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WORK OF RUPTURE AS AN INDICATOR TO ABRASION RESISTANCEPROPERTY OF SELECTED WOVEN FABRICS

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ABSTRACT

This paper is concerned with the study of work of rupture as a quick mean for evaluating abrasion resistance of fabrics without having to go through the lengthy process of the actual testing procedure itself. The work of rupture of fabrics was calculated by calculating the area under the load - elongation curve obtained from the tensile strength and elongation results for each type of fabrics.Samples of PET woven fabrics with different weave structure and different weft densities were the object of the investigation. Results have shown that in some instances work of rupture can be a valuable and efficient tool to evaluate abrasion resistance without going through the procedure of the common abrasion resistance test itself. The plain weave structure at 40 picks/cmshowed the best results to abrasion resistance expressed as the percentage of weight loss when compared to the basket and twill samples. Moreover, the plain weave sample at 40 picks/cm scored the highest result for work of rupture. The improved resistance of plain fabrics to abrasion and higher work of rupture values can be attributed to compactness of the fabric as well as to the crimp length values for each of the fabric types. Results showed that it is possible for certain types of weave structure to use results of work of rupture as a tool to predict the abrasion resistance performance.

Keywords: Abrasion Resistance, Weight Loss, Work Of Rupture, Weave Structure, Fabric Density, Indicator.

I. INTRODUCTION

1.1Tensile Properties of Woven Fabrics

Tensile properties are one of the most important characteristics governing fabric performance in use and this includes both breaking load and elongation aspects of the tested material. Despite that fact, their study involves many difficulties due to the great degree of bulkiness in fabric structure and the strain variation during deformation. In particular, each piece of fabric consists of a large quantity of constituent fibers and yarns and hence any slight deformation of the fabric will give rise subsequently to a chain of complex movements of these[1], [2].Accordingly,results depend on specimen geometry, fiber type and arrangement, as well as the fabric structure. These mechanical properties are important for all textile users including fabric processors, garment manufacturers, designers and customers.[3]

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1.2 Work of Rupture

Work of rupture, sometimes called toughness, is the energy needed to break a fiber or fabric. It gives a measureof the ability of the material to withstand sudden shocks of given energy. The units for this are joules. As a result, when a mass (m), attached to a textile specimen, is dropped from a height (h), it acquires akinetic energy, equal to (mgh). Accordingly, if this energy is greater than the work of rupture, breakage will occur. On the contrary, if the energy is less, the specimen will withstand the shock. Thusthe work of rupture is the appropriate quantity to consider in such events as theopening of a parachute, a falling climber being stopped by a rope and all the occasionswhen sudden shocks are liable to cause breakage. It should be noted that the significant feature in the application of the work of rupture is that the shock contains a given amount of energy; the fact that it occurs rapidly is not directly relevant, though the rate of loading will affect the value of the work of rupture. In comparing materials to see which is least likely to break, it is important to consider the conditions under which breakage would occur and then to decide which quantity is the appropriate one to use. For instance, it is no use for a climbing rope to have a high tenacity if its work of rupture is low. In actual practice, more complicated tensile conditions may occur, for example a sudden shock may be applied to a specimen already carrying a steady load. It should also be remembered that breakage may occur as a result of the repeated applications of forces, not necessarily along the fiber axis.[4]–[6]

Accordingly, If we consider a fiber under a load (F), increasing in length by an amount (dl), then work of rupture can be calculated fromthe following equations:

Work done = force × displacement = $F \cdot dl$

Total work done in breaking the fiber = work of rupture

Work of rupture $= \int_0^{break} F.dl$

This equals the area under the load–elongation curve, as shown in Fig. (1)

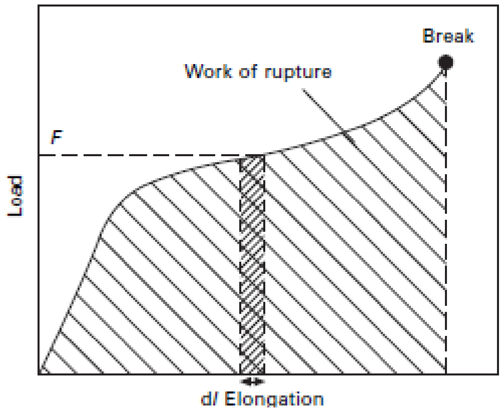

Fig (1): Work of rupture calculated as area under the curve of the Stress-Strain graph

1.3 Abrasion resistance of woven fabric

Abrasion is the mechanical deterioration of fabric components by rubbing them against another surface. Abrasion ultimately results in the loss of performance characteristics, such as strength, but it also affects the appearance of a fabric. Diminished fabric performance, damage, and wear are the main results for abrasion fatigue. However, the abrasion resistance is only one of several factors contributing to wear performance or durability. Abrasion can occur in many ways and can include fabric to fabric rubbing when sitting or wearing, fabric to ground abrasion during crawling, and sand being rubbed into upholstery fabric. That being said, it can be very difficult to mimic these different abrasion factors by only one type of abrasion resistance test. As a result, abrasion resistance is usually gauged using different types of abrasion resistance tests in order to get as close as possible to mimicking real world application scenarios.[3]

Collars and certain other parts of the garments such as cuffs and pockets are more susceptible to abrasion wear which limits considerably their service life. Likewise, abrasion is a serious problem for home textiles like as carpets and upholstery fabrics and technical textiles as well. Moreover, Abrasion does not only affect fabric surface, but it also has an effect on its internal structure.[7]

The abrasion resistance of textile materials is effected by many factors (e.gfiber fineness, yarn count, yarn type, weave etc.) in a very complex, and as yet little understood manner.[7], [8]

Accordingly, thepaper is concerned with the study of work of rupture as a quick tool for evaluating abrasion resistance of fabrics without having to go through the lengthy process of the actual testing procedure itself. Accordingly, both tensile strength and elongation at break for different varieties of fabrics were measured as well as their abrasion resistance to verify the possibility of using the work of rupture as an indication for abrasion resistance as mentioned earlier.

II. MATERIALS AND METHODS

In the present work, 9 samples of PET woven fabrics with different weaves and different weft densities were studiedas listed in Table (1). The fabrics were manufactured on the basis of the same warp yarn countof 150 denier, and number of threadsof 72/cm. Moreover, three main weave categories (plain 1/1, basket 2/2, and twill 1/3), and three picks densities for each selected weave(32, 36, and 40 picks/cm) were chosen. Weight loss due to abrasion resistance and tensile strength were measured according to standard testing methods ASTM 4966[9] and EN ISO 13934-, 1999 strip method[10] respectively.Furthermore, work of rupture in weft direction was calculated from area under load- elongation curve obtained by tensile strength test.

Table(1):Sample parameters of tested samples

sample no.	sample type	fiber type	warp density/cm	weft density/cm
1	plain1/1	PET	72	40
2	basket2/2	PET	72	40
3	twill1/3	PET	72	40
5	plain1/1	PET	72	36
6	basket2/2	PET	72	36
7	twill1/3	PET	72	36
9	plain1/1	PET	72	32
10	basket2/2	PET	72	32
11	twill1/3	PET	72	32

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III. RESULTS AND DISCUSSIONS

As far as abrasion resistance test results are concerned, one way Anova was conducted to test for significant results for each tested group of samples as listed in Annex(A). Accordingly, only significant results for abrasion resistance are listed in Table (2). Moreover, only results for tensile strength in weft direction are listed in Table (3) as all the parameters for the warp are constant across all tested samples.

Table(2):Weight loss percentage due to abrasion

sample no.	sample type	weft density /cm	abrasion resistance after 1000 cycle		
			weightbefore testing (gm)	weightafter testing (gm)	weight loss (%)
1	plain1/1	40	3.37	3.36	0.30
2	basket2/2		3.2	3.15	1.56
3	twill1/3		3.46	3.34	3.46
5	plain1/1	36	3.44	3.41	1.00
6	basket2/2		3.35	3.29	1.79
7	twill1/3		3.37	3.26	3.26
9	plain1/1	32	3.13	3.11	0.57
10	basket2/2		3.29	3.26	0.91
11	twill1/3		3.32	3.27	1.51

Table(3):Tensile strength and elongation of fabrics

sample no.	sample type	weft density /cm	tensile strength (N) weft direction	elongation (%) weft direction
1	plain1/1	40	840	21
2	basket2/2		857	16.6
3	twill1/3		938	16
5	plain1/1	36	1000	15
6	basket2/2		810	15
7	twill1/3		780	15
9	plain1/1	32	1018	15
10	basket2/2		868	15.3
11	twill1/3		850	15

3.1 Abrasion Resistance According to Fabric Density

Statistical analysis showed that abrasion resistance results of plain weave samples at densities 40, 36, and 32 picks/cm are significant. This may be attributed to the compactness of the fabric, especially for the 40 picks/cm sample, which in turn restricts the yarn movement inside the fabric while subjected to the abrasion motion during the testing procedure. This notion can be further explained by theoretically calculating the float length for each density for the plain weave group of samples. Accordingly, float length of plain 1/1 samples in weft direction at densities 40, 36, and 32 picks/cm is 1/40 cm (0.025 cm) for the 40 picks/cm sample, 1/36 cm (0.028 cm) for the 36 picks/cm sample, and finally 1/32 cm (0.031 cm) for the 32 picks/cm sample . Consequently, the abrasion resistance of plain 1/1 weave at 40 picks/cm is higher than the rest densities for the same weave group. The difference of abrasion of basket 2/2 weave and twill 1/3 weave at densities 40,36, and 32 picks/cmproved to be insignificant as listed in Annex(A).

3.2 Abrasion Resistance According to Fabric Structure

Anova results show that weave structure has a significant effect on abrasion resistance of tested samples. Moreover,the difference of abrasion resistance of (plain 1/1- basket2/2- twill 1/3) fabrics at all densities proved to be significant as shown in Annex (A).The float length for twill 1/3 samples is (0.075,0.084, and 0.094 cm) at densities of 40,36, and 32 picks/cm respectively. Similarly,for basket 2/2 samples the float length is (0.05,0.056,and0.063 cm) at densities of 40,36, and 32 picks/cm respectively. Finally, the float length for plain 1/1 samples is (0.25, 0.028,and0.031cm) at densities of 40, 36 and 32 picks/cm respectively. By comparing the aforementioned results it is clear that the abrasion resistance of plain 1/1 is higher than basket 2/2 and twill 1/3 at all densities. This may be explained by the fact that the float length for twill 1/3 is longer than that of basket 2/2 and plain 1/1 samples respectively.Accordingly, constituent yarns in the twill 1/3 samples are more exposed to the abrading element during the abrasion test procedure resulting in higher rate of abrasion and accordingly elevated rate of weight loss when compared to both plain and basket samples.

3.3 Work of Rupture(Area Under Load- Elongation Curve)

Only abrasion resistance results that proved to be significant, Tables (4) to (7),were chosen to be calculated for work of rupture. Work of rupture values listed in Table (4) to (7) were calculated from the results of tensile strength test results listed in Table (3).Moreover, the work of rupture of fabrics was calculated by substituting with the numerical values which are extracted from area under load- elongation curvesin the equationsas shown in Annex (B). Those extracted numerical values represent the initial and final values at break for bothtensile strength and elongation.

Table(4):Work of ruptures and weight loss percentage for plain weave at40,36, and 32 picks/cm

sample no.	sample type	weft density p/ cm	work of rupture	weight loss %
1	plain 1/1	40	9562	0.3
5	plain 1/1	36	8096.25	1.00
9	plain 1/1	32	8231	0.57

Table (5):Work of ruptures and weight loss percentagefor different fabric weaves at 40 picks/cm

sample no.	sample type	weft density p/cm	work of rupture	weight loss %
1	plain 1/1	40	9562	0.3
2	basket2/2	40	7997.2	1.56
3	twill1/3	40	7654.4	3.46

Table(6):Work of rupture and weight loss percentagefor different fabric weavesat 36 picks/cm

sample no.	sample type	weft density p/cm	work of rupture	weight loss %
5	plain 1/1	36	8096.25	0.1
6	basket2/2	36	6678.75	1.79
7	twill1/3	36	6300	3.26

Table(7):Work of rupture and weight loss percentagefor different fabric weavesat 32 picks/cm

sample no.	sample type	weft density p/cm	work of rupture	weight loss %
9	plain 1/1	32	8231	0.57
10	basket2/2	32	7630	0.91
11	twill1/3	32	7350	1.51

3.4 Work of Rupture According to Fabric Density

As listed in Table (4) to (7), across all weave structures, the 40 picks/cm samples scored the highest values for work of rupture. This can be attributed to the fact that the higher the density, the more yarns is available per each centimeter to store energy. Accordingly, the larger number of yarns is translated in higher capacity for energy storage giving rise to better work of rupture values when compared to the lesser weft densities. These results are in agreement with the results of percentage of weight loss listed in Table (2) where the 40 picks/cm samples gave the lowest weight loss percentage and hence the highest abrasion resistance results.

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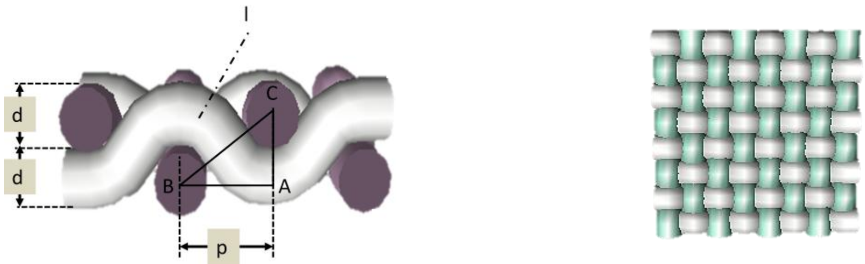
3.5 Work of Rupture According to Fabric Structure

As listed in Tables (4) to (7) for work of rupture values, plain 1/1 weave has recorded the highest value for work of rupture at all weft densities when compared to basket 2/2 and twill 1/3 samples at their corresponding densities. This can be explained by the higher weft crimp for the plain fabric (20.9%) when compared to the basket 2/2 and twill 1/3 samples (both 13%). The crimp percentages for all fabric structures were calculated with the aid of pierce model for crimp calculation[11] as shown in Fig (2) to (4) and Equations (1) to (3).For this model threads were regarded as close together as possible without distortion of their circular cross section.

Plain 1/1

$$\because 1 + c = \frac{l}{p} = \frac{2\pi d}{3 \times 1.732 d} = 1.209 \qquad \text{(Equation 1)}$$

$$\therefore c = 20.9\%$$



(A) **(B)**

Fig.(2): plain 1/1 weave(A) cross section – (B) surface patterrn

Basket 2/2

$$\because 1 + c = \frac{l}{s} = \left[d + \frac{2\pi d}{6}\right]/\sqrt{3} = 1.13 \qquad \text{(Equation 2)}$$

$$\therefore c = 13\%$$

(A) **(B)**

Fig.(3): Basket weave 2/2 (A) cross section – (B) surface patterrn

Twill 1/3

$$\because 1 + c = \frac{l}{s} = \left[2d + \left(\frac{4\pi d}{6} \times 2\right)\right]/2d + 2\sqrt{3d} \qquad \text{(Equation 3)}$$

$$\therefore 1 + c = \frac{6.18}{5.46} = 1.13$$

$$c = 13\%$$

(A) **(B)**

Fig.(4): Twill weave 1/3 (A) cross section – (B) surface patterrn

Accordingly, the higher crimp percentage for the plain 1/1 samples is translated in higher work of rupture values when compared to the basket 2/2 and twill 1/3 samples because of the ability of the plain samples to absorb more energy before it breaks or fails.

Furthermore, the intersection points in plain 1/1 samples arehigher than both basket and twill samples which is translated in higher friction between the warp and weft yarns. This in turn results in increased work of rupture values when compared to the other weaves as evidenced in Tables (5) to (7).

Moreover, the higher work of rupture value for basket samples when compared to twill samples despite their equal crimp values can be explained by the fact that in the basket 2/2 samples the threads move in pairs which in turn enhances the energy needed to break the fibers despite the same crimp value.

These results are in agreement with the results of percentage of weight loss listed in Table (2) where the 40 picks/cm samples gave the lowest weight loss percentage and hence the highest abrasion resistance results.

IV. CONCLUSION

The results of abrasion resistance and work of rupture can be summarized in the following main points:-

1. As far as the effect of fabric density on abrasion resistance is concerned, it has been found that abrasion resistance is affected by the change in fabric density where the plain weave at 40, 36, and 32 picks/cm showed the best abrasion resistance as per the weight loss results. Among all densities the 40 picks/cm showed the lowest weight loss and hence the best abrasion resistance
2. As far as the effect of weave structure on abrasion resistance is concerned, all weave structures proved to have a significant effect on abrasion resistance of tested samples. Moreover, the abrasion resistance of plain 1/1 is higher than basket 2/2 and twill 1/3 at all densities
3. As far as work of rupture and fabric density is concerned, across all weave structures, the 40 picks/cm samples scored the highest values for work of rupture. These results are in agreement with the results of percentage of weight loss where the 40 picks/cm samples gave the lowest weight loss percentage and hence the highest abrasion resistance results
4. As far as work of rupture and weave structure is concerned, plain 1/1 weave has recorded the highest value for work of rupture at all weft densities when compared to basket 2/2 and twill 1/3 samples at their corresponding densities. These results are in agreement with the results of percentage of weight loss listed where the 40 picks/cm samples gave the lowest weight loss percentage and hence the highest abrasion resistance results

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Annex (A)

Anova single factor

Weight loss for plain 1/1 samples at 40-36-32 picks/cm

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
40	3	1.008738	0.336246	0.000305
36	3	2.986976	0.995659	0.078034
32	3	1.72509	0.57503	0.000116

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.668771	2	0.334386	12.78631	0.006863	5.143253
Within Groups	0.156911	6	0.026152			
Total	0.825682	8				

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Weight loss for basket 2/2 samples at 40-36-32 picks/cm

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
40	3	4.600073	1.533358	0.15546
36	3	5.140327	1.713442	0.072343
32	3	2.854977	0.951659	0.057275

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.951118	2	0.475559	5.004514	0.052645	5.143253
Within Groups	0.570156	6	0.095026			
Total	1.521274	8				

Weight loss for twill 1/3 samples at 40-36-32 picks/cm

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
40	3	9.874806	3.291602	20.58612
36	3	7.111027	2.370342	9.287176
32	3	3.857123	1.285708	0.011611

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	6.048762	2	3.024381	0.303603	0.748859	5.143253
Within Groups	59.76981	6	9.961636			
Total	65.81858	8				

Weight loss at 40 picks/cm for plain 1/1- basket 2/2 – twill 1/3

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
plain 1/1	3	1.008738	0.336246	0.000305
basket 2/2	3	4.600073	1.533358	0.15546
twill 1/3	3	9.011472	3.003824	0.675095

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	10.71132	2	5.355661	19.33778	0.002422	5.143253
Within Groups	1.66172	6	0.276953			
Total	12.37304	8				

Weight loss at 36 picks/cm for plain 1/1- basket 2/2 – twill 1/3

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
plain 1/1	3	2.958708	0.986236	0.069209
basket 2/2	3	5.140327	1.713442	0.072343
twill 1/3	3	8.474606	2.824869	0.550444

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	5.144666	2	2.572333	11.1518	0.009526	5.143253
Within Groups	1.383991	6	0.230665			
Total	6.528658	8				

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Weight loss at 32 picks/cm for plain 1/1- basket 2/2 – twill 1/3

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
plain 1/1	3	1.72509	0.57503	0.000116
basket 2/2	3	3.006492	1.002164	0.026338
twill 1/3	3	4.132346	1.377449	0.063993

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.967158	2	0.483579	16.03961	0.003912	5.143253
Within Groups	0.180894	6	0.030149			
Total	1.148053	8				

Annex (B)

Work of rupture calculations

Sample (1) Plain 1/1 (40 picks/cm)

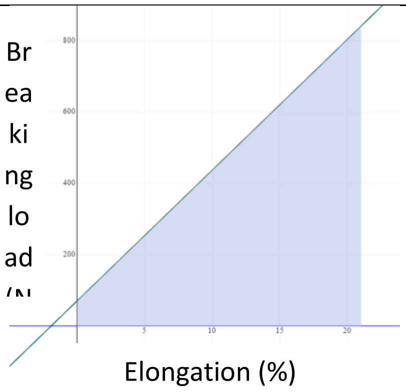

Table (4-a) Numerical values for work of rupture of plain weave at 40 weft/cm

21	**0**	**X**
840	**70**	**Y**

$$\textbf{slope} = \frac{840-70}{21-0} = 36.7$$

$$f(x) = 36.7\,X + 70$$

Definite integral

$$\int_0^{21} 36.7\,X + 70 = 9562.35$$

Sample (2) Basket 2/2 (40 picks/cm)

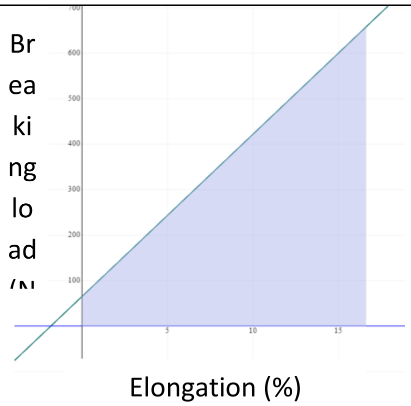

Table (4-a) Numerical values for work of rupture of basket weave at 40 weft/cm

16.6	0	X
874	90	Y

$$\text{slope} = \frac{874 - 90}{16.6 - 0} = 47.2$$

$$f(x) = 47.2\,X + 90$$

Definite integral

$$\int_0^{16.6} 47.2\,X + 90 = 7997.2$$

Sample (3) Twill 1/3 (40 picks/cm)

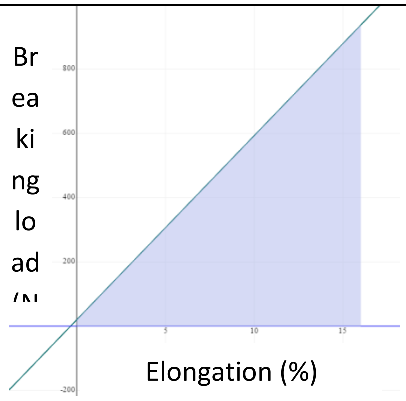

Table (4-a) Numerical values for work of rupture of twill weave at 40 weft/cm

16	0	X
938	20	Y

$$slope = \frac{938 - 20}{16 - 0} = 36.7$$

$$f(x) = 57.3\,X + 20$$

Definite integral

$$\int_0^{16} 57.3\,X + 20 = 7654.4$$

Sample (5) Plain 1/1 (36 picks/cm)

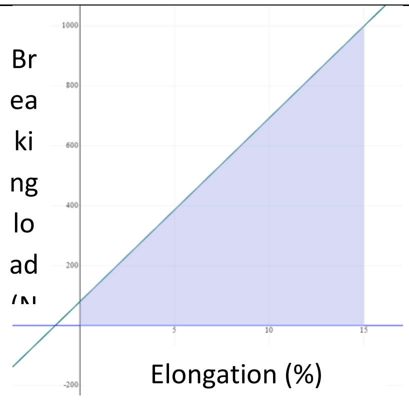

Table (4-a) Numerical values for work of rupture of twill weave at 40 weft/cm

15	0	X
1000	80	Y

$$\text{slope} = \frac{1000 - 80}{15 - 0} = 61.3$$

$$f(x) = 61.3\,X + 80$$

Definite integral

$$\int_0^{15} 61.3\,X + 80 = 8096.25$$

Sample (6) Basket 2/2 (36 picks/cm)

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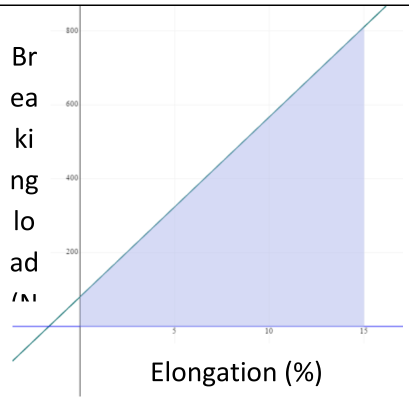

Table (4-d) Numerical values for work of rupture basket 2/2 at 36 weft /cm

15	0	X
810	80	Y

$$slope = \frac{810 - 80}{15 - 0} = 48.7$$

$$f(x) = 48.7\,X + 80$$

Definite integral

$$\int_0^{15} 48.7\,X + 80 = 6678.75$$

Sample (7) Twill 1/3 (36 picks/cm)

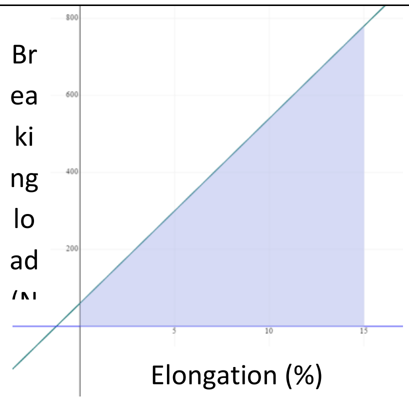

Table (4-e) Numerical values for work of rupture twill 1/3 at 36 weft /cm

15	0	X
780	60	Y

$$slope = \frac{780 - 60}{15 - 0} = 48$$

$$f(x) = 48\,X + 60$$

Definite integral

$$\int_0^{15} 48\,X + 60 = 6300$$

Sample (9) Plain 1/1 (32 picks/cm)

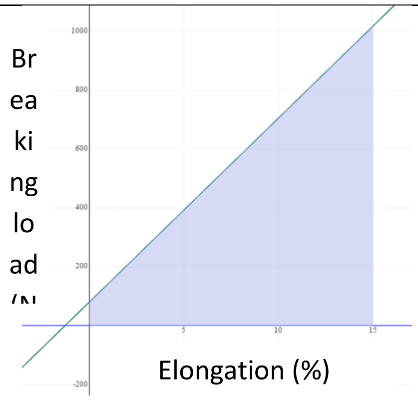

Table (4-c) Numerical values for work of rupture of plain weave at 32 weft/cm

15	0	X
1018	80	Y

$$slope \frac{1018 - 80}{15 - 0} = 62.5$$

$$f(x) = 62.5\,X + 80$$

Definite integral

$$\int_0^{15} 62.5\,X + 80 = 8231$$

Sample (10) Basket 2/2 (32 picks/cm)

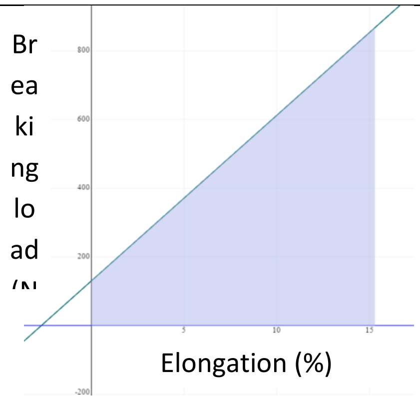

Table (4-f) Numerical values for work of rupture basket 2/2 at 32 weft /cm

15.3	0	X
868	130	Y

$$slope = \frac{868 - 130}{15.3 - 0} = 48.3$$

$$f(x) = 48.3\,X + 130$$

Definite integral

$$\int_{0}^{15.3} 48.3\,X + 130 = 7630$$

Sample (11) Twill 1/3 (32 picks/cm)

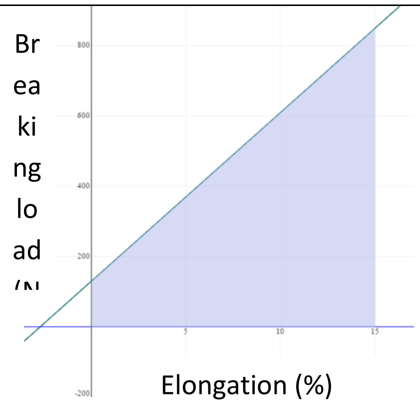

Table (4-g) Numerical values for work of rupture twill 1/3 at 32 weft /cm

15	0	X
850	130	Y

$$slope = \frac{850 - 130}{15 - 0} = 48$$

$$f(x) = 48\,X + 130$$

Definite integral

$$\int_{0}^{15} 48\,X + 130 = 7350$$