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Prediction of Extra Long Egyptian Yarn Tenacity Using Fibre Quality Index (MFQI)

Abstract
Predicting the spun yarn tenacity from fibre properties is essential. The tenacity of spun yarns is one of the most important properties in determining the yarn quality, since it directly affects the winding, weaving and knitting production efficiency as well as the use of the fabric. Many research works tackled this subject trying to predict yarn properties from fibre properties. In this research work, a general review on the yarn tenacity topic was performed and a fibre quality index was developed and used for the prediction of yarn tenacity. A study on the potential of predicting yarn tenacity from single fibre tenacity and bundle fibre tenacity was presented, followed by the introduction of the MFQI as a viable factor for the prediction of yarn tenacity for ring and compact spun yarn. The results showed that Bundle fibre tenacity gives better results than single fibre tenacity in predicting the yarn tenacity. Index MFQI is proved to be highly correlated with the yarn tenacity.

Key words: *staple yarn, fibres bundle, single fibres, Fibre Quality Index, SFC, MFQI.*

Introduction

The tenacity of staple yarns has been intensively investigated for a long time. The tenacity of spun yarns is one of the most important properties in determining the yarn quality since it directly affects the winding, weaving and knitting production efficiency.

The mechanism of failure in staple yarns is strongly influenced by the yarn structure, namely the configuration, alignment and packing of constituent fibres in the yarn cross section. The structure of a yarn is solely determined by the methods of consolidating the fibres into yarns such as ring, rotor, air jet and friction spinning with different structural parameters, namely the mean fibre extent, helix angle of the fibres, percentage of hooks and their extents, the number of fibres in the yarn cross section and yarn diameter. The yarn tenacity also depends on testing parameters such as the gauge lengths and strain rates of tensile testers [1].

The mechanism of yarn failure is usually explained on the basis of the stress-strain characteristic of yarn showing the nonlinear mechanical behaviour of yarn with linearity restricted for very small stress only where slippage is prevented by friction. In the second region fibres start to slip, and for higher stress one can observe both the slippage and breakage of fibres till yarn breakage. There is a significant relationship between yarn tensile properties and some structural parameters. Furthermore a strong link exists between the value and uniformity of yarn diameter and that of the breaking load. Despite the yarn structure, the yarn diameter and its non-uniformity are strongly correlated with the breaking load and elongation at break as well as with other mechanical properties of the yarn. The higher the yarn diameter, the higher the breaking load and elongation [2]. Brittle fibres exhibit large variability in failure tenacity and strain, which is due to the variation in fibre diameter, the presence of flaws on the surface as well as the interior of the fibres [3].

Predicting the spun yarn tenacity from fibre properties is essential. Many research works attempted this, trying to predict yarn properties from fibre properties [4 - 12]. Fast and accurate measurements of fibre properties by means of High Volume Instrumentation HVI and more powerful computers helped to spread this tendency.

The utilisation of single fibre tensile and bundle fibre tensile properties as predictors of yarn tenacity was the state of the art [13]. Single fibre tensile properties could be estimated from the load-elongation curves of slack bundles [14, 15]. Its estimation from the stress-strain curve, breaking force and elongation at break of a fibre bundle was performed by Neckar [16]. Correlations between the fibre properties and yarn tenacity were also performed by Mustafa [17] and Langenhove [10].

It is well known that the tenacity of a yarn is not anticipated accurately by averaging the tenacity of individual fibres. Pan et al. [18] conducted a survey of literature regarding the relationship between the tenacity of a single fibre, a bundle and a yarn. They defined the difference between a bundle and a yarn to be that fibres in a yarn have some twist while a bundle has no twist and only consists of parallel fibres. Pan et al. concluded that the two main factors that determine the tenacity difference between fibre and yarn are the occurrence of the fragmentation process and fibre tenacity variation. The introduction of twist in a yarn affects the interaction of the fibres with each other. Twist is generally introduced as a way of increasing the lateral cohesion of yarn and making its handling easier. Studies have shown that the tenacity of the yarn increases with the introduction of twist up to a maximum value and then decreases with further twist introduced.

Different modeling techniques such as finite element models have been developed to calculate tensile loads and untwisting moments of yarns at certain strains, given the structure of the yarn and the properties of fibres [19 - 21].

Yet a complete understanding of the mechanism of the relationship between tensile, the extension of staple yarns and the properties of constituent fibres on one hand and the detailed structural geometry of the yarn on the other are the subject of many research works conducted by textile scientists.

El Messiry M. and Mohsen S. [22] introduced a new index, Modified Fibre Quality Index (MFQI), for evaluation of fibre quality. Extensive comparisons between the efficiency of the MFQI and that of the Spinning Consistency Index (SCI) were developed, showing its better suitability to represent the quality of cotton fibres [22]. In this research work, the index MFQI is used for the prediction of the expected maximum value of the tenacity of yarn produced from extra-long Egyptian cotton varieties. Hence these types of cotton are usually used for the production of fine counts, where the yarn tenacity is of vital importance. The introduction of the

MFQI as a viable factor for the prediction of yarn tenacity is implemented.

Material and methods

Types of cotton used

Samples from five different varieties of Egyptian cotton were drawn (Giza 86, Giza 87, Giza 88, Giza 90, and Giza 45).

Fibre testing

From the random cotton samples, fibres were selected and 50 single fibre tenacity measurements were performed on each sample. A Vibroscop was used for the measurement of the tenacity characteristics of single fibres. For each sample, numerical values for the fibre count, breaking force, elongation at break, tenacity and Young's modulus were recorded. Bundle fibre properties were subsequently measured using a HVI tester.

Yarn samples

To study the relation between the fibre properties and yarn tenacity, carded ring spun yarns of 20 tex linear density (count) and twist factor 34.5 (turns/cm × (tex^0.5)) were spun from different types of Egyptian cotton representing the different varieties.

Another set of experiments using different Egyptian cotton varieties with different MFQI were spun into combed ring and compact yarns of different linear densities (counts): 12 tex, 6 tex & 3.7 tex and twist factor: 34.5 (turns/cm × (tex^0.5)). Yarn tenacity was measured using an Uster Tensorapid.

Results and discussions

Fibre analysis

Single fibre properties

The single fibre tenacity and elongation were measured. Furthermore graphical presentations of the tenacity-elongation curve for single fibres and the mean tenacity-elongation curve for each cotton variety were obtained. ***Table 1*** shows the mean values, CV%, minimum and maximum values of single fibre tenacity for the five cotton varieties under investigation. The stress strain curves obtained for the five cotton varieties are summarised in ***Figure 1***. The curves show the single fibre tenacity-elongation behaviour for individual fibres representing different types of cottons. The high degree of variability between the tenacities of individual fibres is obvious. From the analysis of fibre properties, it is clear that the fibre tenacity of Egyptian cotton varies between 32 - 39 cN/tex with a breaking elongation of 6 - 9%. The Young's modulus varies between 289 – 392 cN/tex.

Bundle fibre properties

The same cotton varieties were also tested in tuft form on High Volume Instrumentation (HVI). A summary of the results is shown in ***Table 2***.

A statistical analysis was performed to study the relation between the single fibre tenacity, bundle tenacity and yarn tenacity. The results obtained indicate that the bundle tenacity is higher than the single fibre tenacity and has lower variability. However, the elongation is less.

Prediction of yarn tenacity

Many investigators have tried to find out the relation between fibre properties and yarn tenacity [4 - 12], some of which were based on single fibre properties and others on tuft properties. Despite these differences it is possible to specify basic cotton fibre properties having potential influence on the cotton yarn tenacity [23]. The tensile tenacity of the different yarns produced were tested,, the results of which are given in ***Table 3***.

A regression analysis was then performed between yarn tenacity and single fibre tenacity. The results obtained showed a very poor correlation between both parameters, which is due to the extremely high variability in the values of single fibre tenacities, as given in ***Table 1***, making it impossible to give a significant prediction of the yarn tenacity using single fibre mean tenacity as the low tenacity fibres – which are far away from the mean fibre tenacity values – are much more re-

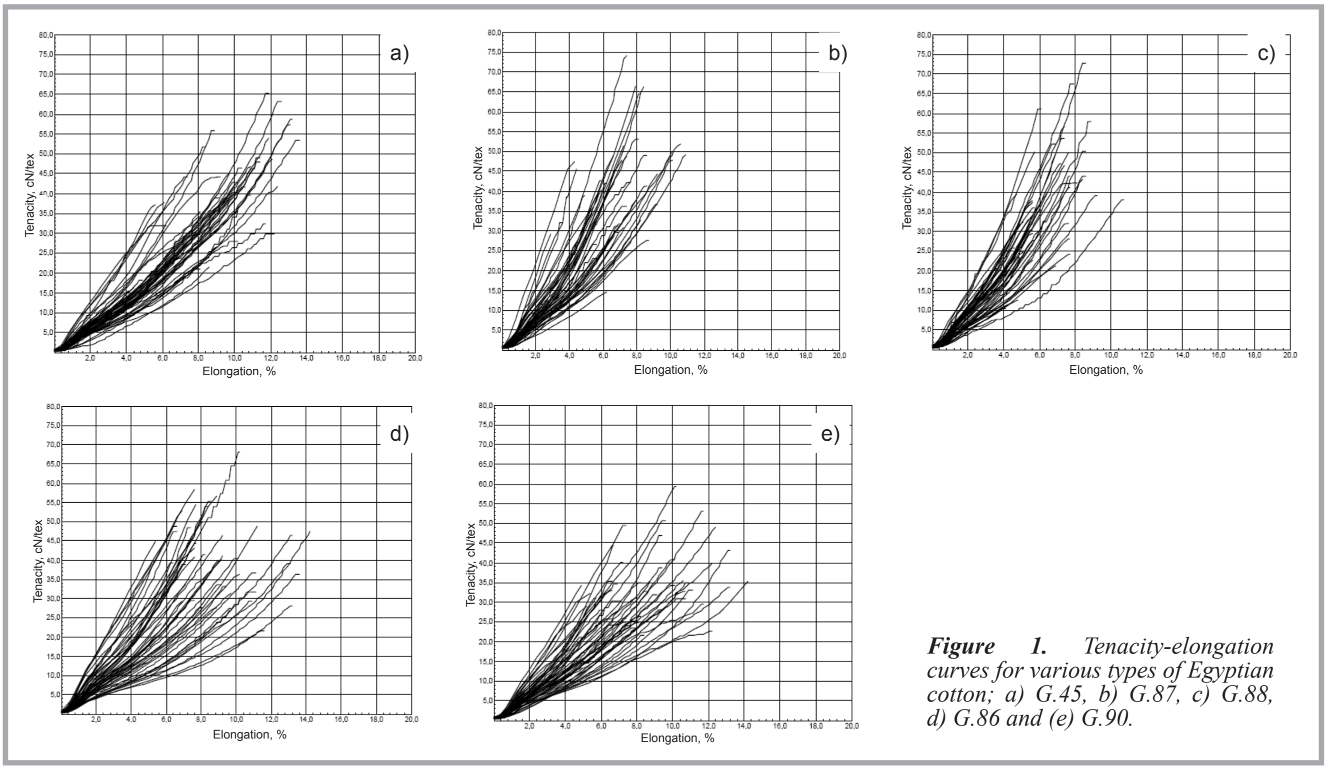


Figure 1. *Tenacity-elongation curves for various types of Egyptian cotton; a) G.45, b) G.87, c) G.88, d) G.86 and (e) G.90.*

__Table 1.__ Data for different cotton varieties.

Type	Parameter	Fibre linear density, dtex	Tenacity, cN/tex	Elongation, %	Young's modulus, cN/tex
G.45	Mean	1.33	37.88	9.24	288.99
	CV%	20.97	34.59	26.86	39.83
	Min.	0.76	9.3	4.1	99.45
	Max.	1.7	65.3	13.6	646.47
G.87	Mean	1.51	37.13	6.53	383.31
	CV%	17.52	41.17	33.43	41.46
	Min.	1.06	9.47	1.9	161.19
	Max.	2.14	74.09	10.9	1037.61
G.88	Mean	1.62	35.55	6.32	391.95
	CV%	21.04	41.89	26.92	34.9
	Min.	1.07	7.66	3.1	151.29
	Max.	2.4	72.66	10.7	799.65
G.86	Mean	1.76	39.01	8.69	378.81
	CV%	17	29.73	27.17	43.2
	Min.	1.05	12.65	4.2	180.72
	Max.	2.38	68.11	14.2	785.79
G.90	Mean	1.64	32.75	8.51	308.7
	CV%	21.39	29.99	30.17	32.62
	Min.	1.1	13.19	3.9	131.22
	Max.	2.33	59.36	14.2	575.55

sponsible for the initiation of yarn failure than those of higher tenacities. The correlation factors between the yarn tenacity, fibre bundle tenacity and single fibre tenacity are as shown in ***Table 4.***

The above analysis shows that the bundle fibre tenacity is relatively highly correlated to the yarn tenacity with a correlation factor of (0.76), which is in agreement with several studies [4, 12, 19]. This is due to the relatively low variability in the values of bundle tenacities compared to those of single fibre tenacities, as shown in ***Tables 1*** and ***2***. This shows that the high variability in single fibre tenacity is not reflected in the bundles consisting of the same single fibres. However, it is well known that the yarn tenacity is a function of several fibre characteristics and not only the fibre tenacity [23].

__Table 2.__ Tuft fibre tenacity measured by HVI.

Cotton variety	Parameter	Mean	CV%
G.45	Fibre tenacity, cN/tex	42.3	3.3
	Elongation, %	6.0	3.2
G.87	Fibre tenacity, cN/tex	45.2	3.6
	Elongation, %	6.5	3.1
G.88	Fibre tenacity, cN/tex	45.1	3.9
	Elongation, %	5.1	3.0
G.86	Fibre tenacity, cN/tex	43.1	4.9
	Elongation, %	5.8	3.5
G.90	Fibre tenacity, cN/tex	33.5	4.0
	Elongation, %	7.7	3.9

Prediction of yarn tenacity using the fibre quality index - MFQI

In order to improve the possibility of predicting the yarn tenacity from the fibre properties, the Modified Fibre Quality Index (MFQI), given by ***Equation 1*** [22], which characterises the quality of different cotton fibre varieties was used.

$$MFQI = UHM \times UI \times \times STRb \times (1 + EL)\times(1 - SF)/MIC \quad (1)$$

Where, the fibre length is expressed by the upper half mean UHM in mm, UI in % stands for the fibre length uniformity index, STRb in cN/tex the bundle tenacity, EL in % the fibre elongation at break; (MIC) the micronaire value representing the fibre fineness and maturity, and SF in % for the short fibre content. The index MFQI is used for the prediction of yarn tenacity, which is a function of not only the fibre tenacity but also its length, its short fibre content, its fineness and its elongation at break. These properties should be taken into consideration while predicting the tenacity of yarns. Samples from different cotton varieties were tested and the value of MFQI was calculated for each variety. The fibres were spun into yarns of different linear densities: 12 tex, 6 tex and 3.7 tex and twist factor: 34.5 (turns/cm × (tex^0.5)). The tenacity of the yarns produced was then tested and a statistical analysis was performed, the results of which are shown in ***Figure 2***.

From ***Figure 2***, a high correlation factor - 0.96 could be detected between the MFQI and yarn tenacity for each of the three counts produced. This high correlation is justified as the MFQI – unlike the traditional SCI – takes the elongation and short fibre content into consideration, which are expected to have a significant effect on the yarn tenacity. Therefore a comparison of the efficiency of the SCI as a predictor of yarn tenacity was a must. Therefore the relation between the SCI and yarn tenacity was investigated as shown in ***Figure 3***, which gave a relatively low R^2 value of 0.699, showing that the MFQI is not only more effective in characterizing fibre quality but also in predicting yarn tenacity. The general regression equation for the prediction of yarn tenacity as a function of MFQI was found to be:

$$Sy = 0.041\ MFQI + 5.798 \quad (2)$$

The values of yarn tenacity given by ***Equation 2*** were then compared to the actual values of yarn tenacity for the different yarn linear densities under investigation. The R^2 value between the actual values of yarn tenacity and those calculated was found to be 0.7652. The curve between actual and predicted values is shown in ***Figure 4.***

Another set of samples from the same cotton varieties were spun on compact

__Table 3.__ Tensile tenacity of yarns produced from different cotton varieties.

Cotton variety	Mean yarn tenacity, cN/tex	CV%
G.45	20.02	7.89
G.88	23.81	8.38
G.86	16.50	10.10
G.90	14.31	8.87

__Table 4.__ Correlation factors between single fibre tenacity, bundle fibre tenacity and yarn tenacity.

Parameter	Single fibre tenacity	Bundle fibre tenacity	Yarn tenacity
Single fibre tenacity	1	0.80	0.21
Bundle fibre tenacity	0.80	1	0.76
Yarn tenacity	0.21	0.76	1

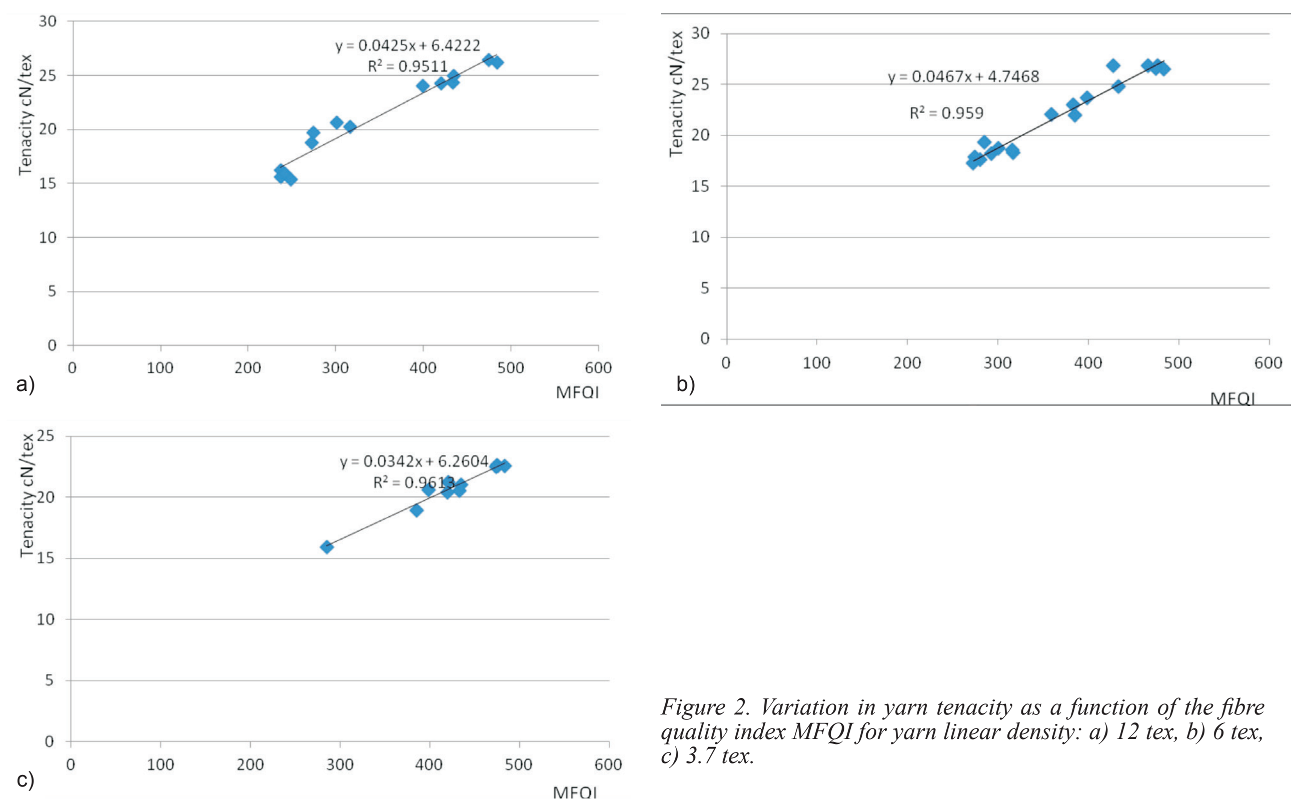
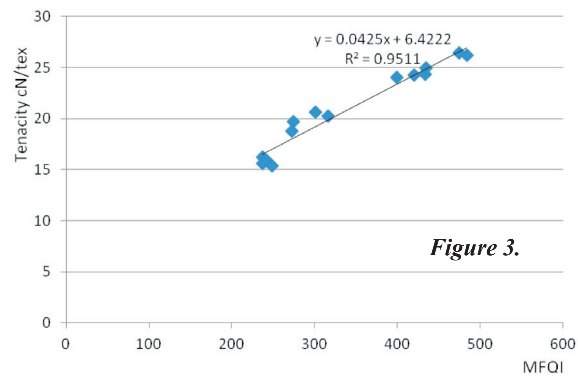
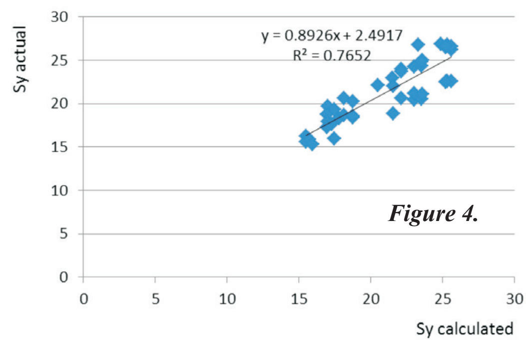


Figure 2. Variation in yarn tenacity as a function of the fibre quality index MFQI for yarn linear density: a) 12 tex, b) 6 tex, c) 3.7 tex.





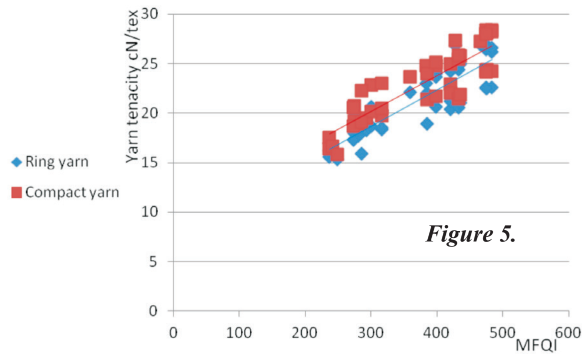


***Figure 3.** Variation in yarn tenacity as a function of the Uster Spinning Consistency Index SCI.*

***Figure 4.** Calculated value versus the actual value of yarn tenacity.*

***Figure 5.** Variation in yarn tenacity as a function of the fibre quality index - MFQI for ring and compact spun yarns.*

and ring spinning machines under identical spinning preparation conditions. The yarn tenacity was tested for different values of MFQI. A comparison of the yarn tenacity of both ring spun and compact spun yarns was performed, as shown in ***Figure 5***.

In both cases, a high correlation could be detected between yarn tenacity and MFQI. It was noticed that the slopes of the two trend lines are the same with a nearly equal value of $R^2 = 0.7652$ for ring spun yarn and $R^2 = 0.7651$ for compact spun yarn. This indicates that the value of MFQI can be used for the prediction of the tenacity of ring and compact spun yarns. Based on the regression equation, relating the fibre quality index for predicting compact yarn tenacity can be given by ***Equation 3***;

$$Sy = 0.0361\ MFQI + 9.3238 \quad (3)$$

Conclusion

The fibre properties have a pronounced influence on the yarn internal structure and mechanical properties such as yarn tenacity. In this research:

1. The bundle tenacity proved to be much more effective than single fibre tenacity as the variability between the individual readings of bundle tenacity is much less than that of the single fibre tenacity.
2. The MFQI was tested for its efficiency as a predictor of yarn tenacity and a strong correlation between them was detected (R^2 = 0.95). The reason for this high correlation is that the MFQI proved to have better competency than the SCI in determining the quality of cotton fibres.
3. The MFQI takes the short fibre content and the fibre extension at break into consideration. These parameters affect the yarn tenacity, which gives another indication of the success that the MFQI proved in predicting yarn tenacity.
4. (MFQI) is capable of expressing the cotton fibre quality as well as predicting the yarn tenacity for ring spun yarns as well as for compact spun yarns.

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Received 13.06.2012 Reviewed 03.10.2012