A study on cotton fibre elongation measurement

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ABSTRACT

Results from a recent study on cotton fibre elongation measurement using 17 Upland and three Pima cottons found significant correlations between average single fibre elongation values measured by the Textechno Favimat and bundle elongation values measured by the CSIRO Sirolan-Tensor but not with values measured by high volume instrument (HVI). The study also revealed positive correlations between Tensor and Favimat tenacity and elongation values. These correlations were further improved when specific elongation values were used. Following the concept of specific strength, applied to the ratio between a material's strength and its density, the term specific elongation is applied to the normalized value. The study also confirmed a previous study that showed little correlation between average single fibre elongation by the Favimat and bundle elongation values measured by HVI.

INTRODUCTION

Fibre elongation at break or the breaking elongation, herein referred to as elongation, is an important cotton fibre property that directly affects yarn elongation and work-to-break values. Many studies have shown the importance of fibre elongation and its contribution to yarn quality and specifically to yarn toughness or work-to-break values [1-6].

Elongation can be measured in either single fibre or bundle form, of which the latter is more usual. Single fibre tests show considerable scatter between tested fibres and as such, accurate values typically require more than 300 fibres per sample to be tested. Whilst accurate in principle, the scatter and time consuming nature of single fibre testing reduces its application to pure research questions rather than routine quality assurance. Instead, bundle testing by HVI is the most widely used elongation test method. Whilst the most widely used test method, a previous study reported at the 2014 meeting of the International Textile Manufacturers Federation's (ITMF) International Committee for Cotton Test Methods (ICCTM) [7] showed poor correlations between HVI elongation values and elongation values from single fibre and other bundle test methods.

To confirm these findings a follow-up study was recently carried out at the Commonwealth Scientific and Industrial Research Organisation (CSIRO). In this study, 20 international cotton samples were tested for elongation using the Favimat instrument (Textechno, Mönchengladbach, Germany) and two bundle testing methods; the CSIRO Sirolan-Tensor [8, 9], a fibre bundle tensile testing instrument developed by CSIRO, and the HVI 1000 (Uster Technologies, Knoxville TN, USA). Pictures of the Favimat and Sirolan-Tensor test instruments are shown in Figures 1(a) and (b).

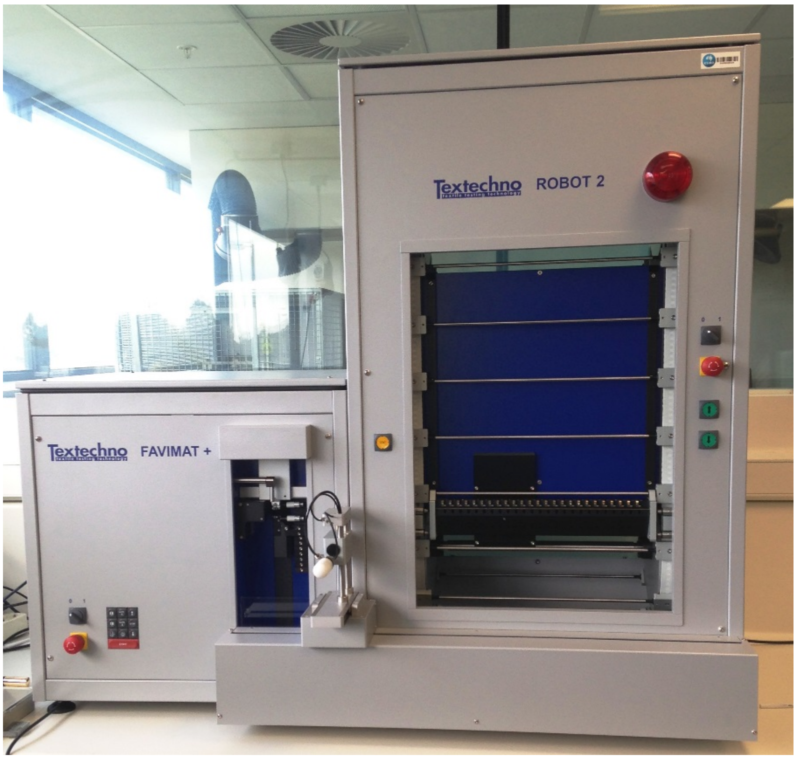

Figure 1(a) – Textechno Favimat instrument

Figure 1(b) – CSIRO Sirolan-Tensor instrument

MATERIALS AND METHODS

Samples of 20 cottons (17 Upland and three Pima) were sourced from a Chinese fine count yarn ring spinning mill. Cotton samples (150 to 200 g) were picked from single bales in the same bale laydown at the mill and sent to the CSIRO in Geelong, Australia for testing. The samples originated predominantly from the USA but also from China.

All single fibre and bundle testing was conducted under standard testing conditions of 20 ± 2^0C and 65 ± 2% relative humidity. Single fibre testing was performed on the Favimat instrument using a 201 cN load cell and a pre-tension of 0.3 cN/tex. Three hundred fibres per sample were tested across a gauge length of 11 mm at a constant rate of extension of 11 mm/min.

The Sirolan-Tensor, an instrument originally developed at CSIRO for wool staple testing was utilised for bundle tests. The advantage of the Sirolan-Tensor is its precision in measuring the breaking load applied to a fibre bundle and the ability to normalize the strength value by a directly weighed fibre bundle (typically weighing between 4 and 6 mg). A gauge length of 5 mm was used and testing was conducted at a constant rate of extension of 20 mm/min. Ten tests per sample were conducted on each sample.

High volume instrument tests on an Uster HVI 1000 machine were conducted at Auscott Classing Services (Sydney, Australia).

Test data was analysed using Minitab (Version 17).

RESULTS AND DISCUSSION

Descriptive statistics for elongation and tenacity values for the twenty samples by each test method are shown in Table 1. Pearson correlation coefficients and ρ-values for relations between these parameters are shown in Table 2.

Table 1 – Average elongation (ELO) (%) and tenacity (TEN) (cN/tex) values of the sample set by the three test methods; Favimat, Tensor and HVI.

Variable	Mean	Std. Dev.	Minimum	Median	Maximum
Favimat ELO	5.32	0.69	4.35	5.2	7.15
Favimat TEN	33.73	4.69	24.99	33.02	43.97
Tensor ELO	8.17	0.75	7.15	8.55	9.75
Tensor TEN	21.9	2.75	18.57	21.86	29.06
HVI ELO	6.09	1.12	4.5	7.13	8.3
HVI TEN	33.3	3.94	27.3	33.88	41.8

Table 2 – Pearson correlation coefficients and probability values > |R| under H_o: ρ = 0 for correlations between elongation (ELO) (%) and tenacity (TEN) (cN/tex) values by three test methods. Significant ρ values highlighted in bold.

Variable	Favimat ELO	Favimat TEN	Tensor ELO	Tensor TEN	HVI ELO
Favimat TEN	0.269 *0.251*				
Tensor ELO	**0.595** ***0.006***	**0.770** ***0.000***			
Tensor TEN	0.417 *0.067*	**0.724** ***0.000***	**0.764** ***0.000***		
HVI ELO	0.013 *0.956*	0.101 *0.673*	0.108 *0.649*	**-0.435** ***0.055***	
HVI TEN	**0.523** ***0.018***	**0.837** ***0.000***	**0.807** ***0.000***	**0.929** ***0.000***	**-0.278** ***0.236***

The data show distinct differences in reported values by each method. Sirolan-Tensor elongation values were higher and tenacity values lower than both Favimat and HVI values. With consideration to the gauge length and bundle size used by each method, these numbers tend to accord. It is understood via the weak-link theory [10] that as gauge length is increased, tenacity values will be reduced. According to the same theory tenacity values also decrease as the number of fibres in the test bundle is increased. Sasser *et al* [11] showed the tension applied per fibre decreased by half on a logarithmic scale from a one fibre through to a bundle of 100 fibres. In these tests the HVI method used the smallest gauge length (2.6 mm) [12], followed by the Sirolan-Tensor (5 mm) and the Favimat (11 mm).

The standard deviation of elongation values between the 20 samples was smallest for the Favimat and Sirolan-Tensor reflecting the narrower range (max – min) of values measured by these methods; 2.9 for the Favimat and 2.6 by the Sirolan-Tensor *cf.* 3.8 for the HVI.

Correlations coefficients of values between test methods are tabulated in Table 2. These show strong correlations between tenacity values by all methods and poorer correlations between elongation values. In particular, elongation values by HVI correlated poorly with values measured by Favimat and Sirolan-Tensor. Figures 2 and 3 show elongation and tenacity values respectively by each method for each of the 20 samples examined. Evident in Figure 2 is the poor agreement between HVI elongation values and the other two methods. This result is in agreement with the previous study. In contrast, Figure 3 shows the relatively good agreement between tenacity values by all methods and particularly between Favimat and HVI values.

Good correlations between single and bundle elongation testing has also been observed by other researchers. The results from a study by Virgin *et al* [6] showed that elongation values from bundle tests relate well to single fibre elongation with $R^2 = 0.80$. Delhom *et al* (2010) [13] conducted single fibre tensile testing on eight (US) cotton samples using Favimat and compared the single fibre results with bundle testing results from the Stelometer and HVI. A reasonably good correlation between Favimat single fibre elongation and bundle elongation with Stelometer was observed with $R^2 = 0.64$.

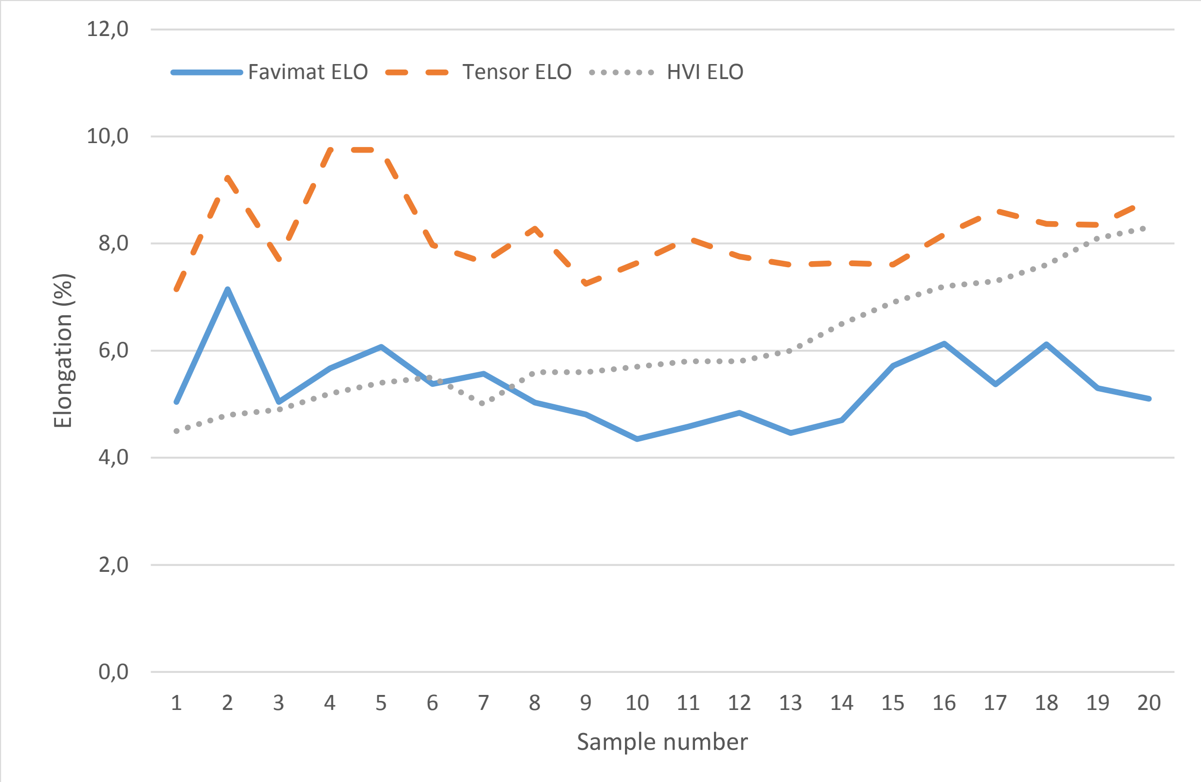

Figure 2 – Elongation values for each sample by the three test methods

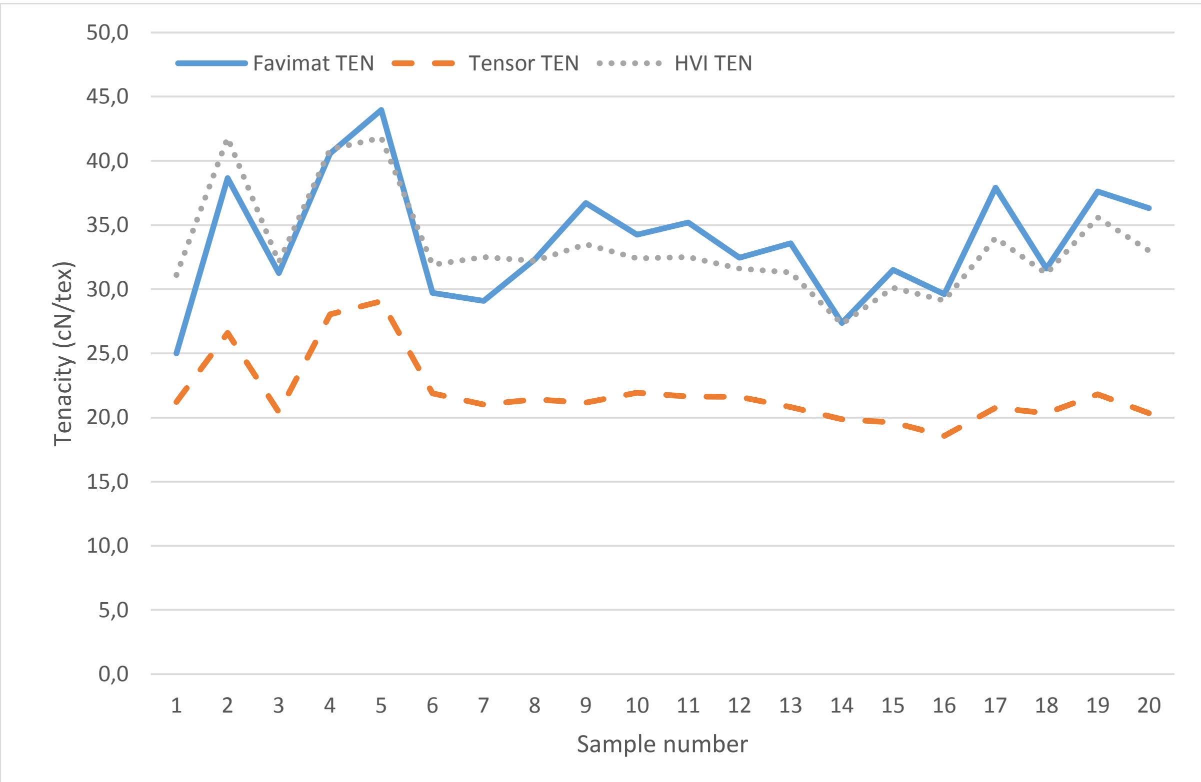

Figure 3 – Tenacity values for each sample by the three test methods

Positive correlations between Favimat elongation and tenacity values, and also for Tensor elongation and tenacity values were observed (see Figures 4 and 5). The larger scatter in the

Favimat results is attributed to the nature of the single fibre testing and the fact that only 300 fibres are represented in the Favimat averages. It is understood that if more fibres are tested then the scatter would be reduced. These positive relationships dispel beliefs that high tenacity cotton fibres have low elongation values, which undoubtedly have originated from the negative relationship observed between HVI values of these properties. Indeed, the correlations between HVI tenacity and elongation show this negative relationship (see also Figure 6). The correlation (R = -0.277) measured in Figure 6 reflects relationships measured by Moghazy and Broughton [14] in their comparison of HVI lines in the early 1990s. They found correlation coefficient values of -0.233 and -0.269 between tenacity and elongation values for the then Motion Control and Spinlab HVI lines respectively.

The reason for the negative correlation is not well documented, although a number of factors that affect the HVI tensile strength result have been investigated. These include pre-crimp tension, fibre length and rates of extension by Taylor [15] and the effect of fibre length distribution, the size of the fibre beard and the subsequent position of the HVI jaw clamp more recently by Naylor and Naylor *et al* [12, 16]. In particular, it was observed by Naylor *et al* [12] that reported HVI elongation values displayed both a significant bias due to fibre length and also a dependence on the size of individual beards tested. A brief examination of the relationship between HVI length and bundle tensile properties, which offers some insight into the reason for the negative correlation, is examined later in this paper.

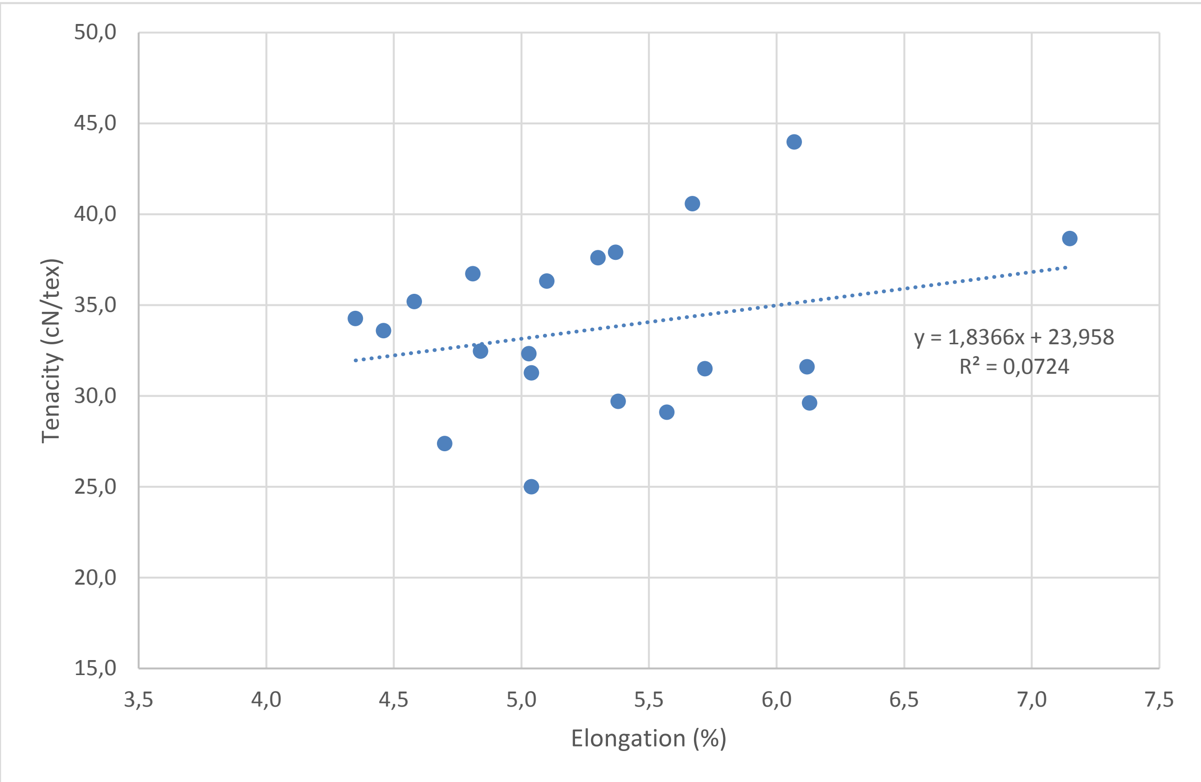

Figure 4 – Favimat tenacity versus elongation values

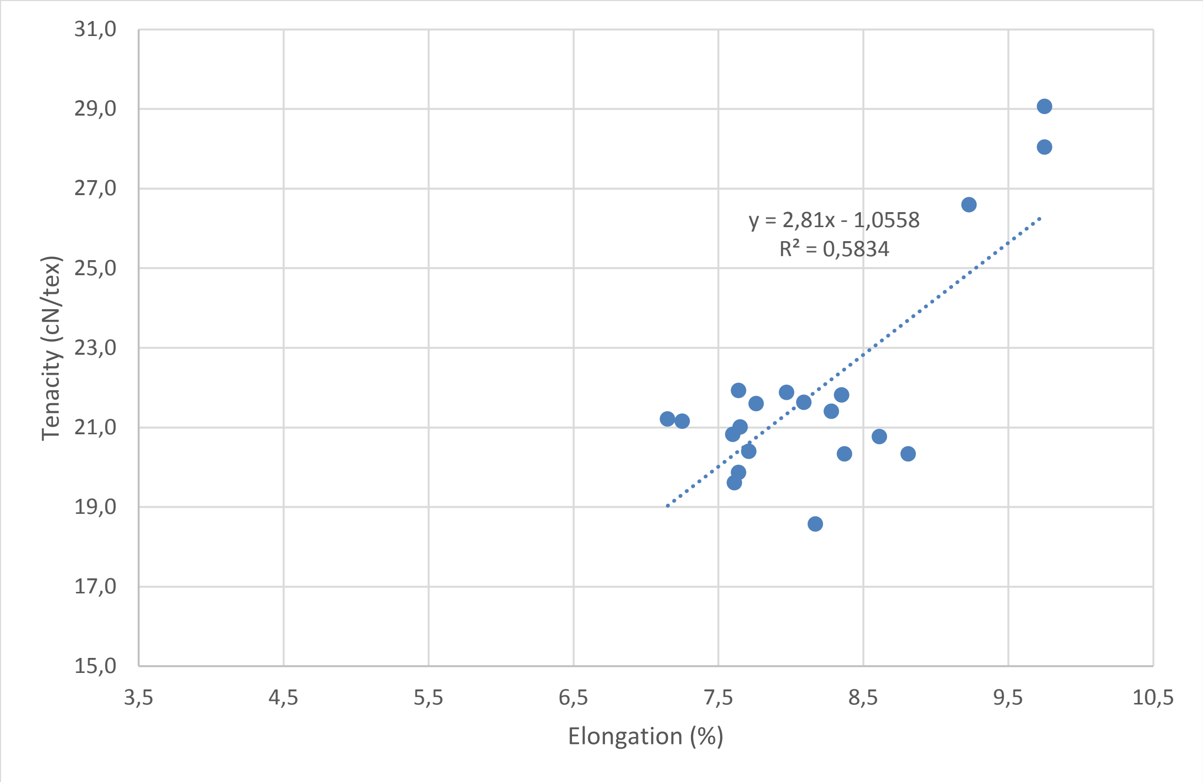

Figure 5 – Tensor tenacity versus elongation values

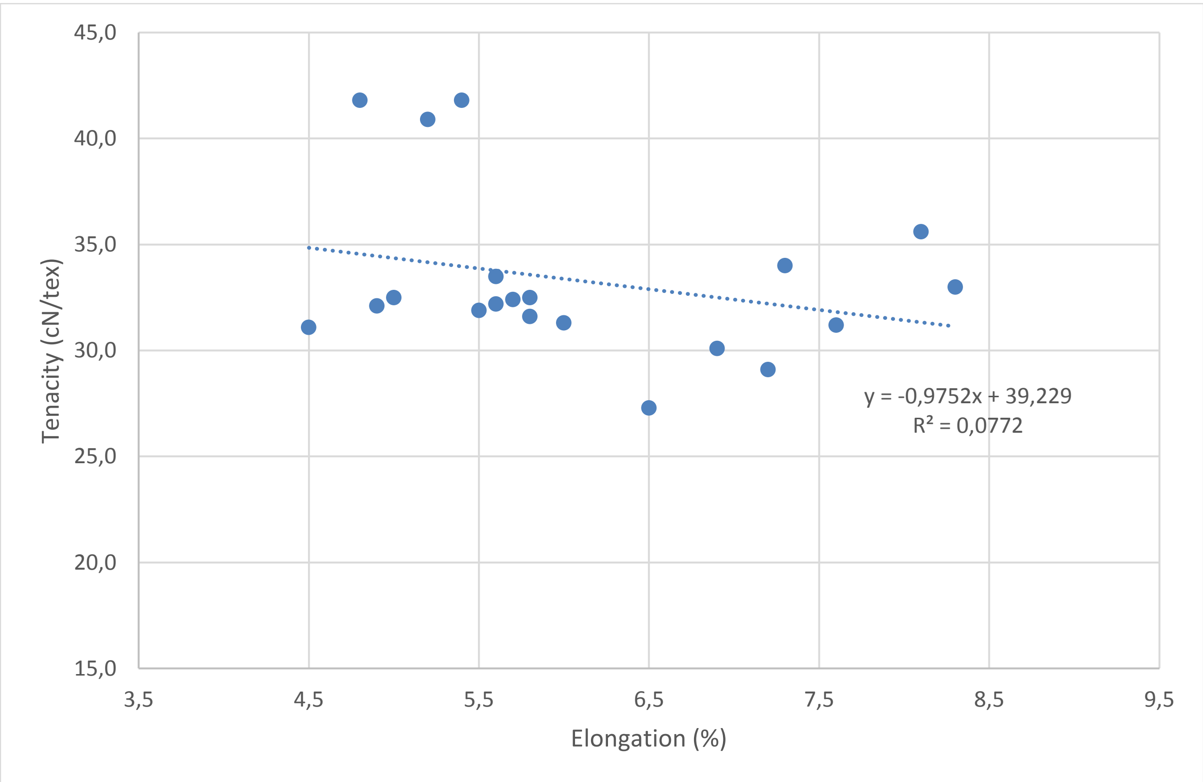

Figure 6 – HVI tenacity versus elongation values

Specific elongation

Similar to the definition of a fibre's tenacity, which is defined as the ratio of the fibre (bundle) breaking strength to the fibre's (linear) density (or bundle mass), a new concept of specific elongation is introduced. It is defined as the ratio of the fibre or bundle elongation-to-break value to its linear density or bundle mass. Table 3 records Favimat and Sirolan-Tensor values against the linear density of their respective specimens, i.e. single fibres for Favimat and fibre bundles for the Sirolan-Tensor. It is noted that no equivalent bundle mass values are given for HVI values despite the specimen (beard) mass being estimated by a light absorption method.

Under the proposed concept it is assumed that elongation values are linear density and maturity dependent, i.e. the finer and more mature the fibre, the greater the elongation. Under this scenario, cotton with finer, more mature fibre will have higher work-to-break value than cotton that is coarser and less mature. Following this assumption, if the measured elongation is corrected for the fibre's linear density, the specific value ought to reflect more closely the fibre's work-to-break value. This hypothesis was tested using vibroscope fineness (linear density) values measured by the Favimat and the weighed bundle masses for the Tensor results to normalize the respective elongation values to produce specific values (SELO). For comparison, substitute work-to-break (W-t-B) values were calculated by multiplying the respective elongation values with tenacity values.

Pearson correlation coefficients and ρ-values for the relations between these calculated parameters are shown in Table 4.

Table 3 – Elongation (ELO) (%), tenacity (TEN) (cN/tex) and linear density (LD) values for fibre (Favimat) and bundle (Sirolan-Tensor) for the 20 international cotton samples. Pima cotton values are indicated in italics.

Sample	Favimat ELO	Favimat TEN	Favimat LD (dtex)	Tensor ELO	Tensor TEN	Tensor LD (mg)
1	5.04	24.99	1.74	7.15	21.21	371.35
2	*7.15*	*38.66*	*1.54*	*9.23*	*26.59*	*337.49*
3	5.04	31.26	1.64	7.71	20.40	361.98
4	*5.67*	*40.57*	*1.46*	*9.75*	*28.04*	*339.56*
5	*6.07*	*43.97*	*1.43*	*9.75*	*29.06*	*325.50*
6	5.38	29.70	1.77	7.97	21.88	373.44
7	5.57	29.09	1.53	7.65	21.01	355.21
8	5.03	32.32	1.77	8.28	21.40	381.24
9	4.81	36.72	1.60	7.25	21.15	364.10
10	4.35	34.25	1.64	7.64	21.93	366.14
11	4.58	35.18	1.71	8.09	21.63	368.74
12	4.84	32.46	1.70	7.76	21.60	363.02
13	4.46	33.58	1.65	7.60	20.82	370.31
14	4.70	27.37	1.82	7.64	19.87	343.24
15	5.72	31.49	1.73	7.61	19.61	342.71
16	6.13	29.60	1.82	8.17	18.57	348.42
17	5.37	37.90	1.60	8.61	20.77	366.01
18	6.12	31.60	1.87	8.37	20.33	357.80
19	5.30	37.60	1.59	8.35	21.81	376.56
20	5.10	36.31	1.71	8.81	20.33	382.56

Table 4 – Pearson correlation coefficients and probability values > |R| under H_o: ρ = 0 for correlations between specific elongation (SELO), tenacity (TEN) (cN/tex) and work-to-break (W-t-B) values by Favimat and Sirolan-Tensor methods. Significant ρ values highlighted in bold.

Variable	Favimat SELO	Tensor SELO	Favimat TEN	Tensor TEN	Favimat W-t-B
Tensor SELO	***0.815*** ***0.000***				
Favimat TEN	***0.557*** ***0.011***	***0.711*** ***0.000***			
Tensor TEN	***0.708*** ***0.000***	***0.813*** ***0.000***	***0.724*** ***0.000***		
Favimat W-t-B	***0.907*** ***0.000***	***0.885*** ***0.000***	***0.810*** ***0.000***	***0.751*** ***0.000***	
Tensor W-t-B	***0.762*** ***0.000***	***0.924*** ***0.000***	***0.783*** ***0.000***	***0.962*** ***0.000***	***0.845*** ***0.000***

The correlations in Table 4 show the effect of normalizing elongation values to fibre and bundle (linear) density values on the relationships between elongation and tenacity, and also between elongation and substitute work-to-break values. Whereas the correlations between elongation and tenacity in Table 3 and Figures 4, 5 and 6, particularly for the Favimat data, were relatively poor, the relationship between specific elongation values and tenacity is significantly improved from a correlation coefficient of 0.269 ($\rho = 0.251$) to 0.511 ($\rho = 0.011$) and from 0.764 ($\rho = 0.000$) to 0.813 ($\rho = 0.000$) for Sirolan-Tensor values. Figures 7 and 8 show the plots for Favimat and Sirolan-Tensor data respectively. Utilising the concept of specific elongation the positive correlation between elongation and tenacity for both methods is significantly improved.

The smaller level of improvement in the Sirolan-Tensor data is associated with the insensitivity of the bundle mass number to the specific fibre quality (fineness) of the fibre. Whilst these results are preliminary they do substantiate previous work and lend weight to the proposal that elongation should be corrected for linear density because of the (elongation-to-break) values dependence on its linear density and maturity, or material structure. It still remains for investigators to examine in more detail the exact relationships of cross-section parameters on tensile properties in terms of their structural material and instrument interactions. For example, it is understood that cotton exhibits different cellulose packing densities along its fibre axis, which give rise to a plethora of convolutions, reversals and crimp that from a material fracture perspective affect its tensile properties.

Figure 9 shows Favimat work-to-break plotted against the equivalent Sirolan-Tensor and HVI work-to-break values. The graph shows poor correlations between Favimat work-to-break and the respective HVI value, which is largely associated with the poor relationship between elongation values by these methods (see also Figure 2). The relationship between Favimat and Sirolan-Tensor results reflects the good relationships recorded between these test methods.

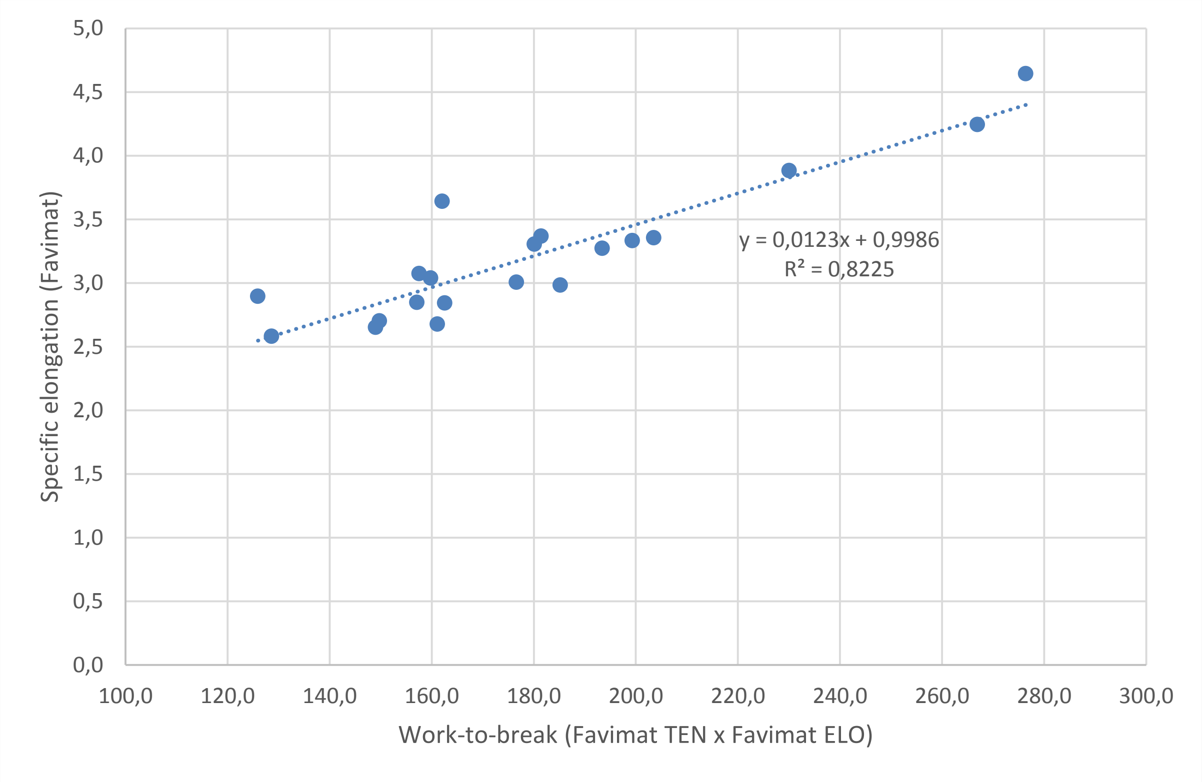

Figure 7 – Specific elongation (Favimat) versus work-to-break (Favimat)

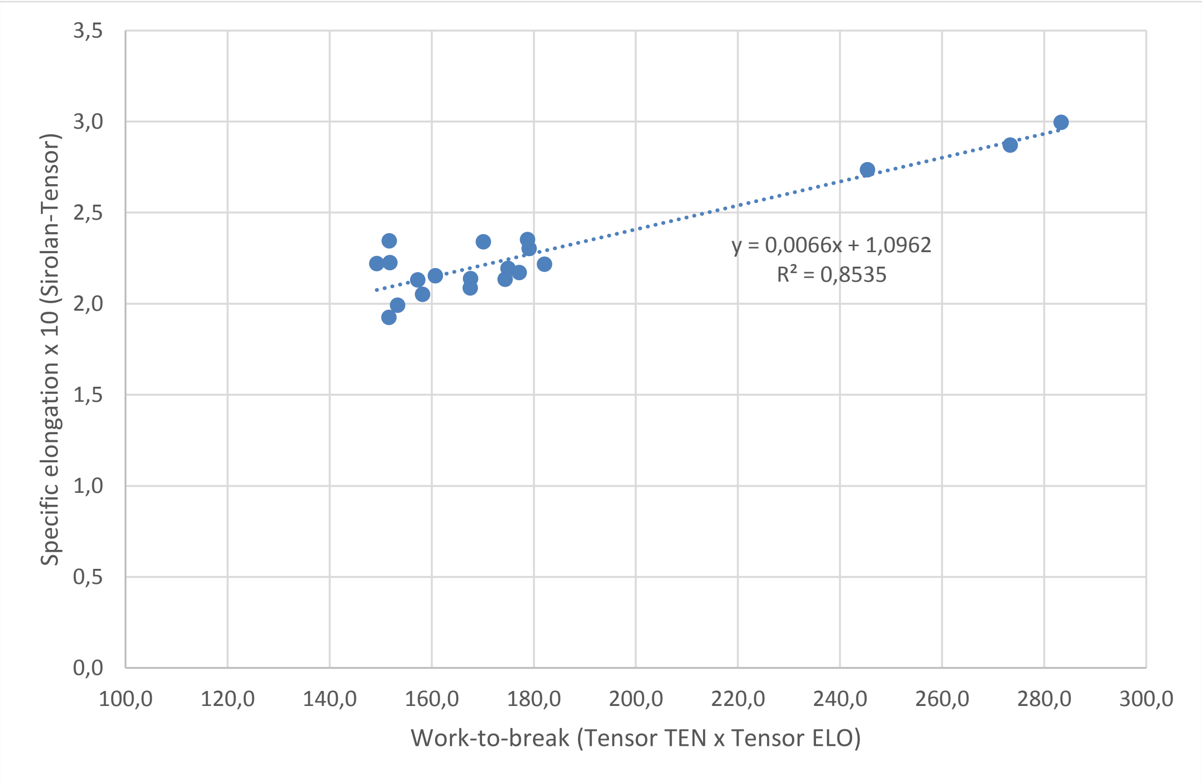

Figure 8 – Specific elongation (Tensor) versus work-to-break (Tensor)

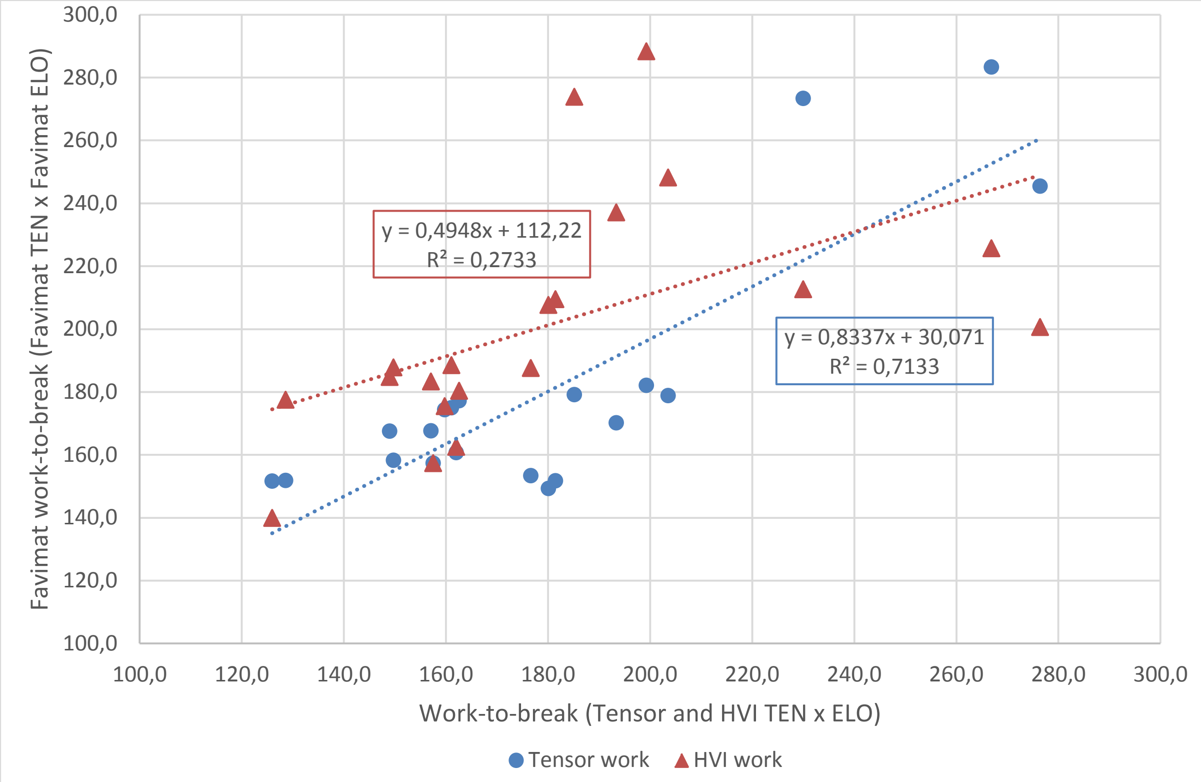

Figure 9 – Work-to-break values for Favimat, Sirolan-Tensor and HVI methods

Impact of fibre length on bundle tensile properties

Given that both Favimat single fibre measurement and Sirolan-Tensor bundle measurements show positive correlations between cotton fibre elongation and tenacity, it is worthwhile to further examine reason(s) why HVI bundle testing gives a negative correlation between the two parameters. According to previous work [12, 14 - 16] fibre length is a significant variable in HVI tensile measurement, although the exact cause of the effect has been difficult to model. It is thought that fibre length has an effect on the registered 'amount' of beard measurement in the HVI and subsequently on the position of the beard in which the HVI jaws clamp. It is well known that fibre tenacity measurements are positively correlated to fibre length [5].

The relationship between Favimat single fibre tenacity and upper half mean length (UHML) as measured by the HVI is plotted in Figure 10. The plot shows a positive correlation between fibre tenacity and UHML. Similarly, the relationship between bundle tenacities from Sirolan-Tensor and two HVI lines operated in the same classing office and UHML (see Figures 11 and 12) also show positive correlations. A summary of the regression equations for the relationships is given in Table 5.

Table 5 – Regression equations of fibre tenacity with UHML

Methods	**Regression equation**	**R^2**
Favimat	FT = 17.00 UHML + 13.76	0.18
Tensor	FT = 17.87 UHML + 0.91	0.57
HVI 1	FT = 24.15 UHML + 4.65	0.54
HVI 2	FT = 32.00 UHML – 4.66	0.66

From the equations in Table 5, it can be seen that the regression coefficients for Favimat single fibre measurement and Tensor bundle measurement are similar, between 17 and 18. However, the average regression coefficient for the two HVI lines is >60% stronger at 28, suggesting a more exaggerated relationship between fibre tenacity and UHML by HVI. Naylor [12, 16] reported a length bias in the HVI strength measurement associated with the positioning of the instrument's clamping jaws relative to the beard and the size of each individual beard, according to the HVI 'amount' parameter.

According to this very brief analysis, it is believed the observed negative correlation between HVI tenacity and elongation is a result of the length bias in the HVI measurement and the subsequent interaction between fibre length and, as per Naylor *et al* [12], the 'amount' of fibre measured in the beard.

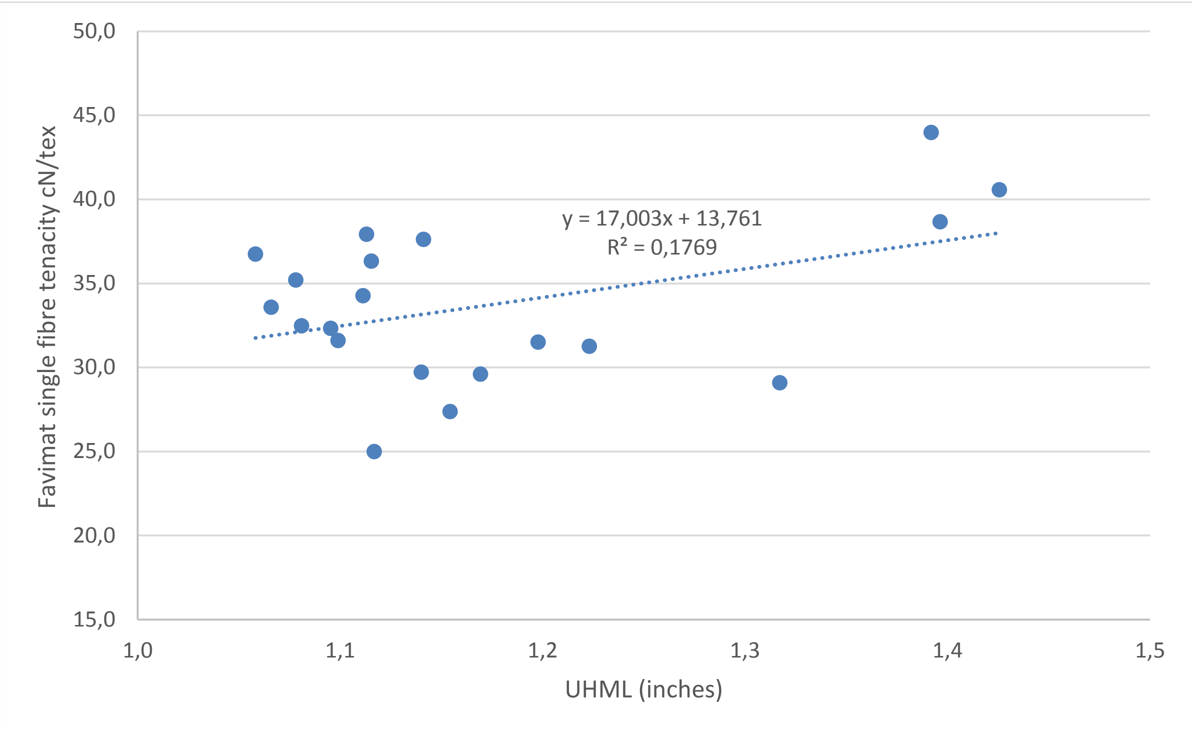

Figure 11 – Favimat single fibre tenacity vs. UHML

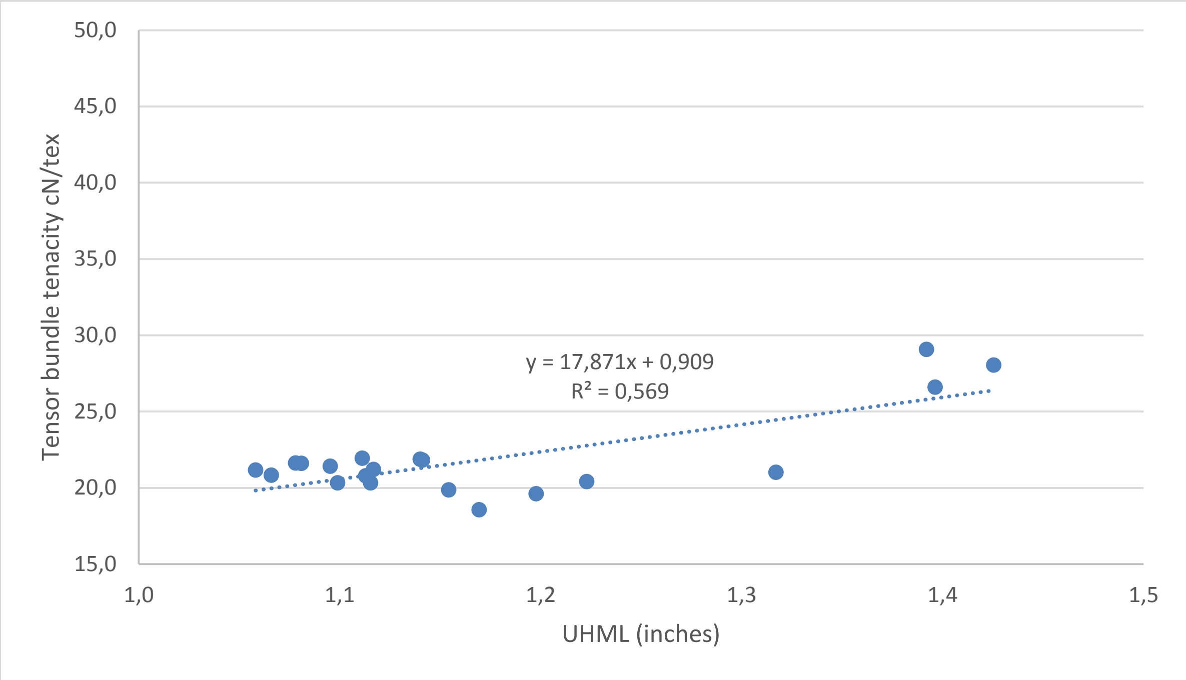

Figure 12 – Tensor bundle tenacity vs. UHML

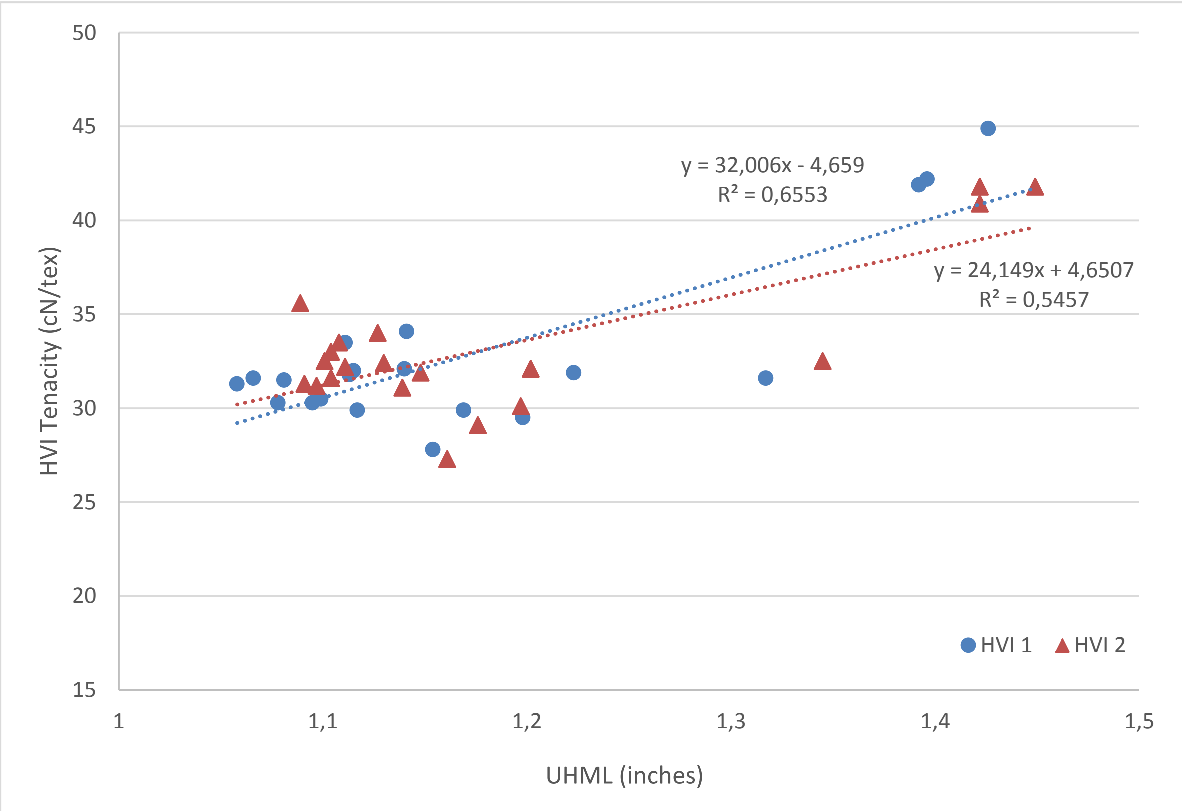

Figure 13 – HVI bundle tenacity (HVI 1 and 2) vs. UHML

CONCLUSION

This study has confirmed findings from a previous study that there are good correlations between Favimat single fibre elongation and Tensor bundle elongation values and that these improved by introducing a new concept of specific elongation. This study also confirmed there is no correlation between Favimat single fibre elongation and HVI bundle elongation, which indicates some issues with the HVI elongation measurement. Further to such questions, this study also showed there should be a positive correlation between cotton fibre elongation (single or bundle) and fibre tenacity, as evidenced from the results of both Favimat single fibre testing and Tensor bundle testing. The negative correlations from HVI measurement observed in this study and reported by other researchers are believed to be caused by a fibre length bias and variable jaw positioning in HVI fibre tenacity and elongation measurements. These issues require further investigation.

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