Effect tensile behavior of spandex/polyester yarns on the stress–strain curves for woven fabrics

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Abstract:

The main goals of this study were to determine the effect of three yarn structural factors (yarn count, cross section and spandex ratio) and their interactions on tensile and breaking extension properties tensile behavior effect of spandex/polyester spun yarns respective on woven fabrics. Moreover, stress-strain curves were plotted and the yield points and breaking points and their corresponding properties (toughness, stiffness and Initial Young Modulus) were derived. The association between tensile and elongation parameters for spandex/polyester yarn and their woven fabrics was computed using simple correlation coefficient, results explained that all tensile and breaking extension properties significantly increased as the yarn count increased while the effect of cross section was weak or marginal. It is obvious that yield strain, yield stress, breaking extension, breaking tenacity decreased as a result of increasing the spandex content but the decrease percents (%) were generally weak. With respect to the 1st and 2nd order interaction effects, they were no significant for most tenacity and elongation properties of spandex/polyester spun yarns and their respective woven fabrics. The current study appeared that using spandex/polyester spun yarns with lowest spandex content gave the best tensile and breaking extension properties of spandex/polyester spun yarns and their respective woven fabrics. The correlation coefficients between tensile and elongation parameters for spandex/polyester yarn and their corresponding woven fabrics were positive and highly significant (except Initial Young's modulus) indicating that the tensile and breaking extension properties of the spandex/polyester yarns could be used as good indicators for the strength and elongation of fabrics manufactured by these spandex/polyester yarns.

Keywords:

Spandex/Polyester Yarns, Stress-Strain Curves, Tensile And Breaking Extension Properties, Woven Fabrics.

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INTRODUCTION

The use of Spandex has been spectacular since its commercialization in 1970. Spandex (also known as elastane) is a manufactured fiber in which the fiber-forming substance is a long chain synthetic elastomer consisting of at least 85% by weight of segmented polyurethane **(AL-ansary, 2011).** Fabrics containing Spandex have established themselves in variety of end products including knickers, hosiery, swimwear, and sportswear. The extent of the market acceptance of Spandex-based fabrics has been truly phenomenal and one of the most profitable and growing fields in the global textile industry. Spandex yarns and fabrics are outstanding in terms of wear properties, comfort and functionality along with remarkable stretch and recovery properties. These attributes helped in ushering a new era of comfort in the textile industry **(Mathur *et al*., 2008).**

Ghosh *et al*, (2005) described that the yarns tensile and elongation properties play a phenomenal role in the quality of the end products. Knowledge of the full course of the stress–strain curves is more desirable, since it provides the whole information about the behavior of stresses under various levels of strains. Beside the yarn and fabric strength and breaking extension, there are other useful parameters which can be computed from the stress–strain curves. They are work of rupture or toughness, secant modulus or stiffness, Initial Young's Modulus.

The work of rupture or toughness measures the ability of the yarn to absorb energy and as a consequence, withstand a sudden shock. Secant modulus or stiffness is the ratio of change in stress to change in strain between two points of zero and breaking stress. The Initial Young's Modulus is a measure of the force required to produce a small extension and hence it determined the initial resistance to extension **(Kamal *et al*., 1988)**.

It is known that woven fabrics strength and elongation are complex properties that affected by different structural factors. Optimum fabrics strength and elongation properties for a particular end use can be obtained by applying the appropriate structural factors such as yarn count, cross-section, and spandex ratio. Yarn count is a numerical value, which express the coarseness or fineness of yarn and also indicate the relationship between length and weight of that yarn.

Kaynak nd Babaarslan (2015) found that the higher fabric breaking strength are observed using finer filaments in fabric structure. They attributed this result to the higher cohesion force between filaments due to higher total specific surface area of finer filaments in the yarn cross section. Also, they added that the filament fineness have no considerable effect on fabric breaking elongation.

Abdel Daim (2020) used stress-strain curves to indicate that finer yarns of Egyptian cotton were weaker and had lower extension at break than coarser yarns.

Therefore, the main target of this investigation was to determine the effects of three yarn structural factors (yarn count, cross-section, and spandex ratio) and their interactions on the tensile and breaking extension behaviors (stress-strain curves and its correlative parameters) of spandex/polyester spun yarns and their corresponding woven fabrics.

MATERIALS AND METHODS

Lycra polyester material was chosen to be used for the present study. The experimental samples were taken from Octagon for Textile Industries in Al-Obour Industrial City, where the experimental samples were produced using three account yarns of (75, 150, 300) and three cross sections (36, 72, 144) and three spandex ratios were applied (3.5, 7 and 10 %) to study their effects and interactions on the tensile and elongation behaviors of the mechanical properties for a single thread as well as their respective woven fabrics.

The STATIMAT automatic tensile tester was used to measure the single yarn mechanical properties and also to plot the stress-strain curves. The test was performed according to the German Standards (DIN-53-834) under controlled atmospheric conditions. The gauge length of test specimen was 50 centimeters and the time to break that specified by the ASTM was 20 ± 3 seconds. The Load-Elongation curves given by the STATIMAT tester were converted to stress-strain curves by changing the units without affecting the slope or shape of the curve. The stress values were expressed in terms of (Kilogram/Force, Kgf) whereas the corresponding strain values were calculated by dividing the actual elongation by the original test length (50 cm) and were expressed as percentage. In accordance, the stress-strain curves were constructed with the yield points and breaking points. The other points in between were defined according to the values of stress corresponding to each 1% strain.

<u>Tensile strength</u>

Testing method ASTM D1682-64 (1975) is used for recording the tensile properties of fabric in Egyptian Organization for Standards & Quality where the determination of maximum force was done using the grab method in the direction of weft to plot the stress-strain curves by changing the units without affecting the slope or shape of the curve. The stress values were expressed in terms of (Kilogram/Force, Kgf) whereas the corresponding strain values were calculated by dividing the actual elongation by the original test length (20 cm) and were expressed as percentage. In accordance, the stress-strain curves were constructed with the yield points and breaking points. The other points in between were defined according to the values of stress corresponding to each 5% strain. A tensile strength tester brand was “INSTRON” Year of manufacture 2006 and origin was USA. The experimental sample was taken as 5 cm x 20 cm and the sample size was 5 in the direction of weft only, speed tensile the sample was 380 mm/min .

Toughness is expressed as a reliable criterion of the work of rupture and was calculated as one-half the product of breaking tenacity by breaking extension as follows:

$$Toughness = breaking\ tenacity \times breaking\ extension\ (decimal)/2$$

With respect to secant modulus or stiffness, it was calculated as the ratio of breaking tenacity to breaking extension as follows:

$$Stiffness = Breaking\ tenacity\ /Breaking\ extension\ (decimal)$$

The yield stress and yield strain (at the yield point) which were determined form the stress-strain curve, were used to calculate the Initial Young’s Modulus as follows:

$$Initial\ Young's\ Modulus = Yield\ stress\ /\ Yield\ strain\ (decimal)$$

Kamal *et al.* (1988) stated that lower stiffness would produce more flexible fabrics while the yarns of high stiffness would resist deformation by any abrupt changes in tension. The Initial Young’s Modulus is calculated as the ratio of yield stress to yield strain. However, the high initial young’s modulus indicates inextensibility, while low modulus denotes better extensibility.

Weaving specification: It is used 10 picks/cm weft density weaves from the activation of the binary system (1, 2, 4) from the picks with the three used count yarns, so that the use of count yarn 300/1 D with the first order of the binary system and count yarn 150/1 D with the second order of the binary system and finally the count yarn 75/1 D with the third binary system in use , and 40 ends/cm warp density for the samples were , all of the fabrics were woven using structure palin weave 1/1.

<u>Statistical analysis</u>

The collected data were subjected to analysis of variance (ANOVA) as full factorial design with the three yarn structural factors according to the procedure outlined by **Snedecor and Cochran**

(1989). Also, least significant difference (L.S.D.) at 5 % probability level was used to compare the treatment means. The association between tensile and elongation parameters for spandex/polyester yarn and their related woven fabrics was computed using simple correlation coefficient as outlined by **Draper and Smith (1981).** All statistical analyses were automated using SPSS version 13 (**SPSS, 2004**) and Minitab version 14 (Minitab, 2005) statistical packages.

RESULTS AND DISCUSSION

1- Effect of three yarn structural factors on the tensile and elongation behavior of spandex/polyester spun yarns.

1- 1- Main effects

It is worth to define the effects of yarn count, cross-section, and spandex ratio and their interactions on the tensile and breaking extension behavior (stress-strain relationship and its inherent properties) of spandex/polyester spun yarns and their corresponding woven fabrics.

Results in Table (1) and the stress-strain curves in Figure (1) showed how the increase of yarn count would affect the stress-strain curves for spandex/polyester spun yarns. There were significant differences among the average values for the three yarn counts (75, 150 and 300 denier or 1.21, 2.43 and 4.86 denier per filament) for all spandex spun yarns mechanical properties computed from the stress-strain curves indicating that the yarn count had considerable impact on the tensile and elasticity behavior of spandex/polyester spun yarns.

It is clear that yield strain, yield stress, breaking extension, breaking tenacity and toughness significantly increased as the yarn count increased gradually from 75 up to 300 denier. The current results indicate that the finer yarns are more weak compared to the coarser yarns. Subsequently, there are positive association between yarn counts (75, 150 and 300 denier) and tensile behavior of spandex/polyester spun yarns as shown in Fig. (1). There was no clear trend obtained between stiffness and initial Young's modulus and yarn count where their highest values were recorded under yarn count equal 150 denier compared to 300 denier. Using stress-strain curves, **Kamal *et al*. (1988)** proved that the breaking tenacity and breaking extension decreased when the yarn count was gradually increased from (24.6 tex) to (9.8 tex). They stated that the coarser yarns are stronger, more extensible, tougher and have lower initial young's modulus than the finer yarns. They added that secant modulus or stiffness did not strongly affected by yarn count. **Ortlek and Ulku (2007)** found that the effect of yarn count on the tenacity of core-spun vortex cotton yarns was not significant but its effect on the breaking elongation was significant. They stated that the coarser yarns had lower breaking elongation than finer yarns. **Abdel Daim (2020)** modeled stress-strain curves on cotton yarns and explained that yield strain, yield stress, breaking extension and breaking tenacity significantly decreased when the yarn count increased from 20's to 40's Ne. He added that finer yarns are weaker and have lower extension at break than coarser yarns.

Table (1): The yarn count effect on tensile and elongation behavior of spandex/polyester spun yarn as computed from the stress-strain curves.

Yarn count	Denier per filament	Spandex/polyester spun yarn properties						
		Yield strain (%)	Yield stress (kgf)	Breaking extension (%)	Breaking tenacity (kgf)	Toughness (kgf)	Stiffness (kgf)	Initial Young's modulus (kgf)
75	**1.21**	0.144	0.375	1.792	2.777	0.025	155.005	264.936
150	**2.43**	0.199	0.541	1.667	3.186	0.027	192.394	276.095
300	**4.86**	0.264	0.591	2.102	3.915	0.041	187.150	227.434
LSD $_{0.05}$		0.018	0.011	0.037	0.073	0.001	4.72	18.56

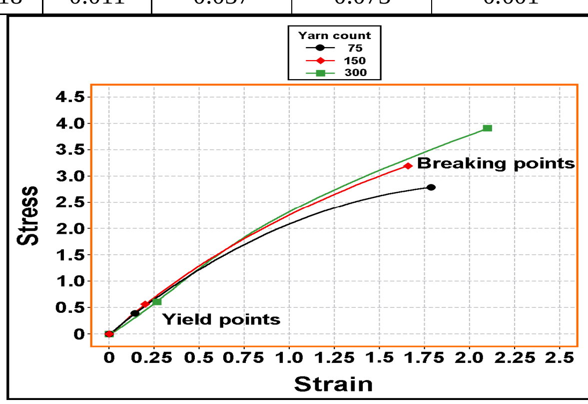


Fig. (1): Stress-strain curves of spandex/polyester spun yarn as affected by yarn count.

Table (2) showed the average values of spandex/polyester spun yarn properties computed from the stress-strain curves as affected by three cross sections being 36, 72 and 144. Results revealed that there were not significant differences among the used three cross sections for all spandex/polyester spun yarn properties indicating that the cross section had marginal effect on the spandex spun yarn properties in the present study. The stress-strain curves for three cross sections as demonstrated in Fig. (2) confirmed the previous results where their yield and breaking points were very close on the graph area. These findings may seem reasonable because the compensatory relationship which means that the minimum yarn cross section (36 filaments) had 4.8 denier per filament while the yarn cross section (144 filaments) had only 1.21 denier per filament which ultimately gives convergent behavior with respect to the yarn properties of tenacity and elasticity.

Table (2): The cross section effect on tensile and elongation behavior of spandex/polyester spun yarn as computed from the stress-strain curves.

Cross section	Denier per filament	Spandex/polyester spun yarn properties						
		Yield strain (%)	Yield stress (kgf)	Breaking extension (%)	Breaking tenacity (kgf)	Toughness (kgf)	Stiffness (kgf)	Initial Young's modulus (kgf)
36	**4.86**	0.209	0.509	1.857	3.356	0.031	179.871	252.933
72	**2.43**	0.203	0.504	1.852	3.267	0.031	176.499	255.870
144	**1.21**	0.195	0.495	1.852	3.256	0.031	178.179	259.662
LSD 0.05		NS	NS	NS	NS	NS	NS	NS

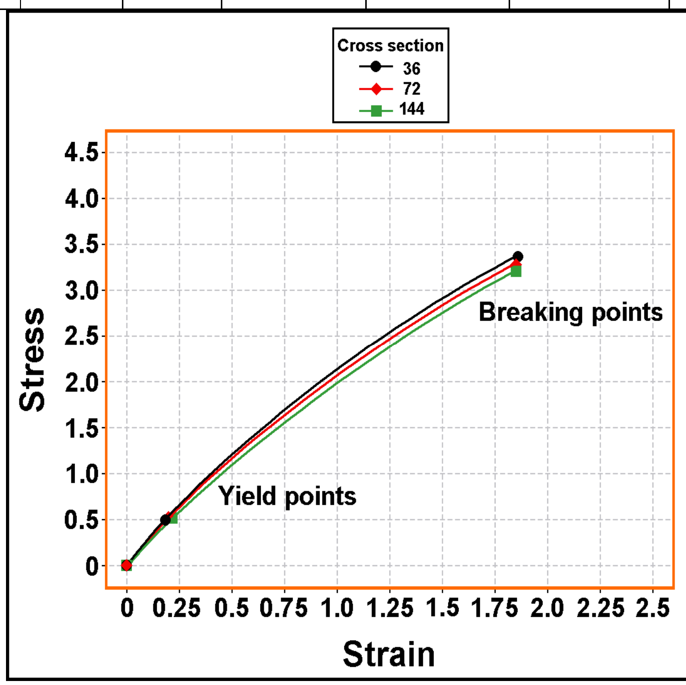


Fig. (2): Stress-strain curves of spandex/polyester spun yarn as affected by yarn cross section.

The effect of three spandex ratios (3.5, 7 and 10 %) on tensile and elongation behaviors of spandex/polyester yarns are tabulated in Table (3) and diagrammed plotted in stress-strain curves as shown in Fig. (3).

No significant differences were detected among the three spandex ratios (3.5, 7 and 10 %) for all tensile behavior of spandex/polyester yarns except yield strain and yield stress. Generally, it is clear that yield strain, yield stress, breaking extension, breaking decreased as a result of increasing the spandex ratios from 3.5 up to 10 % but the decrease ratios were generally minor or trivial. The current results concluded that the spandex ratio had slight effect on the tenacity and breaking elongation properties of spandex/polyester spun yarn. Testing Fig. (3), it is easily to note that the stress-strain curves of spandex/polyester spun yarn as affected by the spandex ratio (3.5, 7 and 10) are almost identical. **Ortlek and Ulku (2007)** stated that core-spun vortex cotton yarns containing spandex ratio reflected lower tenacity and higher breaking elongation values than core-spun vortex cotton yarns without spandex ratio**.**

Table (3): The spandex ratio effect of on tensile and elongation behavior of spandex/polyester spun yarn as computed from the stress-strain curves.

Spandex ratio	Spandex/polyester spun yarn properties						
	Yield strain (%)	Yield stress (kgf)	Breaking extension (%)	Breaking tenacity (kgf)	Toughness (kgf)	Stiffness (kgf)	Initial Young's modulus (kgf)
3.5 %	0.218	0.521	1.870	3.308	0.031	176.528	246.474
7 %	0.202	0.504	1.852	3.293	0.031	178.382	256.833
10 %	0.187	0.483	1.838	3.278	0.030	179.639	265.158
LSD $_{0.05}$	0.018	0.011	NS	NS	NS	NS	NS

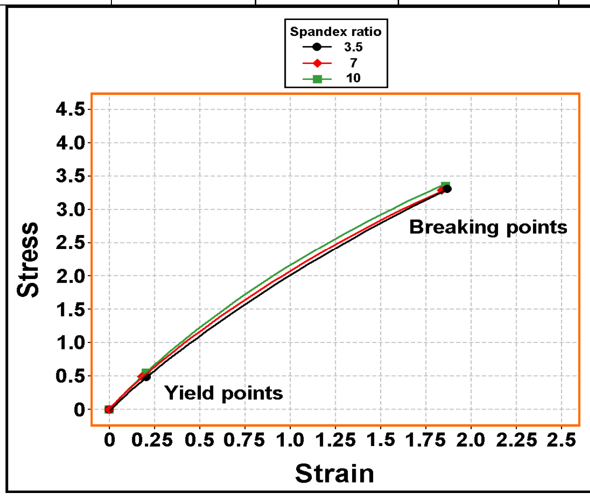


Fig. (3): Stress-strain curves of spandex/polyester spun yarn as affected by spandex ratio.

1- 2- First-order interaction effects

When spandex ratio was held constant, the mean values of spandex/polyester spun yarn properties computed from the stress-strain curves as affected by the first-order interaction between yarn count and cross section are shown in Table (4). Also, Stress-strain curves of for the three cross sections under the each yarn count are plotted in Fig. (4).

Results presented in Table (4) revealed that the yarn count x cross section interaction effect was significance for all tensile behavior of spandex/polyester spun yarn except yield strain and initial Young's modulus. The significant interaction means that mechanical properties of spandex/polyester spun yarns are differently responded for increasing cross section under different yarn counts. As a comprehensive view of the contents of Table (4), it is obvious that the effect of yarn count was more pronounced compared to the cross section effect. Results explained that the maximum values of yield strain, yield stress, breaking tenacity and stiffness were recorded when spandex/polyester yarns were spun using yarn count (300 D) and cross section (36) with denier per single filament equal 8.33. However, the breaking extension and work of rupture, expressed in terms of toughness property reflected the highest values using yarn count (300 D) and cross section (72 or 144).

As a general trend, it is clear from stress-strain curves (Fig. 4) that the coarser yarns with fewer fibers in the cross section are more stronger, good elasticity and more capable to absorb and withstand a sudden shock of energy and hence they are more durable than the finer yarns.

Table (4): The effect of yarn count x cross section interaction on tensile and elongation behavior of spandex/polyester spun yarn as computed from the stress-strain curves.

Yarn count	Cross section	Denier per filament	Spandex/polyester spun yarn properties						
			Yield strain (%)	Yield stress (kgf)	Breaking extension (%)	Breaking tenacity (kgf)	Toughness (kgf)	Stiffness (kgf)	Initial Young's modulus (kgf)
75	**36**	**2.08**	0.150	0.398	1.750	2.719	0.024	155.419	269.526
	72	**1.04**	0.144	0.373	1.799	2.779	0.025	154.513	265.157
	144	**0.52**	0.139	0.354	1.828	2.834	0.026	155.082	260.126

150	**36**	**4.17**	0.202	0.528	1.866	3.338	0.031	179.036	264.512
	72	**2.08**	0.200	0.544	1.629	3.109	0.025	191.124	276.223
	144	**1.04**	0.194	0.553	1.506	3.110	0.024	207.023	287.549
300	**36**	**8.33**	0.274	0.602	1.955	4.011	0.039	205.158	224.762
	72	**4.17**	0.265	0.595	2.128	3.911	0.042	183.860	226.230
	144	**2.08**	0.252	0.578	2.222	3.824	0.042	172.432	231.312
LSD $_{0.05}$			NS	0.02	0.063	0.127	0.002	8.17	NS

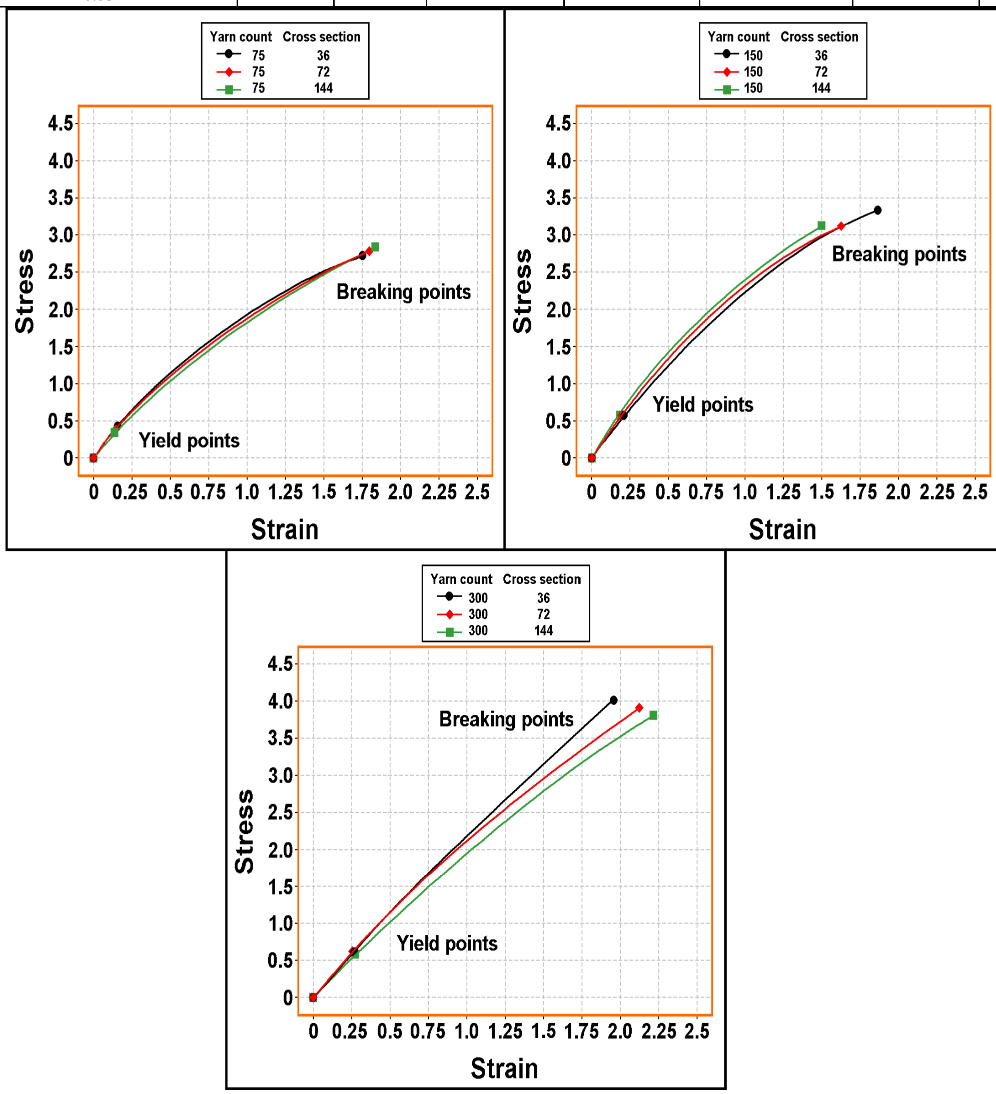


Fig. (4): Stress-strain curves of spandex/polyester spun yarn as affected by the interaction effect between yarn count and cross section.

Results in Table (5) summarized the mean averages of spandex/polyester spun yarn properties as affected by the 1st order interaction effect between yarn count and spandex ratio considering the cross section was held constant. As well as, the effect of this interaction on the tensile and elongation behavior of spandex/polyester yarns (stress–strain curves) is portrayed in Fig. (5).

Results showed that the yarn count x spandex ratio interaction effect was significant for all tensile and elongation properties except for yield strain, stiffness and initial Young's modulus. Looking at the stress-strain curves (Fig. 5), under each spandex ratio value, it is obvious that yield stress, breaking extension and breaking tenacity, work of rupture or toughness increased with each increment in yarn count from 75 D up to 300 D. On the contrary, the tensile and elongation properties tended to decrease when the spandex ratio increased from 3.5 up to 10 % but with minor decrease ratios. In accordance, the best tensile and extension properties was observed when using yarn count (300 D) plus spandex ratio (3.5 %) as shown in Table (5). The current results may be returned to that the most loading stress in the spandex/polyester yarns is depended on the less extensible part of staple fibers while the small spandex content has weak contribution in the yarn strength. These results are in harmony with those obtained by **Ortlek and Ulku (2007)** who found that the tenacities of core-spun vortex yarns decreased with increasing spandex ratio.

Table (5): The effect of yarn count x spandex ratio interaction on tensile and elongation behavior of spandex/polyester spun yarn as computed from the stress-strain curves.

Yarn count	Spandex ratio	Spandex/polyester spun yarn properties						
		Yield strain (%)	Yield stress (kgf)	Breaking extension (%)	Breaking tenacity (kgf)	Toughness (kgf)	Stiffness (kgf)	Initial Young's modulus (kgf)
75	**3.5 %**	0.162	0.404	1.737	2.647	0.023	152.478	255.858
	7 %	0.145	0.377	1.785	2.764	0.025	154.910	265.430
	10 %	0.126	0.344	1.854	2.921	0.027	157.626	273.522
150	**3.5 %**	0.215	0.552	1.695	3.203	0.027	189.385	261.017
	7 %	0.195	0.543	1.680	3.214	0.027	192.659	278.767
	10 %	0.186	0.530	1.626	3.140	0.026	195.139	288.500
300	**3.5 %**	0.276	0.606	2.179	4.073	0.044	187.721	222.548
	7 %	0.267	0.592	2.090	3.900	0.041	187.577	226.302
	10 %	0.248	0.576	2.036	3.773	0.038	186.153	233.453
LSD $_{0.05}$		NS	0.020	0.063	0.127	0.002	NS	NS

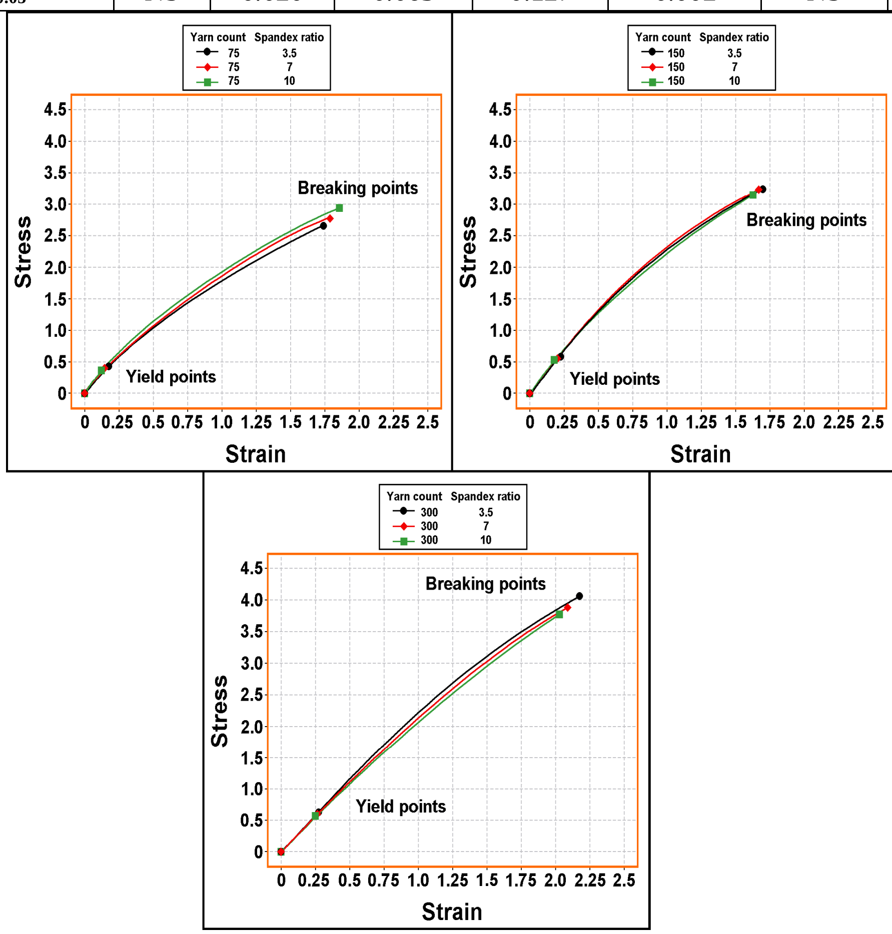


Fig. (5): Stress-strain curves of spandex/polyester spun yarn as affected by the interaction effect between yarn count and spandex ratio.

The cross section x spandex ratio interaction effect on the spandex/polyester spun yarn properties and their corresponding stress-strain curves are presented in Table (6) and are graphically plotted in Fig. (6), respectively.

It is shown that the interaction effect was not significant for all spandex/polyester spun yarn properties except breaking extension meaning that the effect of spandex ratio on spandex/polyester spun yarn properties was relatively weak and similar under each cross section except breaking extension. Results of stress-strain curves under each cross section cleared that the highest yarn strength and higher energy-absorbing capacity were obtained by using the lowest spandex ratio (3.5 %) proving the negative relationships between spandex ratio and the tensile and elongation properties regardless the cross section. The breaking extension and breaking tenacity values were only increased with increasing spandex ratio from 3.5 up to 10 % under cross section (36).

Table (6): The effect of cross section x spandex ratio interaction on tensile and elongation behavior of spandex/polyester spun yarn as computed from the stress-strain curves.

Cross section	Spandex ratio	Spandex/polyester spun yarn properties						
		Yield strain (%)	Yield stress (kgf)	Breaking extension (%)	Breaking tenacity (kgf)	Toughness (kgf)	Stiffness (kgf)	Initial Young's modulus (kgf)
36	3.5 %	0.225	0.531	1.825	3.339	0.031	181.263	242.868
	7 %	0.209	0.508	1.863	3.343	0.031	178.696	254.227
	10 %	0.192	0.488	1.884	3.386	0.032	179.653	261.705
72	3.5 %	0.219	0.521	1.890	3.288	0.032	173.397	246.181
	7 %	0.203	0.508	1.843	3.257	0.030	176.754	256.177
	10 %	0.186	0.483	1.822	3.255	0.030	179.346	265.253
144	3.5 %	0.209	0.510	1.896	3.296	0.032	174.923	250.374
	7 %	0.195	0.496	1.850	3.279	0.031	179.696	260.095
	10 %	0.181	0.478	1.810	3.194	0.029	179.919	268.518
LSD $_{0.05}$		NS	NS	0.063	NS	NS	NS	NS

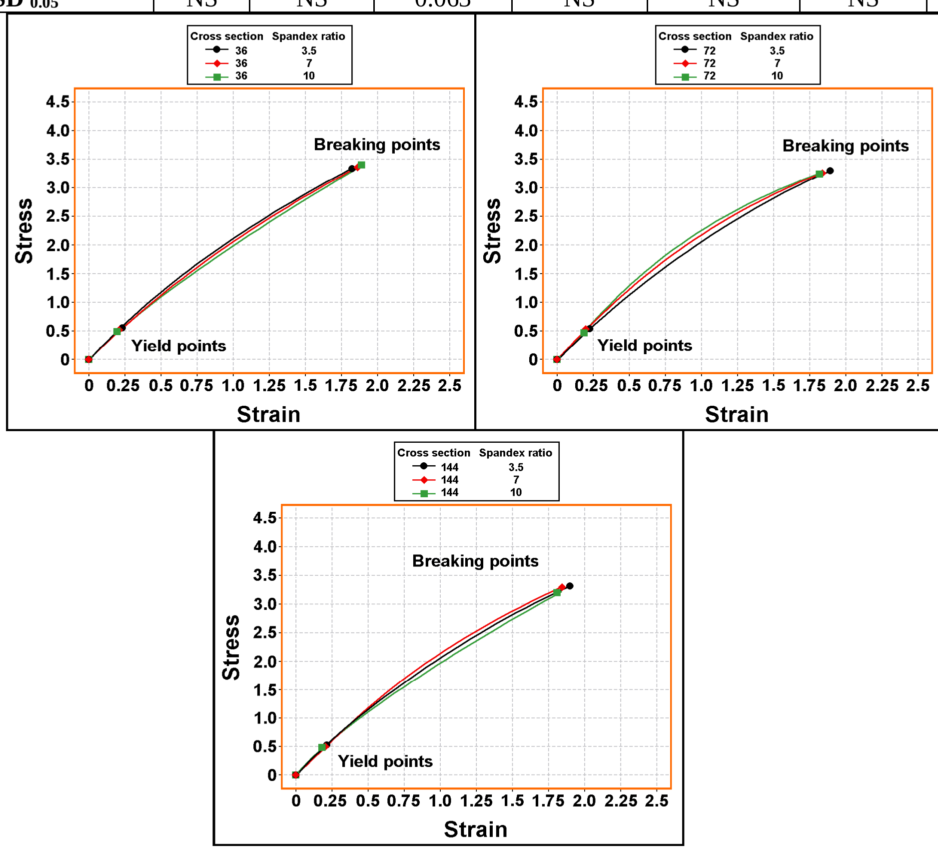


Fig. (6): Stress-strain curves of spandex/polyester spun yarn as affected by the interaction effect between cross section and spandex ratio

1- 3- Second-order interaction effect

The effect of second-order interaction among the three yarn structure factors (yarn count, cross section and spandex ratio) on the spandex/polyester spun yarn properties is presented in Table (7). Also, the stress-strain curves of the interaction among the three yarn structure factors are plotted in Fig. (7).

Results in Table (7) and Fig. (7) revealed that this interaction had no significant effect for all spandex/polyester spun yarn properties except breaking extension and toughness. These results explained that each one of three yarn structure factors (yarn count, cross section and spandex ratio) are similarly responded under each level of the two other factors. Generally, overall three yarn structure factors (yarn count, cross section and spandex ratio), it is apparent that the best spandex/polyester spun yarn properties were obtained by using the coarser yarns with lowest cross section and least spandex content. In the same context, it is appeared that both of cross section and spandex ratio were less effective on the spandex/polyester spun yarn properties compared to the yarn count effect.

Table (7): The effect of interaction among yarn count, cross section and spandex ratio on tensile and elongation behavior of spandex/polyester spun yarn as computed from the stress-strain curves.

Yarn factors			Spandex/polyester spun yarn properties						
Yarn count	Cross section	Spandex ratio	Yield Strain (%)	Yield Stress (kgf)	Breaking extension (%)	Breaking tenacity (kgf)	Toughness (kgf)	Stiffness (kgf)	Initial Young's Modulus (kgf)
75	36	3.5 %	0.169	0.438	1.665	2.579	0.021	154.839	260.462
		7 %	0.151	0.396	1.759	2.704	0.024	153.784	271.319
		10 %	0.132	0.361	1.825	2.874	0.026	157.632	276.797
	72	3.5 %	0.162	0.400	1.765	2.647	0.023	150.040	258.943
		7 %	0.145	0.378	1.785	2.758	0.025	154.726	263.455
		10 %	0.125	0.341	1.847	2.932	0.027	158.773	273.073
	144	3.5 %	0.156	0.374	1.781	2.716	0.024	152.554	248.168
		7 %	0.138	0.358	1.813	2.831	0.026	156.221	261.515
		10 %	0.122	0.330	1.890	2.956	0.028	156.472	270.695
150	36	3.5 %	0.219	0.543	1.769	3.209	0.028	181.493	249.110
		7 %	0.198	0.527	1.882	3.333	0.031	177.286	267.562
		10 %	0.189	0.514	1.947	3.471	0.034	178.327	276.863
	72	3.5 %	0.218	0.552	1.706	3.173	0.027	186.155	259.245
		7 %	0.195	0.547	1.630	3.120	0.025	191.434	280.583
		10 %	0.187	0.531	1.550	3.035	0.024	195.784	288.842
	144	3.5 %	0.208	0.561	1.609	3.226	0.026	200.506	274.695
		7 %	0.193	0.554	1.527	3.190	0.024	209.258	288.157
		10 %	0.182	0.544	1.380	2.914	0.020	211.307	299.796
300	36	3.5 %	0.287	0.613	2.039	4.229	0.043	207.457	219.032
		7 %	0.280	0.602	1.947	3.991	0.039	205.019	223.799
		10 %	0.257	0.590	1.878	3.813	0.036	203.000	231.454
	72	3.5 %	0.278	0.610	2.199	4.045	0.044	183.996	220.354
		7 %	0.268	0.598	2.115	3.893	0.041	184.103	224.492
		10 %	0.248	0.578	2.070	3.797	0.039	183.481	233.843
	144	3.5 %	0.264	0.595	2.298	3.945	0.045	171.710	228.258
		7 %	0.253	0.577	2.209	3.816	0.042	173.609	230.614
		10 %	0.240	0.561	2.159	3.711	0.040	171.978	235.062
$LSD_{0.05}$			NS	NS	0.11	NS	0.003	NS	NS

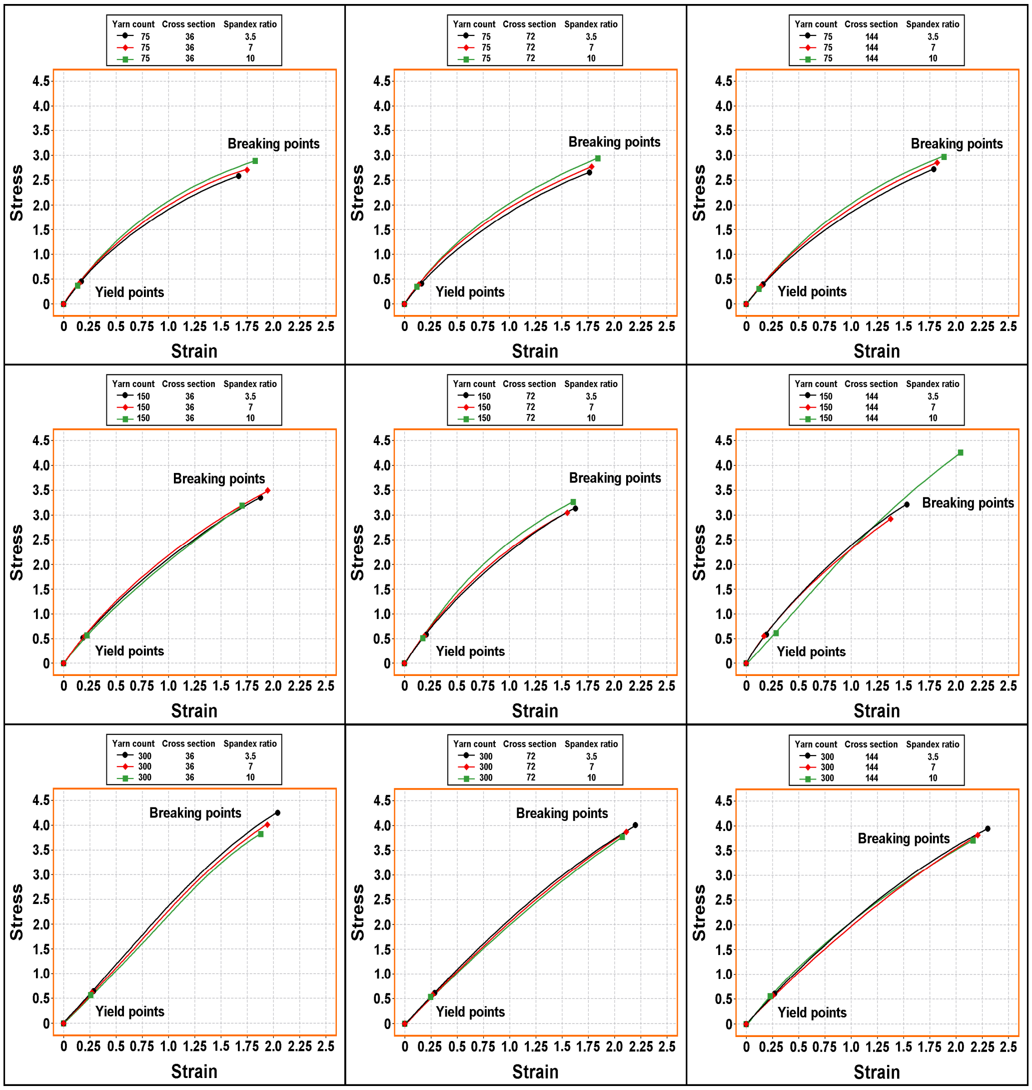


Fig. (7): Stress-strain curves of spandex/polyester spun yarn as affected by the interaction effect among yarn count, cross section and spandex ratio.

2- Effect of three yarn structural factors on the tensile and elongation behavior of Spandex/polyester woven fabrics.

Fabric tensile strength is the force expressed as Newton which is used to break the fabric sample. The yarn structure is corner stone that influence the structural and performance properties of woven fabrics especially the tensile and elongation properties as presented by stress–strain curves.

2-1- Main effects

The average values of spandex/polyester woven fabrics properties (yield strain, yield stress, breaking extension, breaking tenacity, toughness, stiffness and Initial Young's modulus) versus three yarn count (75, 150 and 300 D) are demonstrated in Table (8) and portrayed in stress-strain curves (Fig. 8).

Results revealed that the effect of yarn count was highly significant for all tensile and breaking extension properties of spandex/polyester woven fabrics except Initial young's modulus.

It is seen from Table (8) that as the yarn count increases, all tensile and elongation properties of spandex/polyester woven fabrics are also increase. Accordingly, there are positive relation between yarn counts (75, 150 and 300 denier) and all tensile and elongation properties of spandex/polyester woven fabrics as shown in Fig. (8). It is appeared that when the yarn count changed from 75 D up to 300 D, the average values of yield stress, breaking tenacity and work of rupture, expressed in terms of toughness property are duplicated by increase ratio approximately close to be 100 %. These findings indicated that spandex/polyester woven fabrics made using coarser yarns are markedly stronger, more elasticity and hence they are more durable than those fabrics woven using finer spandex/polyester yarns.

Table (8): The yarn count effect on tensile and elongation behavior of spandex/polyester woven fabrics as computed from the stress-strain curves.

Yarn count	Woven fabrics mechanical properties						
	Yield strain (%)	Yield stress (kgf)	Breaking extension (%)	Breaking tenacity (kgf)	Toughness (kgf)	Stiffness (kgf)	Initial Young's modulus (kgf)
75	9.90	26.96	30.89	65.65	10.18	214.63	277.52
150	13.43	38.32	27.24	91.30	12.45	337.42	287.42
300	18.10	51.44	35.39	121.20	21.48	344.35	286.03
LSD $_{0.05}$	0.80	1.06	1.34	1.90	0.84	12.27	NS

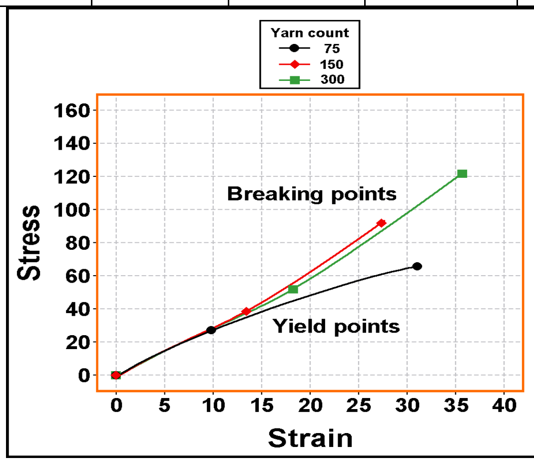


Fig. (8): Stress-strain curves of spandex/polyester woven fabrics as affected by yarn count.

Results in Table (9) and Fig. (9) explained how the change in cross section affecting the stress-strain properties of spandex/polyester woven fabrics. Significant differences were observed among the three cross sections (36, 72 and 144) for all tenacity and breaking extension properties of spandex/polyester woven fabrics except yield strain and work of rupture or toughness indicating that these two properties are less influenced by the cross section factor. However, it is shown that yield stress, breaking tenacity, stiffness and Initial Young's modulus are significantly increased when the cross section increased from 36 to 144 but the rates of increase were low compared to the effect of yarn count. Subsequently, this result indicates that the yarn cross section (144 filaments) had only 1.21 denier per filament gave the best fabric tensile strength. With respect to yield strain and breaking extension, their associations with cross section were negative indicating that the good fabric elongation was satisfied using yarn cross section (36 filaments) had only 4.86 denier per filament. Subsequently, this result indicates that using yarn cross section (144 filaments) had only 1.21 denier per filament would give the best fabric tensile strength but with somewhat low elongation. **AL-ansary (2012)** elucidate that, as the number of filaments in the cross section of filling yarns increases, fabric thickness, tensile strength, fabric elongation and crease recovery increases. **Kaynak and Babaarslan (2015)** stated that the finer spandex/polyester gave the highest fabric breaking strength. They described that this result may be attributed to increase the total specific surface area of filaments in the yarn cross section, a higher cohesion force for finer filaments occurs in the fabric structure during tensioning.

Table (9): The cross section effect of on tensile and elongation behavior of spandex/polyester woven fabrics as computed from the stress-strain curves.

Cross section	Woven fabrics mechanical properties						
	Yield strain (%)	Yield stress (kgf)	Breaking extension (%)	Breaking tenacity (kgf)	Toughness (kgf)	Stiffness (kgf)	Initial Young's modulus (kgf)
36	14.01	37.96	32.07	90.86	14.70	286.15	272.57
72	13.75	38.12	31.71	92.03	14.87	290.45	278.75
144	13.68	40.64	29.74	95.26	14.55	319.80	299.65
LSD $_{0.05}$	NS	1.06	1.34	1.90	NS	12.27	14.68

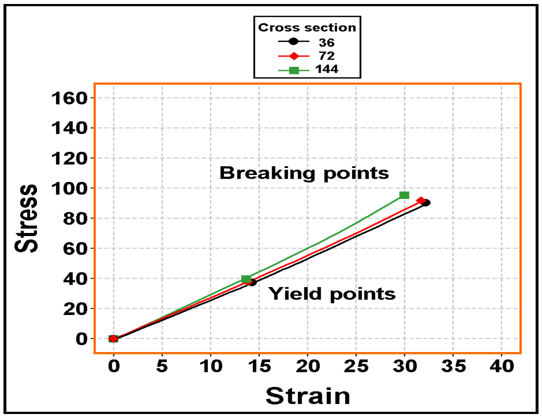


Fig. (9): Stress-strain curves of spandex/polyester woven fabrics as affected by cross section.

The effect of three spandex ratios on tensile and elongation characteristics of spandex/polyester woven fabrics are tabulated in Table (10) and plotted in stress-strain curves as shown in Fig. (10). There were significant differences among the three spandex ratio (3.5, 7 and 10 %) for all tensile and elongation properties of spandex/polyester woven fabrics. Results showed that yield strain, yield stress, breaking extension, breaking tenacity and toughness significantly decreased as a result of increasing the spandex ratio from 3.5 up to 10 % but the decrease rates were generally weak. Accordingly, these are negative associations between spandex ratio and each of tensile and elongation behavior of spandex/polyester woven fabrics. These results may be returned to the lower tenacity of spandex fibers compared to the polyester fibers. In spite of the high elongation of spandex fibers, but there elasticity was markedly reduced in the spandex/polyester fabrics. The reversed pattern was hold true for secant modulus or stiffness and initial Young's modulus, where they tended to increase with the increase in spandex ratio.

Mathur *et al*, (2008) mentioned that the final stretch properties of a fabric depend on the properties of the Spandex, the Spandex combination yarn, the amount of Spandex used, the degree to which it is stretched during fabric production and the construction of the fabric. **AL-ansary (2011)** found that the spandex ratio in cotton-core spun yarns has a remarkable effect on physical and mechanical properties of woven fabrics. She showed that increasing the spandex ratio enhanced the fabric extensibility, and rate of air permeability. On the other hand, increasing spandex ratio reduces fabric tensile strength, shrinkage and growth of woven fabrics.

Table (10): The spandex ratio effect of on tensile and elongation behavior of spandex/polyester woven fabrics as computed from the stress-strain curves.

Spandex ratio	Woven fabrics mechanical properties						
	Yield strain (%)	Yield stress (kgf)	Breaking extension (%)	Breaking tenacity (kgf)	Toughness (kgf)	Stiffness (kgf)	Initial Young's modulus (kgf)
3.5 %	14.90	40.05	33.19	95.35	16.08	287.87	268.63
7 %	13.84	38.83	31.16	92.60	14.66	297.81	282.82
10 %	12.69	37.84	29.18	90.19	13.37	310.72	299.52
LSD $_{0.05}$	0.80	1.06	1.34	1.90	0.84	12.27	14.68

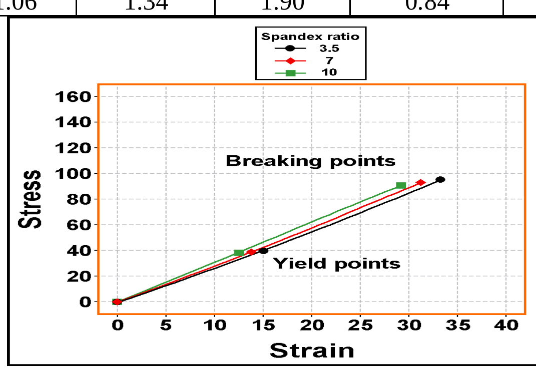


Fig. (10): Stress-strain curves of spandex/polyester woven fabrics as affected by spandex ratio.

2- 2 - First-order interaction effects

When spandex ratio was held constant, the average values of tensile and elongation parameters of spandex/polyester woven fabrics as

influenced by the 1st order interaction effect between yarn count and cross section are tabulated in Table (11) and their corresponding stress-strain curves are diagrammatically depicted in Fig. (11).
Results showed that the interaction effect was significance for all tenacity and breaking extension properties of spandex/polyester woven fabrics except yield strain, stiffness and Intial young's modulus. It is obvious that increasing the yarn count from 75 up to 300 increased all tenacity and breaking extension properties of spandex/polyester woven fabrics regardless of the effect of cross section. Subsequently, this result indicates that the spandex/polyester woven fabrics made by coarser yarns are more strong and extension than that made by finer yarns. However, the cross section reflected limited or weak impact on tenacity and elongation properties of spandex/polyester woven fabrics for the three used yarn counts. **Kaynak and Babaarslan (2015)** mentioned that there is no obvious effect of filament fineness on polyester woven fabric breaking elongation.

Table (11): The effect of 1st order interaction between yarn count and cross section on tensile and elongation behavior of spandex/polyester woven fabrics as computed from the stress-strain curves.

Yarn count	Cross section	Woven fabrics mechanical properties						
		Yield strain (%)	Yield stress (kgf)	Breaking extension (%)	Breaking tenacity (kgf)	Toughness (kgf)	Stiffness (kgf)	Initial Young's modulus (kgf)
75	36	10.27	27.34	33.61	67.78	11.42	201.86	267.92
	72	9.68	25.93	31.29	64.32	10.10	206.50	272.10
	144	9.75	27.61	27.78	64.86	9.02	235.55	292.53
150	36	13.23	36.45	27.49	87.84	12.09	321.77	277.53
	72	13.50	37.53	27.72	90.45	12.55	327.45	280.55
	144	13.55	40.97	26.51	95.60	12.70	363.04	304.20
300	36	18.51	50.09	35.11	116.97	20.57	334.82	272.26
	72	18.07	50.89	36.13	121.32	21.96	337.39	283.60
	144	17.73	53.34	34.93	125.30	21.91	360.82	302.23
LSD $_{0.05}$		NS	1.84	2.33	3.29	1.46	NS	NS

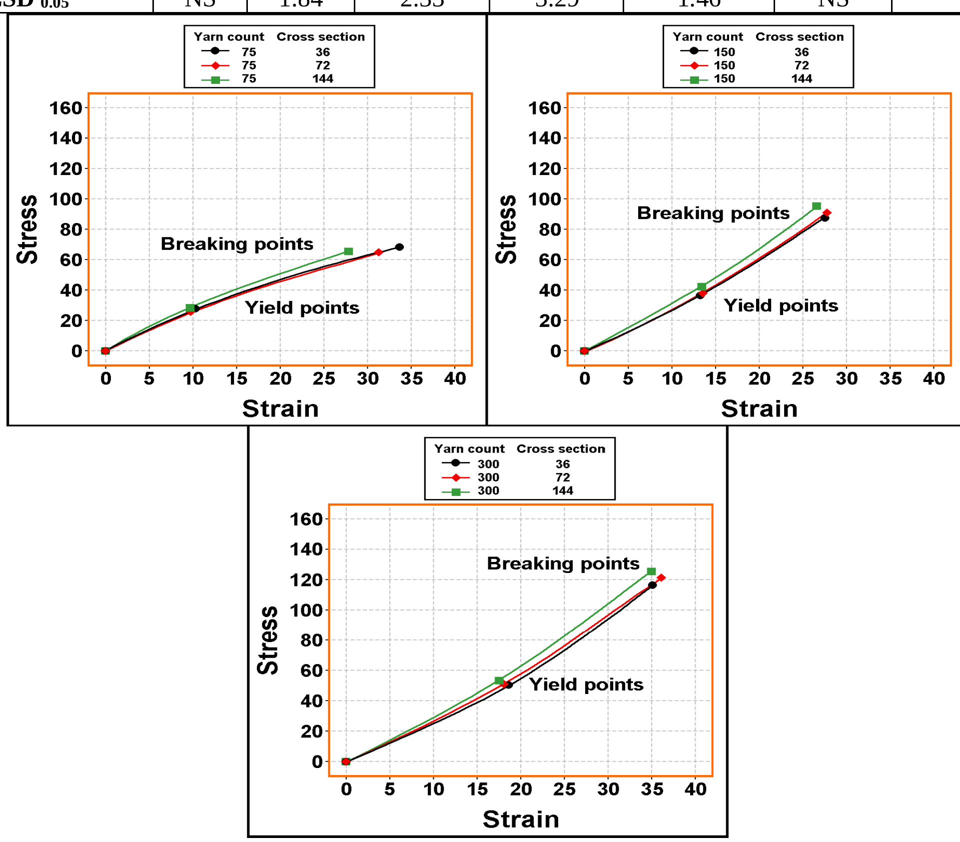


Fig. (11): Stress-strain curves of spandex/polyester woven fabrics as affected by the interaction effect between yarn count and cross section.

Results obtained in Table (12) presented the mean values of breaking tensile and elastic parameters of spandex/polyester fabrics as affected by the yarn count x spandex ratio interaction effect considering the cross section factor was held constant. The interaction effect was not significant for all tenacity and breaking extension properties of spandex/polyester fabrics indicating that the effect of spandex content followed the same trend under the three yarn counts and vice versa . When check the stress-strain curves (Fig. 12), it is obvious that all breaking tensile and elastic parameters of spandex/polyester fabrics increased with each increment in yarn count from 75 up to 300. The reversed pattern was observed in case of spandex ratio, since the mean values of tensile and breaking elongation parameters tended to decrease when spandex content increased from 3.5 up to 10 % except secant modulus or stiffness and Intial Young's modulus. **Mourad *et al* (2012)** studied some physical and stretch properties of woven cotton fabrics containing different rates of spandex. They found that the amount of spandex has a significant influence on physical and elastic properties of woven fabrics. Fabric tensile strength decreases with spandex rate, while fabric breaking elongation increases because of the higher elongation of spandex fibers.

Table (12): The effect of 1st order interaction between yarn count and spandex ratio on tensile and elongation behavior of spandex/polyester woven fabrics as computed from the stress-strain curves.

Yarn count	Spandex ratio	Woven fabrics mechanical properties						
		Yield strain (%)	Yield stress (kgf)	Breaking extension (%)	Breaking tenacity (kgf)	Toughness (kgf)	Stiffness (kgf)	Initial Young's modulus (kgf)
75	3.5 %	11.40	28.71	32.89	70.04	11.54	214.73	254.13
	7 %	9.80	26.90	30.95	65.57	10.16	213.84	279.33
	10 %	8.50	25.27	28.84	61.35	8.85	215.33	299.10
150	3.5 %	14.25	38.79	28.96	92.40	13.39	319.90	274.25
	7 %	13.53	38.25	27.23	91.19	12.42	335.88	284.70
	10 %	12.50	37.92	25.53	90.30	11.54	356.48	303.32
300	3.5 %	19.06	52.63	37.71	123.62	23.32	328.99	277.51
	7 %	18.20	51.34	35.30	121.05	21.39	343.70	284.44
	10 %	17.06	50.34	33.17	118.93	19.74	360.34	296.13
LSD $_{0.05}$		NS	NS	NS	NS	NS	NS	NS

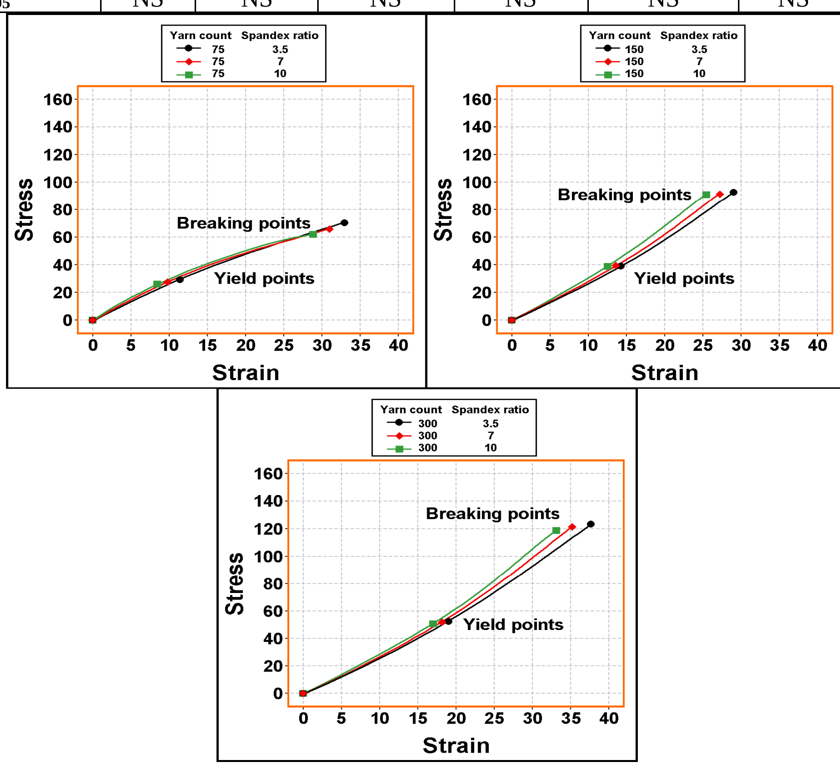
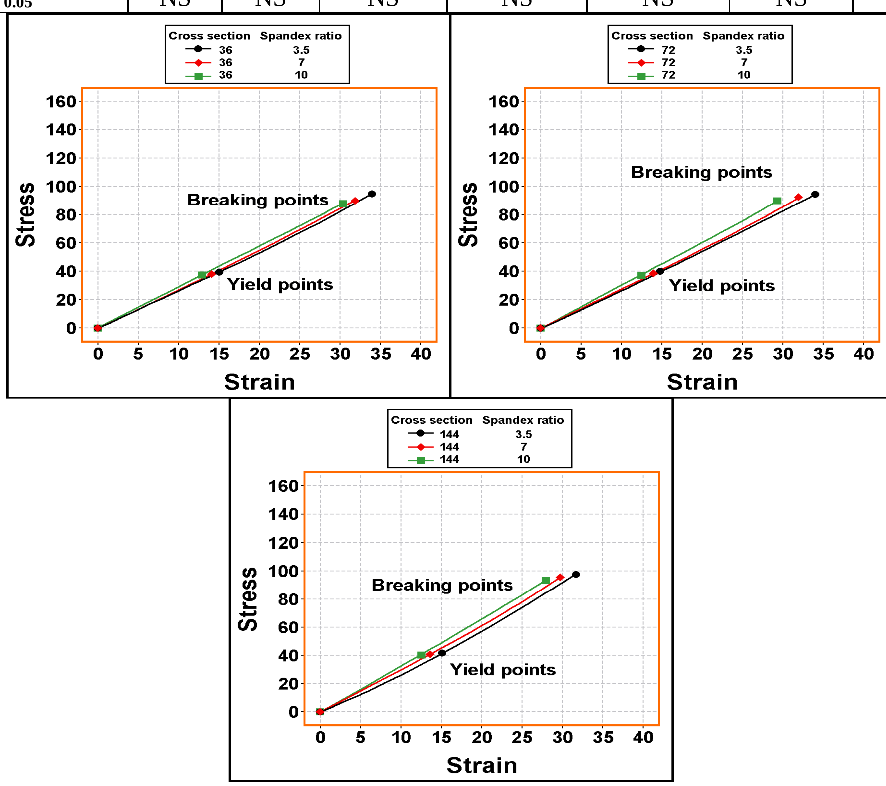


Fig. (12): Stress-strain curves of spandex/polyester woven fabrics as affected by the interaction effect between yarn count and spandex ratio.

Results of the first-order interaction effect between cross section and spandex ratio on tensile and elongation parameters of spandex/polyester woven fabrics are presented in Table (13). Also, stress-strain curves for the three spandex ratios under the applied cross section are graphically plotted in Fig. (13). No significant interaction effect was obtained for all tensile and elongation properties of spandex/polyester woven fabrics indicating that the effect of spandex ratio on tensile and elongation parameters of spandex/polyester woven fabrics was relatively similar regardless the effect of used cross section. Testing the stress-strain curves for any cross section, it is appeared that the maximum yarn strength and higher energy-absorbing capacity would be attained using the lowest spandex content (3.5 %) which confirmed the negative effect of spandex content on tensile and elongation parameters of spandex/polyester woven fabrics. On the other hand, the cross section under each spandex ratio had no considerable effect on spandex/polyester woven fabrics tensile and elongation**.** Establishing relationships between the fabric stretch potential and its construction parameters for a given spandex type permits design of specialized products with required stretch to meet end use performance **(Mathur *et al*., 2008)**.

Table (13): The effect of 1st order interaction between cross section and spandex ratio on tensile and elongation behavior of spandex/polyester woven fabrics as computed from the stress-strain curves.

Cross section	Spandex ratio	Woven fabrics mechanical properties						
		Yield strain (%)	Yield stress (kgf)	Breaking extension (%)	Breaking tenacity (kgf)	Toughness (kgf)	Stiffness (kgf)	Initial Young's modulus (kgf)
36	3.5 %	15.04	39.46	34.01	94.69	16.20	280.65	262.52
72	7 %	14.03	37.84	31.88	90.24	14.52	284.80	271.03
144	10 %	12.94	36.58	30.32	87.66	13.36	292.99	284.16
36	3.5 %	14.75	39.26	33.96	94.18	16.31	277.40	265.95
72	7 %	13.96	38.11	31.86	92.17	14.92	289.14	275.31
144	10 %	12.54	36.99	29.32	89.74	13.39	304.80	294.99
36	3.5 %	14.91	41.42	31.59	97.20	15.74	305.56	277.42
72	7 %	13.53	40.54	29.74	95.39	14.53	319.49	302.13
144	10 %	12.58	39.95	27.89	93.17	13.37	334.36	319.40
LSD 0.05		NS	NS	NS	NS	NS	NS	NS



. (13): Stress-strain curves of spandex/polyester woven fabrics as affected by the interaction effect between cross section and spandex ratio.

2- 3 - Second-order interaction effect

Results of the second-order interaction effect among the three yarn structural factors (yarn count, cross section and spandex ratio) on tensile and elongation parameters of spandex/polyester woven fabrics are presented in Table (7). In addition, their corresponding stress-strain curves are plotted in Fig. (7). Results exhibited that the interaction effect was no significant for all tensile and elongation properties of spandex/polyester woven fabrics meaning that each one of the yarn structural factors gave similar behavior under the other two variables.

Overall cross section and spandex content, it is apparent that the good tensile and breaking extension parameters for spandex/polyester woven fabrics were obtained by using coarser spandex/polyester yarns. Generally, it is clear that the effect of cross section was low and ineffective irrespective the other two factors. Also, it is obtained that the lowest spandex content gave the best tensile and elongation properties of spandex/polyester woven fabrics.

Table (14): The effect of 2nd order interaction among yarn count, cross section and spandex ratio on tensile and elongation behavior of spandex/polyester woven fabrics as computed from the stress-strain curves.

Factors			Woven fabrics mechanical properties						
Yarn count	Cross section	Spandex ratio	Yield Strain (%)	Yield Stress (kgf)	Breaking extension (%)	Breaking tenacity (kgf)	Toughness (kgf)	Stiffness (kgf)	Initial Young's Modulus (kgf)
75	36	3.5 %	11.52	30.04	35.68	74.42	13.25	209.86	261.13
		7 %	10.21	27.18	33.03	67.42	11.13	204.38	267.20
		10 %	9.07	24.81	32.13	61.49	9.89	191.32	275.45
	72	3.5 %	10.98	27.45	33.47	68.08	11.41	204.56	251.66
		7 %	9.80	25.96	31.88	64.40	10.30	202.15	269.75
		10 %	8.27	24.38	28.51	60.48	8.61	212.79	294.91
	144	3.5 %	11.70	28.65	29.53	67.62	9.97	229.76	249.60
		7 %	9.38	27.55	27.94	64.89	9.05	235.00	301.04
		10 %	8.16	26.62	25.87	62.08	8.04	241.88	326.94
150	36	3.5 %	14.30	37.27	29.32	89.82	13.17	307.95	261.13
		7 %	13.25	36.15	27.31	87.13	11.90	320.69	274.93
		10 %	12.15	35.92	25.84	86.58	11.20	336.66	296.52
	72	3.5 %	14.17	37.91	29.10	91.36	13.30	313.98	270.14
		7 %	13.73	37.56	27.74	90.51	12.56	326.93	276.43
		10 %	12.58	37.13	26.33	89.48	11.79	341.43	295.06
	144	3.5 %	14.28	41.18	28.47	96.02	13.69	337.77	291.48
		7 %	13.60	41.04	26.65	95.93	12.79	360.01	302.73
		10 %	12.78	40.69	24.42	94.85	11.63	391.33	318.37
300	36	3.5 %	19.30	51.06	37.04	119.82	22.19	324.15	265.31
		7 %	18.63	50.19	35.31	116.17	20.54	329.34	270.96
		10 %	17.61	49.01	33.00	114.91	19.00	350.99	280.51
	72	3.5 %	19.10	52.41	39.31	123.09	24.21	313.67	276.05
		7 %	18.34	50.80	35.96	121.61	21.91	338.33	279.75
		10 %	16.76	49.46	33.12	119.27	19.76	360.18	295.01
	144	3.5 %	18.77	54.43	36.78	127.95	23.55	349.14	291.19
		7 %	17.62	53.04	34.64	125.36	21.74	363.44	302.62
		10 %	16.80	52.54	33.39	122.60	20.45	369.87	312.88
$LSD_{0.05}$			NS	NS	NS	NS	NS	NS	NS

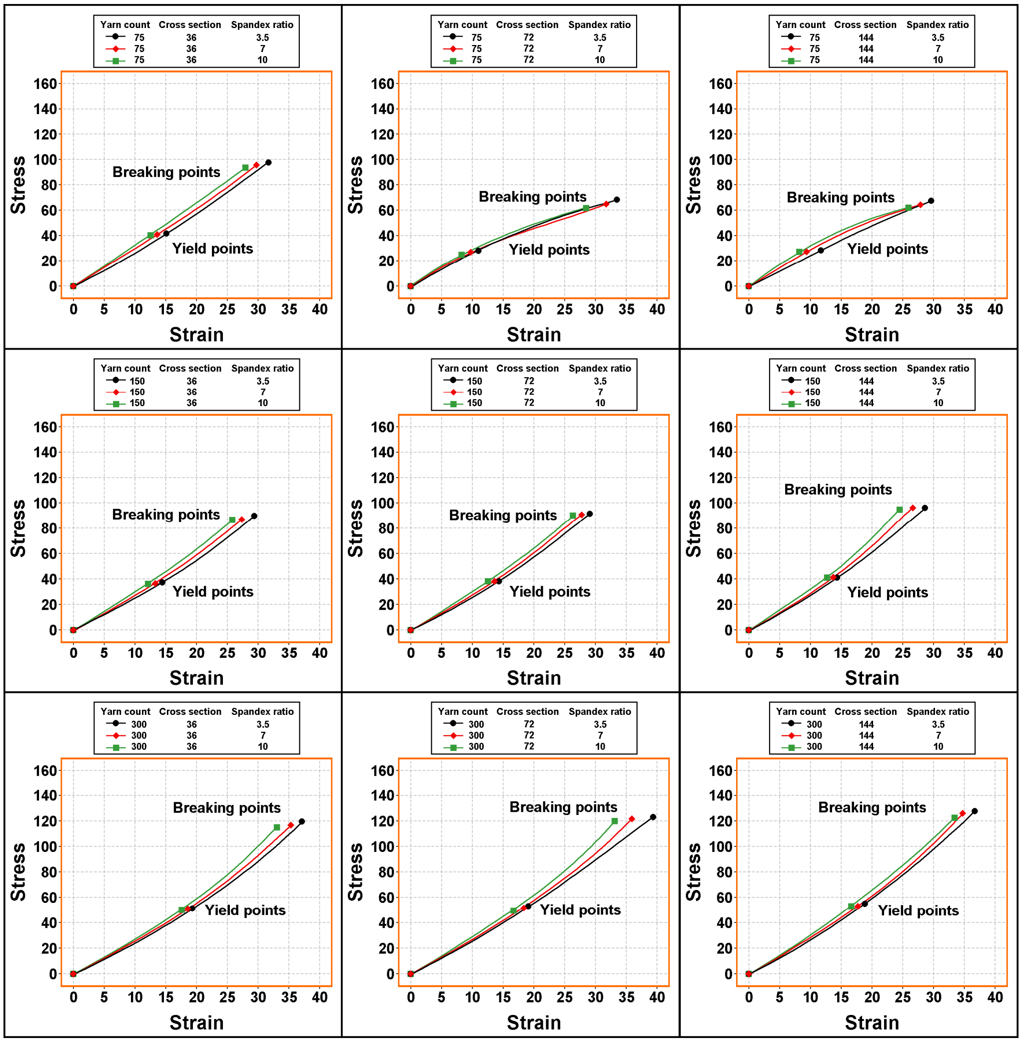


Fig. (7): Stress-strain curves of spandex/polyester woven fabrics as affected by the interaction effect among yarn count, cross section and spandex ratio.

3- The association between tensile and elongation parameters for spandex/polyester yarn and their respective woven fabrics.

The correlation coefficients between tensile and elongation parameters for spandex/polyester yarn and their corresponding woven fabrics are presented in Table (15). Results showed that the most effective relationships for textile industry, were those obtained between yield strain (0.993**), yield stress (0.922**), breaking extension (0.69**), breaking tenacity (0.916**), toughness (0.893**) and stiffness (0.815**) for spandex/polyester yarn and their respective woven fabrics where their simple correlation coefficients were positive and highly significant. On the other hand, the association between Initial Young's modulus for spandex/polyester yarn and their respective woven fabrics (0.264) were weak and insignificant. The current results concluded that the tensile and breaking extension properties of the spandex/polyester yarn (except Initial Young's modulus) can be used as good indicators for the tensile and breaking extension properties of fabrics made by these spandex/polyester yarns.

Table (14): Simple correlation coefficients between tensile and elongation parameters for spandex/polyester yarn and their respective woven fabrics.

Tensile and elongation parameters	Yield Strain (%)	Yield Stress (kgf)	Breaking extension (%)	Breaking tenacity (kgf)	Toughness (kgf)	Stiffness (kgf)	Initial Young's Modulus (kgf)
Correlation coefficients	0.993**	0.922**	0.69**	0.916**	0.893**	0.815**	0.264 ns

ns and **: No significant and highly significant at 0.01 probability level.

CONCLUSION

This research investigated the strength and elongation potential of spandex/polyester spun yarns and their respective woven fabrics. The study showed that the determining factor for the strength and elongation of the of spandex/polyester spun yarns and their respective woven fabrics was the yarn count followed by spandex content while the cross section factor was less effective. Positive association was obtained between the tensile and elongation behavior and yarn count while their relationship with spandex content was negative. However, most interaction effects were no significant for all tensile and breaking extension properties indicating that each one of the three yarn structural factors (yarn count, cross section and spandex ratio) reflect similar behavior regardless the other two factors. It is concluded that the tensile and breaking extension properties of the spandex/polyester yarn (except Initial Young's modulus) can be used as valid indicators toward tensile and elongation properties of fabrics woven by these spandex/polyester yarns.

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