zone}}$, and $\Delta E_{\text{Viscoelastic zone}}$ are found statistically significant (p- <0.05) and high values of the Fisher coefficient. However, yarn count does not significantly impact breaking tenacity and $\Delta F_{\text{viscoelastoplastic zone}}$ (p >0.05) and low values of the Fisher coefficient. Moreover, the Dorlastan® count hasn't any impact on the $\Delta F_{\text{viscoelastic zone}}$ and the part of the viscoelastoplastic zone on the shape of the stress-strain curve according to p-values >0.05 and low Fisher coefficient values.

The statistical results highlight that Dorlastan® draft is the only parameter that affects different zones of the shape of the stress-strain curve of the elastic core spun yarns. The comparison of Fisher coefficient values confirms that the Dorlastan® draft has the highest impact on the regression analysis, reaffirming its dominant role on the tensile behaviour of the Dorlastan® core spun yarns.

4 Conclusion

This study analyses the tensile behaviour of Dorlastan® core-spun yarns by examining the influence of Dorlastan® draft, Dorlastan® count, and yarn count on different deformation zones of the stress-strain curve. The findings reveal that an increase in Dorlastan® draft reduces the proportion of the elastic region while the viscoelastic and viscoelastoplastic zones expand. This trend results from the enhanced alignment and stretching of the core filament, which facilitates greater deformation. Yarn count also plays a crucial role, with finer yarns exhibiting increased elasticity and viscoplasticity, whereas coarser yarns demonstrate greater viscoelasticity due to the higher sheath fibre content. The statistical analysis confirms that Dorlastan® draft is the most influential processing variable affecting the stress-strain behaviour of the core-spun yarns. Both Dorlastan® count and yarn count have significant effects, although their influence varies across different deformation zones. These results can be used to study accurately the mechanical behaviour of denim fabrics, such as the dimensional stability and residual bagging, based on the condition of its constitutions. Moreover, these insights provide valuable guidance for optimising processing parameters to tailor the mechanical performance of core-spun yarns for specific applications.

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