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Effect of Solvent Treatment on Siro and Ring Spun TFO Polyester Yarn

Vpliv obdelave s topilom na poliestrni preji, izdelani po postopku SiroSpun® in prstanskem postopku

Original scientific article/Izvirni znanstveni članek

Received/Prispelo 7-2020 • Accepted/Sprejeto 10-2020

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Abstract

Yarns and fabrics can be improved through structural modifications. Using an organic solvent is a novel and popular approach for a structural modification in the field of textiles. In the present work, Siro-spun® and TFO (Two for one Twisters) polyester yarns were modified with a solvent-acid mixture of acetone and trichloroacetic acid : methylene chloride (TCAMC). Both types of yarn samples were treated in a relaxed state with various concentrations of the solvent's mixture at room temperature. The influence of the treatment with respect to linear density and TCAMC concentration on mechanical properties was investigated. Modified yarns exhibited higher breaking elongation, improved abrasion resistance and lower tenacity. It was also found that the methods of yarn manufacturing contribute significantly to the tensile behaviour of modified yarns. The improvement in elongation was higher in the treated TFO yarn. The abrasion resistance index was found to be lower in the case of siro polyester yarns. Furthermore, significant mass loss in yarn was observed after the treatment of TCAMC. Keywords: TCAMC, modification, polyester, siro, spinning

Izvleček

Lastnosti preji in ploskovnih tekstilij je mogoče izboljšati s strukturnimi spremembami. Uporaba organskega topila je nov in priljubljen način strukturnega modificiranja tekstilij. V tej raziskavi sta bili poliestrski preji, izdelani po postopkih vitja dveh stenjev v sukano prejo (Siro-spun®) in z uporabo sukalnika z dvojnimi vitjem (Two-for-One, TFO), modificirani z mešanico organskih topil trikloroacetne kisline metilenklorida (TCAMC) in acetona. Obe preji sta bili obdelani v nevpetem stanju z različno koncentracijo mešanice topil pri sobni temperaturi. Raziskan je bil vpliv koncentracije TCAMC na mehanske lastnosti modificiranih prej z različno dolžinsko maso. Modificirane preje so imele večji pretržni raztezek, izboljšano odpornost na drgnjenje in nižjo natezno trdnost. Ugotovljeno je bilo, da sta tudi sama postopka izdelave preje pomembno vplivala na natezne lastnosti modificiranih prej. Večji raztezek je imela modificirana preja po postopku TFO. Indeks odpornosti preje na obrabo (RRI) je bil pri poliestrski preji SiroSpun nižji. Pri obdelavi s topilom TCAMC in acetona se je občutno zmanjšala tudi masa preje.

Ključne besede: TCAMC, modifikacija, poliester, SiroSpun, predenje

1 Introduction

Properties of spun yarns are mainly affected by fibre properties, process parameters and the spinning system. Fibre properties and process parameters mainly influence the appearance (melange, slub and neppy yarns), and the mechanical and physical properties [1]. The spinning system influences the yarn structure, as each spinning system tends to produce a distinctive yarn structure with distinct yarn properties. Recent refinements in spinning technologies have yielded significant improvement in the yarn structure [2]. Traditionally, two-fold yarns have been used for weaving since they are stronger and the twisting operation binds the surface fibres into the structure, the latter becoming smoother and more resistant to abrasion during weaving. Siro-spinning with 2-ply multifold yarn is another most widely used new spinning method invented by CSIRO (Division of Textile Industry Laboratories) in Australia and IWS. Such yarn is produced on a conventional ring frame with two separate strands fed in the drafting zone during the spinning process at a predetermined separation. Siro spun yarn is especially better with regard to its tensile properties, while the conventional plying process attracts attention mainly due to lower yarn hairiness [3].

Polyester fibres have been widely used in the textile industry due to its high strength, good handling and easy-care properties. However, polyester fibres exhibit low surface energy and limited chemical reactivity, which lead to poor moisture absorption and accumulation of static charge. In the recent years, various new methods have been identified to modify the surface characteristics of polyester fibres [4]. When polyester fibres are pretreated with highly interacting solvents under suitable conditions, the internal structure, especially the amorphous region, changes producing more voids, cracks etc., which facilitate the entry of dye molecules at lower temperatures. Such modified polyester fibres are developed to replace the conventional ones in a wide range of applications [5–6].

Surface modifications with after treatments of chemicals are another approach for getting a distinct structure and properties in final yarn. The surface modification of polyester suggested improving the hydrophilicity of polyester structure by enzyme treatment, esterase, thermal plasma treatment etc. [7–9]. Researchers have suggested a new approach to modify the internal structure, i.e. by using the TCAMC reagent [10–11]. It can be done at fibre, yarn and fabric stages. In the treatment, the solvent-induced modifi-

cation principle is used to modify polyester yarn. The fast treatment rate at room temperature and easy storability make the TCAMC reagent more appealing for a structural modification of yarn and fabrics [12–13]. In the present study, an attempt was made to compare the effect of a different TCAMC concentration level on the tensile and abrasion properties of TFO and siro yarn. The effect of the treatment on tensile strength and breaking extension was studied for different linear density yarns.

2 Materials and methods

2.1 Yarn preparation

For the present study, polyester (1.33 dtex (1.2 denier), 38 mm) fibre was used to produce TFO and siro yarn. Siro yarns were produced on a Lakshmi short staple spinning line with 8 mm distance between two roving strands. For TFO yarn, single yarns were spun on a Lakshmi spinning line and doubled on a Saurer compact twist TFO machine. The twist multiplier 4.2 and spindle speed were constant in both systems producing yarns.

2.2 TCAMC treatment

The laboratory grade trichloroacetic acid : methylene chloride ($\text{CCl}_3\text{COOHCH}_2\text{Cl}_2$) and acetone (CH_3COCH_3) were used for the surface modification of yarn samples. The pre-treatment of these yarns with a reagent was conducted in a specially made closed trough at room temperature (27 °C). The yarn specimens were immersed in the reagent of desired concentrations of 0.5%, 2.5% and 4.5% (w/v) for 2 min. The yarn to solvent ratio was 1 : 100 and the contents were stirred manually. After the treatment, the specimens were rinsed with pure methylene chloride, followed by acetone to remove any adhering reagent from the yarn. The treated yarns were squeezed and air-dried at atmospheric conditions, taking the advantage of the quick evaporation of acetone at room temperature. A total of 18 samples were made for the study. The design plan of the experiment is given in Table 1.

2.3 Testing methods

The yarns were conditioned for 24 hours at standard atmospheric conditions of $65\% \pm 2\%$ RH and $27^\circ\text{C} \pm 2^\circ\text{C}$ temperature. The number of tests for each parameter was taken to ensure the result to remain within the 95% confidence limit. For a surface analysis, images of treated and untreated samples were captured on a stereo image analyser.

Table 1: Experiment design plan

Sr. No.	Factor	Level					
1	Spinning system	TFO			Siro		
2	Linear density (tex/Ne)	23.6 (2/50)	29.5 (2/40)	39.4 (2/30)	23.6 (2/50)	29.5 (2/40)	39.4 (2/30)
3	TCAMC concentrations (%)	0.5	2.5	4.5	0.5	2.5	4.5

2.3.1 Weight loss of yarn

Leas of all yarn samples were weighed before and after the treatment, and the difference in mass of all samples was measured in terms of weight loss. Standard percentage of the mass loss was calculated using the formula given below:

$$\text{Weight loss (\%)} = \frac{\text{Yarn weight before treatment} - \text{Yarn weight after treatment}}{\text{Yarn weight before treatment}} \times 100 \quad (1)$$

2.3.2 Tensile testing of yarn

A Zwick universal tensile tester was used to measure the tensile properties according to ASTM D 2256. The yarns were tested at 120 mm/min extension rate using gauge length of 250 mm. At least 30 readings were taken for each sample. The effect of the treatment on tensile strength was evaluated in terms of strength loss. Strength loss (%) was calculated according to the formula:

$$\text{Strength loss (\%)} = \frac{\text{Yarn strength before treatment} - \text{Yarn strength after treatment}}{\text{Yarn strength before treatment}} \times 100 \quad (2)$$

Similarly, extension gain was evaluated with the difference in extension before and after the treatment. Extension gain was calculated according to the formula below:

$$\text{Extension gain (\%)} = \frac{\text{Yarn extension after treatment} - \text{Yarn extension before treatment}}{\text{Yarn extension before treatment}} \times 100 \quad (3)$$

2.3.3 Yarn abrasion resistance

The abrasion resistance of yarns was tested on a yarn abrasion tester following ASTM D-4157. The abrasion resistance was expressed in terms of the number of strokes required to rupture yarns completely. A parallel sheet consisting of 20 yarns was kept pressed at constant tension (20 g) against a cylinder wrapped with an abrader. The yarns were abraded by the cylinder surface while it oscillated at constant speed and stopped when all the yarns broke. Relative Resistances Index (RRI) was converted with the average number of strokes by including both the liner density of yarn and the applied pre-tension [3]. The RRI used to compare the resistance of yarns varying in linear density is defined by:

$$\text{RRI} = \frac{\text{No of strokes} \times \text{Pre-tension (g)}}{\sqrt{\text{Liner density (tex)}}} \quad (4)$$

The effect of the treatment on abrasive properties was evaluated in terms of change in percentage for RRI. The change in RRI was calculated with the difference in RRI before and after the treatment.

3 Results and discussion

This paper embodies the effect of the concentration level of trichloroacetic acid methylene chloride on weight, tensile and abrasion properties of TFO and siro yarn. The results were analysed before and after the treatment. The results were evaluated in terms of weight loss, strength loss, gain in extension and abrasion relative resistance index (RRI). An analysis of variance was performed to find the effect of the spinning system, linear density and concentration level on the analysed parameters. Table 2 shows ANOVA analysis results for the studied yarn properties.

Table 2: ANOVA result

Effect of	Weight loss		Strength loss		Increase in extension		Increase in RRI	
	F-value	p-value	F-value	p-value	F-value	p-value	F-value	p-value
S S	113.46	0.0004 (S)	124.02	0.0003 (S)	143.92	0.0003 (S)	39.74	0.0032 (S)
L D	98.46	0.0004 (S)	78.65	0.0006 (S)	86.94	0.0005 (S)	58.04	0.0011 (S)
T C	818.85	0.0001 (S)	467.74	0.0001 (S)	617.57	0.0000 (S)	392.14	0.0001 (S)
S S*L D	1.35	0.36 (NS)	3.39	0.14 (NS)	10.65	0.024 (NS)	1.10	0.42 (NS)
S S*T C	45.58	0.0018 (S)	8.68	0.0351 (S)	3.55	0.129 (NS)	5.65	0.068 (NS)
L D*T C	5.44	0.0483 (S)	8.37	0.0317 (S)	6.12	0.0500 (S)	3.53	0.124 (NS)

S S – Spinning system, L D – Linear density, T C – TCAMC concentration, RRI – Relative resistance index,
S – Significant, NS – Non-significant,

It can be observed from Table 2 that the effect of the spinning system, linear density and concentration level was found significant for all evaluated properties.

3.1 Effect of treatment on yarn surface

Fibre arrangement in yarn being system specific, a different spinning system results in a different arrangement and/or distribution of fibres, causing variation in the product surface and performance. The studied yarn was produced on two different spinning systems; hence, the different structure resulted in the variation of yarn porosity. The effect of the TCAMC solvent on yarn surface is shown in Figure 1.

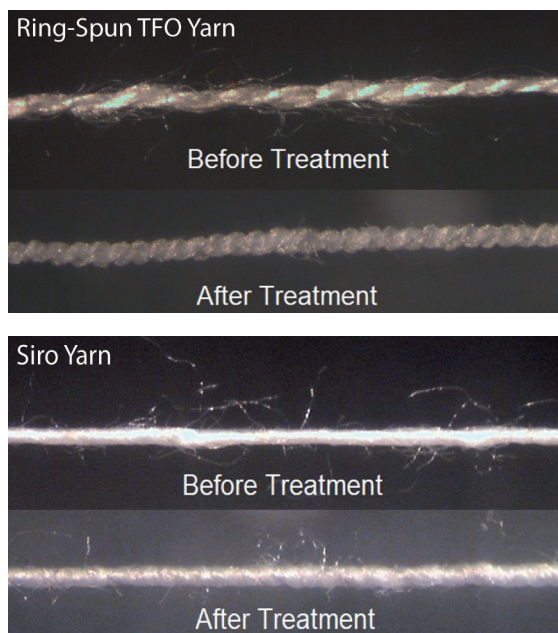


Figure 1: Effect of TCAMC treatment on yarn surface

As Figure 1 shows, the contraction was higher in the case of TFO yarn as compared to siro yarn. The TCAMC treatment causes an increase in the chain mobility and results in a structural rearrangement of polymer chains, which leads to a change in yarn structure. The surface of TFO yarn is helical while the surface of siro yarn is regular. In the case of TFO yarn, the more space is available in its structure for a rearrangement [2]. Thus, TFO yarn was more affected by the treatment and resulted in a more substantial contraction in TFO yarn.

3.2 Effect of TCAMC treatment on weight loss

The weight loss percentage, which is the difference between the specimen mass before and after the treatment, was observed. The weight loss (%) after the treatment for both types of yarns is presented in Figure 2.

Mass loss was observed in all types of treated yarns. Furthermore, it was found that an increment in the concentration of TCAMC increased weight loss in yarn. Higher weight loss was found in higher linear density (tex) yarns at the same level of concentration. Higher linear density of yarn possesses more surface area, which leads to a larger surface to react with TCAMC, causing greater mass reduction. It was also observed that weight loss was higher in the case of TFO yarns compared to siro spun yarns. The inherited structural difference was the reason for higher mass loss in TFO yarns.

3.3 Effect of treatment on tensile strength

The strength loss percentage of both siro and TFO yarns is shown in Figure 3, which depicts that the strength of TCAMC-treated yarns decreased with

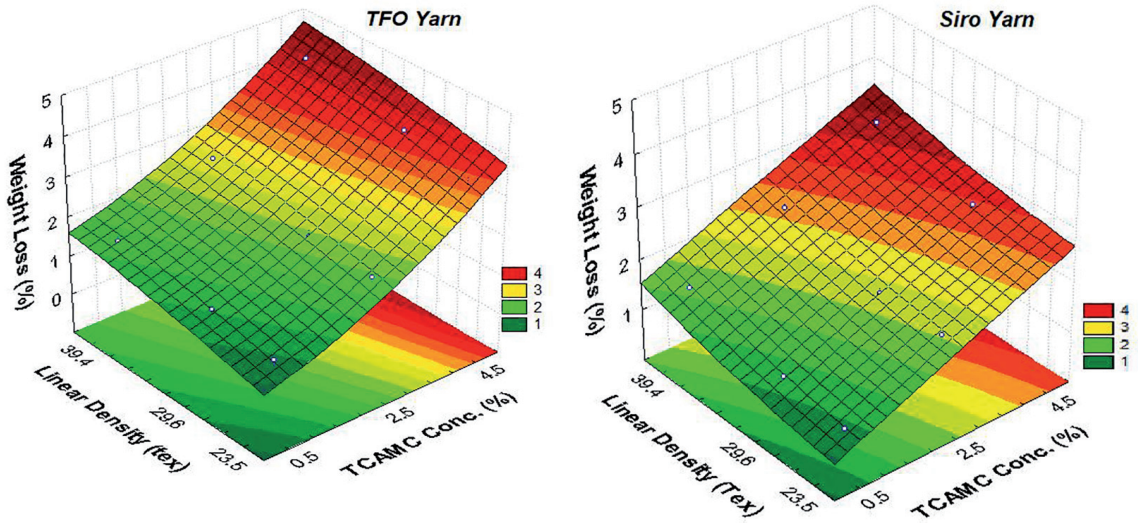


Figure 2: Effect of TCAMC concentration and linear density on weight of polyester yarns

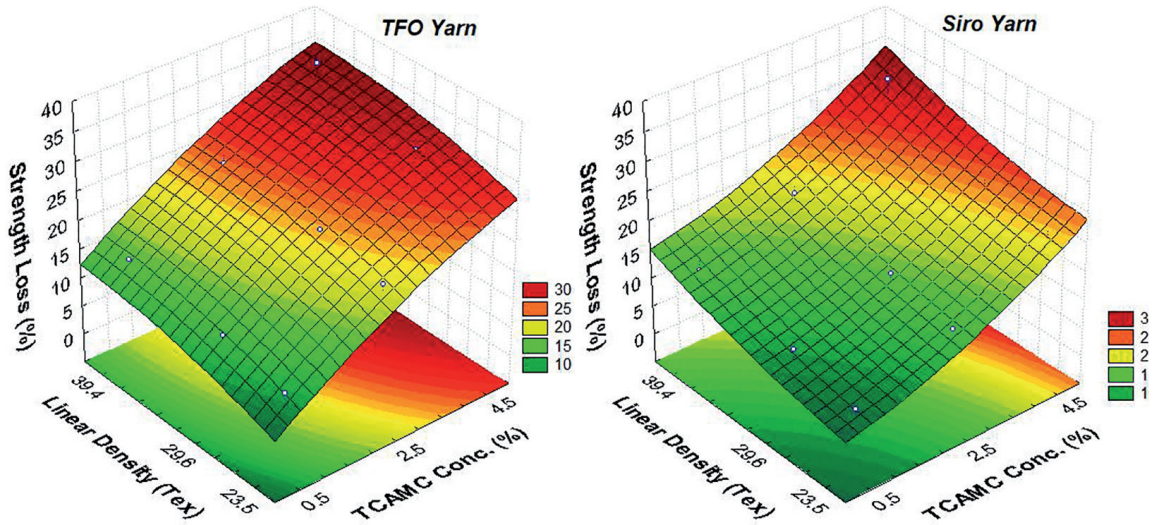


Figure 3: Effect of TCAMC concentration and linear density on strength of polyester yarns

an increase in the concentration of TCAMC. The strength loss was about 7.21–34.28% for TFO yarns and 7.27–31.66% for siro yarns, which shows that the effect of the TCAMC treatment on the strength of TFO yarn was greater than on siro yarn. The structural arrangement in both yarns was different as TFO yarn is made of two single yarns and less compact, while siro yarn is compacter and made of single entity yarns. TFO yarn possesses intra- and inter-yarn spaces, and siro yarn possess only intra-yarn spaces. Therefore, when the treatment was applied on yarn, the possibility of a solvent penetrating into TFO yarn was greater. As a consequence of greater penetration,

the surface became more modified, resulting in higher strength loss in TFO yarns.

The change in the tensile strength of polyester yarns even at lower treatment concentrations suggests that the TCAMC treatment increases the chain mobility and results in the structural rearrangement of polymer chains. Furthermore, it appears that at higher treatment concentrations, TCAMC is capable of penetrating into the crystalline domains of polyester and breaks the forces present in it, resulting in significant strength loss. It is expected that beyond 10% treatment concentrations, TCAMC would disorient crystallinity and facilitate the disintegration of fibres [11].

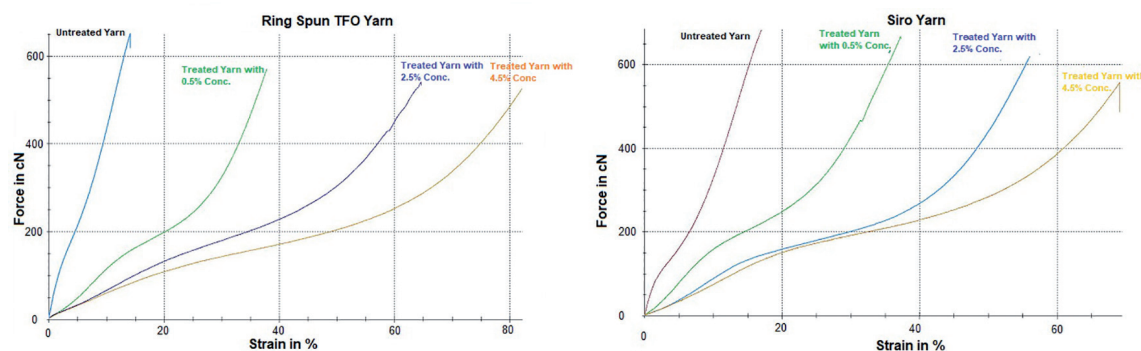


Figure 4: Load strain behaviour of untreated and treated polyester yarn (23.6 tex)

Figure 4 shows the load extension behaviour of the two yarns. Siro yarn showed marginally higher breaking load for both treated and untreated yarn compared to TFO yarn. It was also observed that the breaking extension value of treated TFO yarn was higher than that of siro yarn. Moreover, it was found that the linear density of yarn also affects the strength loss of yarn.

3.4 Effect of treatment on breaking extension

When yarn is subjected to load, constituent fibres share that load. The sharing of load is influenced by the arrangement of these constituent fibres. The arrangement and configuration of fibres again depends on the mode of yarn formation. Depending on the level of load in each fibre, straightening, slippage and/or breakage of fibres can take place, which is manifested as yarn extension [3]. The breaking extension of a synthetic fibre depends on the structural characteristics, e.g. configuration of chain molecules and

energy content due to chemical bonds between the atoms in the chains, and the intermolecular bonds between the chains. Figure 5 shows the increase in breaking extension values of both siro and TFO yarns with the applied treatment.

Figure 5 shows that the breaking extension increased with increased TCAMC concentration. The improvement in the breaking extension of studied yarns at lower treatment concentrations suggests that the TCAMC treatment produces some degree of molecular movement by relaxing lateral forces (intermolecular bonds), which are responsible for holding the chain molecules inside the polymer.

Furthermore, it can be seen in Figure 5 that the gain in breaking extension for TFO yarn is greater if compared to siro yarn due to the difference in the structure of TFO and siro yarn. The effect of the TCAMC treatment on the helical structure is greater, leading to more contraction in the yarn if compared to siro yarn.

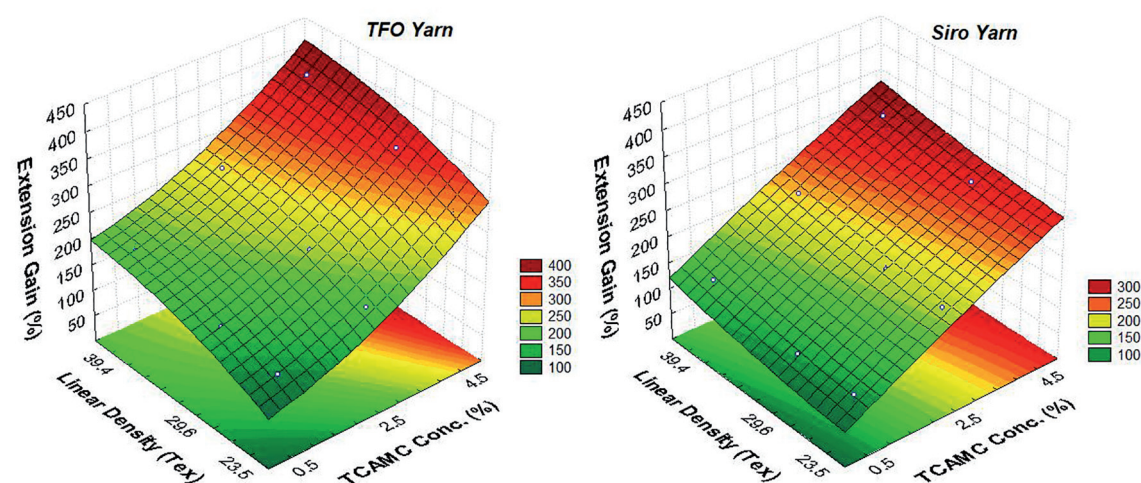


Figure 5: Effect of TCAMC concentration and linear density on breaking extension of polyester yarns

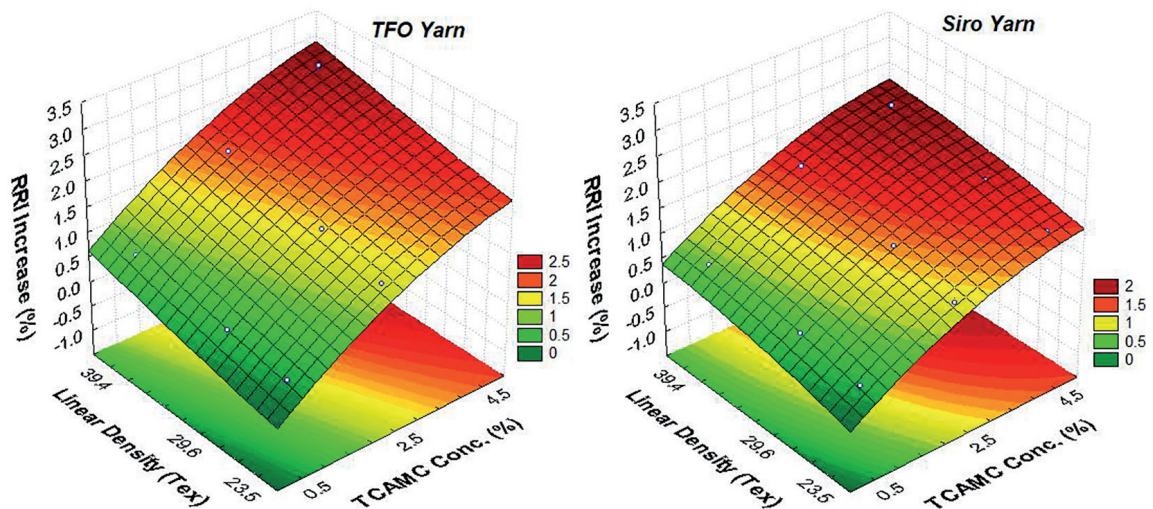


Figure 6: Effect of TCAMC treatment and linear density on RRI of polyester yarns

3.5 Effect of treatment on abrasion resistance (RRI)

Abrasion property is the key factor to predict how yarn performs under high abrasion resistance. A physical destruction of fibres, yarns, resulting from rubbing a surface over another surface is known as abrasion. Abrasion distorts the appearance by pulling fibre ends out from the yarn surface.

Figure 6 demonstrates that RRI increases with an increase in the TCAMC concentration. The highest relative resistance index was observed for the 4.5% concentration level. It appears that higher breaking extension of polyester yarn imparts the plasticisation effect during the treatment. The extensibility of yarn possesses more resistance to yarn abrasion and vice versa. As it can be seen in Figure 6, the increase in RRI for TFO yarn is greater than for siro yarn due to the higher breaking extension of the treated TFO yarn. The surface fibres of individual ply for TFO yarn are protected after the doubling and are relatively difficult to open. On the other hand, the surface fibres in siro yarn are likely to come out of the structure relatively easy during abrasion.

4 Conclusion

A solvent treatment of TCAMC on siro and TFO yarns significantly influences the extensibility, strength and abrasion properties. The strength of treated yarn decreases with increased solvent concentration. A 7.14–34.18% strength drop was found

for TFO yarn and 7.27–31.66% for siro yarns. The treatment caused a reduction in mass of both types of polyester yarn. A higher concentration of TCAMC caused greater weight reduction in yarns. Higher contraction was found in the case of TFO yarn compared to siro yarn after the treatment. The treated polyester yarns exhibited an improvement in breaking extension at a higher concentration of TCAMC. It can be concluded that TCAMC treatment modifies the structural assembly of polyester yarn by relaxing lateral forces. The treatment also influences the abrasive properties of both types of yarn. RRI for TFO yarn is higher if compared to siro yarn.

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