

**Review Article**

# A Review on Different Factors of Woven Fabrics' Strength Prediction

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**Abstract:** There are different fabric manufacturing methods like weaving, knitting, non-woven and braiding. Among them woven fabric shows good dimensional stability and good cover. One of the most important characteristics of woven fabric is strength. Strength is also measured in tensile, tearing or bursting strength. But, so many factors are related to the fabric strength like yarn count, twist, fibre fineness, stiffness, fibre density, fabric structure, cover, yarn density, no. of layer, tightness factor and so on. It is very complex to establish a mathematical relation to determine strength considering all these parameters. This paper will make the clear understanding on the factors that directly or indirectly influence the woven fabric's strength and thus, will be more helpful during further research in woven fabric strength prediction.

**Keywords:** Yarn Strength, Woven Fabric Strength, Weave's Factors

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## 1. Introduction

In selection of the appropriate fabrics for the garments or apparels manufacturing, strength is the first property which has the great influence. It is totally depended on the intended end use. Literature review made us concern that the strength fabric is not only depends on the strength of yarn alone, but also on other factors including type of fibre or blend use, amount, twist direction, yarn count, spinning systems, yarn bending behaviour, frictional properties. It is also shown that fabric geometry, thread density, weave design also has great influence on fabric strength. Experiments already shows us that the strength also changed during wet processing on the basis of the processing condition. Even testing condition like temperature, humidity, loading time, loading amount, between the jaws, testing methods also effects the variation the value of the fabric strength. For all these controllable and uncontrollable fibre, yarn and fabric related factors during manufacturing processes, it is very complex to build up a direct mathematical relationship between the yarn strength

and the resulting fabric strength. In this regard it becomes necessary to find out the best approaches to determine the parameters before the fabric manufacturing to ensure the loss of materials, time, energy, labour and resources. [1-3]

## 2. Literature Reviews

The mathematical modelling of stress-strain relation of woven fabric is a very complicated topic. During last eighty years, many scientists have dedicated their talent in this field. But, it is not so easy as large numbers of factors on which the behaviour of woven fabric depends on. Usually, a mathematical model requires a large number of assumptions, covering missing knowledge or inability to express some of the relevant factors.

Peirce started with the structure-property relationship and derived geometrical relations between yarn spacing, yarn diameter, modular length and weave angle to understand the behaviour of woven fabric on different modes of deformation [4].

On based on that others attempts to show the woven fabric

behaviour by factors like firmness of cloth [5, 8-9], cloth tightness [6, 7, 10], construction factors [11], repeat size [12]. Among all the study most work done to predict either tensile strength or the load-elongation behaviour of woven fabric based on the behaviour of yarn [13-19].

Woven fabrics used as technical textiles are subjected to forces, which are parallel and perpendicular to fabric plane also. The effects of forces, which are parallel to fabric plane, and behaviours of fabric against these forces can be evaluated by measuring breaking strengths and elongation at breaks of fabrics along both warp and weft directions. On the other end, the effects of forces, which are perpendicular to fabric plane, and behaviours of fabric against these forces can be evaluated by bursting strength and impact tests.

A number of studies were carried to search the tensile, bursting and impact strengths of woven fabrics relating to the fabric parameters shown in "Table-1".

### 3. Factors Affecting the Tensile Strength

Fabric strength can be measured in three different ways-

#### 3.1. Tensile Strength (Breaking Strength)

The tensile strength deals with the force required to break a large number of yarn simultaneously in either warp or weft direction. The force at which the material breaks is directly proportional to cross-section. The tensile force recorded at moment of rupture is termed as the tensile strength at break tenacity [35]. Besides cross-section the warp and weft densities also effect the tensile strength. As crimp is with the increase of thread densities and yarn lies more obliquely in relation to the plane of the fabric, greater force is required to balance the load applied in that plane [36].

*Table 1. Research on woven fabric strength.*

| Researcher                      | Finding  | Weave considered   | Factors considered   |
|---------------------------------|--|--|--|
| Ünal andTaşkın [20]             | Breaking strength along both warp and weft directions      | Plain and Twill  | Yarn setting   |
| Oğulatave Kadem [21]            | Breaking strength along both warp and weft directions      | Plain, 2/2 Twill 100% cotton   | Yarn count and setting   |
| Şekerden and Çelik [22]         | Breaking strength  | Different weave  | Weave design, weft count and setting   |
| Mehta et al. [23]               | Tensile strength   | Plain, basket, twill, crepe with same count of yarn                            | Warp and weft setting  |
| Shahpurwala and Schwartz [24]   | Tensile strength   | Plain, twill, satin  | Fibres as cotton, polyester and inter yarn friction at interlacing points  |
| Seyam and El-Shiekh [25]        | Tensile strength in warp direction                         | Plain, basket, twill and satin   | Pick density   |
| Mariatti et al. [26]            | Flexure and tensile properties                             | 2D woven prepreg patterns of plain, basket, twill and satin                    | Float length, fibre count etc.   |
| Biliskand Turhan [27]           | Impact properties  | Multiaxially stitched and unstitched ballistic structure of plain woven fabric | Kevlar 29 @(713)and Kevlar 129 @(802)  |
| Biliskand Korkmaz[28]           | Strength and energy absorption properties                  | Plain woven, Twaron CT714 and Twaron CT716                                     | Warp and weft density  |
| Sun et al. [29]                 | Puncture behaviour   | Plain, 2/1 twill, 2/2 twill  | Interlacing point  |
| Chen et al. [30]                | Breaking strength  | Plain woven ramie fabric   | Loading directions (uniaxial, biaxial, bursting and 3D loading)  |
| Ning Pan [31]                   | Fabric strength  | Plain, 2/1 twill, 3/1 twill, 4/1 twill   | Uniaxial and biaxial extension   |
| Mine AKGÜN at el. [32]          | Breaking strength and strain                               | Plain  | Warp tension   |
| Kotb N. at el. [33]             | Tearing strength   | Pile fabrics   | V-shape & W-shape pile configuration   |
| Malik Z. A. at el. [34]         | Tensile strength   | Plain and twill PC blends  | Strength transfer efficiency of warp and weft  |
| Malik Z. A. at el. [64]         | Predict tensile strength                                   | Plain and twill cotton woven fabrics   | Different construction in warp and warp  |
| Peerzada M. H. at el. [65]      | Weave structural effect on Tensile strength and yarn crimp | 3D Woven fabrics   | 3D woven structures  |
| Rukuižienė Ž, Kumpikaitė E [66] | Warp yarn diameter   | Plain, warp rib, twill and basket weave  | Warp tension and weave influence   |
| M Havlová [67, 68]              | Air permeability (porosity)                                | Eliminated the type of weave   | Sets of warp and weft and their linear densities.  |
| M Havlová [69]                  | Air permeability (porosity)                                | Plain, Rib, Twill and satin  | Sets of warp and weft and their linear densities. yarn diameter, fabric thickness, vertical and horizontal porosity CFF. |
| H. ÖZDEMİR, E. MERT,[70]        | Breaking, bursting, impact strength                        | Diced woven fabrics  | yarn density, interlacement co-efficient and average float length  |
| M. D. Teli at. el. [71]         | Yarn and fabric strength                                   | Plain  | Ring and Rotor yarn structure  |
| Abou-Nassif GA [72]             | Tensile and air permeability properties                    | Plain  | warp and weft count, densities and twist multiplier  |
| Meysam Moezzi et. al. [73]      | Tensile properties   | Woven fabric   | Nylon as weft and Polyester as warp yarn   |
| Swapna Mishra [74]              | Yarn strength utilization                                  | Cotton plain and twll woven fabrics  | warp and weft count and densities  |

The yarn tension or extension due to crimp causes crimp interchange. Thus more crimp helps to extend the fabric more. And more floats on the fabric structure facilitate more thread densities and lessen the extension [37]. Weft and warp tension increasing during the weaving process limits the extensibility of the fabric. Thus, the tensile strength reduced [38]. To determine the tensile strength grab test and strip test is used. During grab test or modified grab test, the jaws' width is less than the specimen width and used for high density fabrics or high strength fabrics. On the other hand, ravelled strip test "Fig. 1" is used by removing the threads from either side of the test piece until it is the correct width for the woven fabric strip test method [ISO 13934-2:1999, ASTM D5034-95, AS 2001.2.3.1-2001, AS 2001.2.3.2-2001].

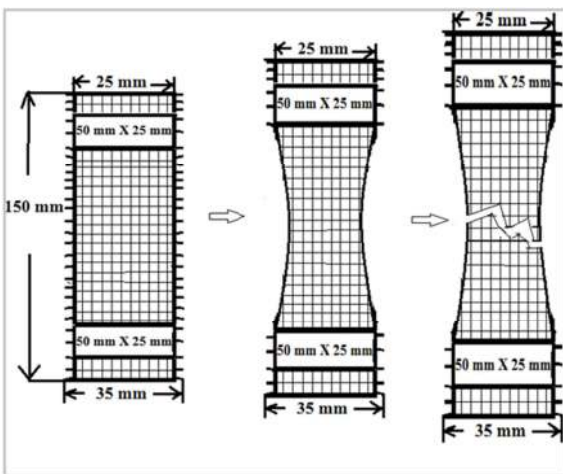


Figure 1. Ravelled strip tensile test.

Here, ravelled strip is better as width correction also effect little on woven strength except knitted fabrics.

### 3.2. Tear Strength (Warp and Weft Direction)

Tear strength is the tensile force required to start, continue or propagate a tear in a fabric under specified conditions. During tearing test firstly, the cloth fails by the breaking of the thread one at a time, or at least in very small groups. Then distortion due to the skewing of the threads and slippage of one set of threads over the other occurs [39].

Here, stresses concentrated at a point on the fabric and only one or at most few yarns share the load "Fig-2" [38]. This failure causes the load being transferred to the adjacent yarn and thus fails in turn. Thought greater extensibility or reduced frictional constraints allow the yarns to bunch at the tear, and therefore increase the tearing strength [40], it is clear that higher yarn strength may not necessarily lead to higher tear strength [41].

Loose open structure or long floats in the fabric construction allows increase in thread density. Thus more threads present as bundles and the tearing strength be more in basket or rib than plain. [42]. The finishing treatment as easy care or coating reduce the tearing strength due to restrict in freedom of movement of the yarns under loading [37]. So, it

clear that tearing strength is more dependent of the of the fabric construction [41]. Using Falling pendulum or Elmendorf gives the average force required to tear and propagate it. And, CRE principles shows irregular results by giving the tearing initiation, then subsequent reading is the force to propagate the tear [ISO 13937-1-2000, ASTM D1423-83, ASTM D751, AS 2001.2.8-2001].

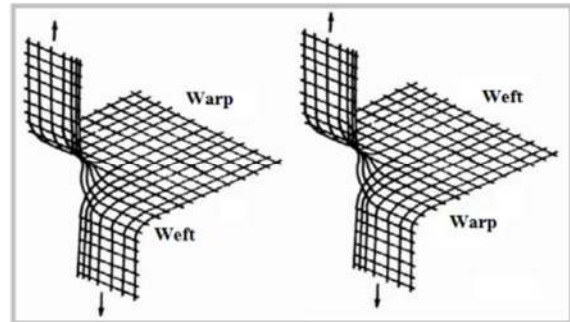


Figure 2. Tear strength test.

### 3.3. Bursting Strength

Burst strength testing is the application of a perpendicular force to a fabric until it ruptures. The bursting strength deals with the strength of the fabric when a multi-directional force is applied on it. Specially for compression fabrics that stresses both in warp and weft direction at the same time this method is a good measurement for strength test.

Compression extension, fabric thickness and weight are important characteristics for engineering different compression garments. This type of fabrics shows immediate or extended compression recovery also [43]. Here, either ball "Fig. 3" or a hydraulic expanded diaphragm "Fig. 4" is used to apply force. Due to multi directional extension fabric fails first at the lowest extension point. And elongation cannot be determined here [ISO 2960, ASTM D3787, AS 2001.2.19-1998, AS 2001.2.4-1990].

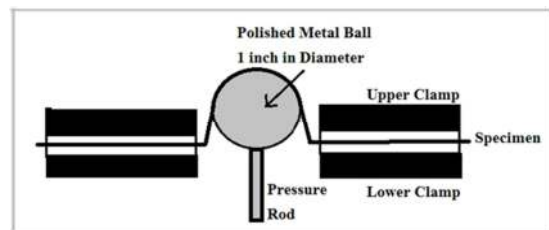


Figure 3. Ball bursting strength testing.

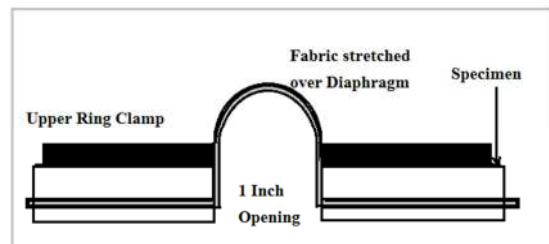


Figure 4. Diaphragm bursting strength testing.

Now, due to different testing methods available to measure the fabric strength in different direction taking compression, extension, weak zones of the fabric in consideration we had to count following factors affect the tensile testing results [44]-

- i. Grab or strip test method related: number of test, gauge length, extension rate, jaws or grips, jaw break within 5 mm of jaw face etc.
- ii. Tear test method related: geometry of test piece, nature of discontinuity, yarn properties, fabric structures, yarn sliding, jamming, density, speed of test, fibre used for yarn construction etc.
- iii. Bursting test method related: elongation, yarn evenness, construction of fabrics etc.

Kothari V. K. Cleared that the fabric mechanical and comfort related properties are related to the structural properties of linear density, twist level, thread densities, crimp levels of warp and weft, cover factor, fabric thickness and fabric skew and bow [45].

It is no doubt that the strength of fabric is directly depended on the strength of yarn. But, the construction variety of yarn “Fig. 5a, 5b, 5c” and the method of spinning has the effect on the fibre arrangement and geometry of yarn for both spun and filament based [46]. The other factors related to the variation of yarn properties specially made of natural fibres are staple length, fibre fineness, fibre strength, twist amount, evenness, fibre length variation, fibre finish, drafting and doubling in spun yarn spinning, chemical treatment like sizing, thick and thin places, slubs, neps, and so on [47]. It is easy to calculate the strength of the yarns using both single yarn strength tester and lea tester [46]. But, as lea strength tester is affected by frictional force present during testing and not sensitive to the weak point of individual yarn as well as do not present the multiple strength of the single thread, it doesn't serve any purpose from the point of further processing.

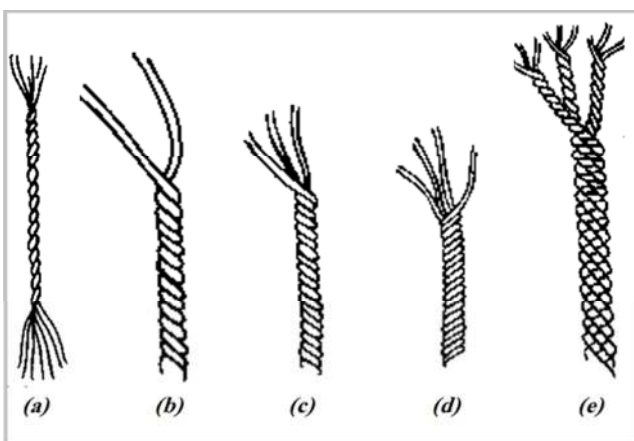


Figure 5(a). Simple yarn construction ((a) simple ply yarn, (b) double ply yarn, (c) three ply yarn, (d) four ply yarn and, (e) simple cord yarn).

As a result, we need to consider here only the single thread testing results to predict the fabric strength from the yarn

strength. But, still the problems of presenting weak places in the specimen and unwanted fall of yarn strength are remaining as a false indication in the prediction [44].

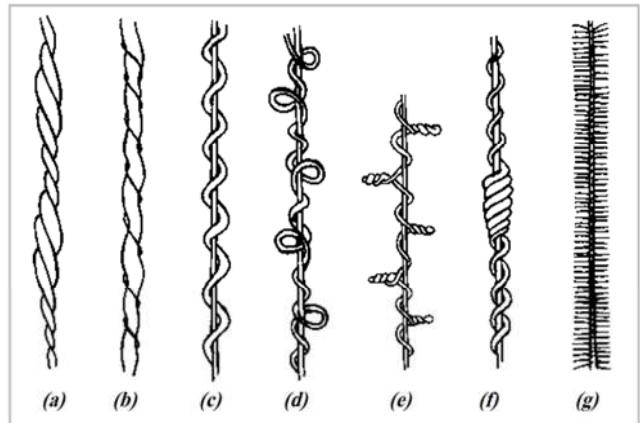


Figure 5(b). Complex yarn construction ((a) slub yarn, (b) spira yarn, (c) boucle yarn, (d) loop yarn, (e) snarl yarn, (f) knop yarn and, (g) chemile yarn).

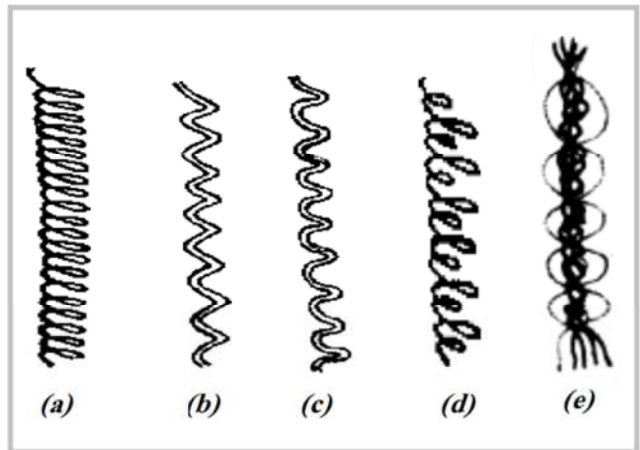


Figure 5(c). Textured yarn construction ((a) coiled yarn, (b) peaked crimp yarn, (c) round crimp yarn, (d) curled yarn and, (e) high bulk yarn).

### 4. Representation of Woven Fabric

After long hard working from the researchers on the determination of fabric parameters now comes in front of us to select the factors which will be helpful in this regard. They already done over 100 years of attempts in combining all the major parameters to represent the fabric that can be helpful for our prediction in terms of different weave factors “Table-2” [4-19].

The greatest problem between all fabric structure parameters is to estimate the fabric weave which is not a digital but a graphical fabric structure picture. Before, we select the best factors to relate the fabric structural parameters to the yarn strength we should go through the recent critics over the factors related to fabric structure.

**Table 2.** Different methods suggested by the researchers to represent the woven fabric parameters.

| Names of factors                                  | Suggested mathematical relationship among different weave parameters  |
|---|---|
| Ashenhurst average float length [48]              | $F_{1(2)} = \frac{R_{1(2)}}{t_{1(2)}}$ <p>But, when <math>F_1 \neq F_2</math>, <math>F = \frac{F_1 R_1 + F_2 R_2}{R_1 R_2}</math></p> <p>And, separate yarns of one system have different medium length of floats, <math>F_{1(2)} = \frac{\sum_{i=1}^{R_{1(2)}} F_{1(2)i}}{R_{1(2)}}</math></p> <p>Here, <math>F_1, F_2</math> = float length, <math>R</math> = repeat, <math>t</math> = intersection</p>   |
| Armitage and Law's maximum thread density [49-50] | $t = S(yN)^{1/2}$ <p>Here, <math>t</math> = maximum ends or picks per inch, <math>y</math> = cloth setting constant that depends on the yarn numbering system, <math>N</math> = yarn count in the indirect system, <math>S</math> = setting ratio varying with weave upto 4 threads per float</p>   |
| Brierley factor for square fabric [5, 51]         | $t = f^m (kN)^{1/2}$ <p>Here, <math>t</math> = maximum ends or picks per inch, <math>k</math> = constant that depends on yarn type and yarn number in an indirect system, <math>m</math> = constant varying according to weave, <math>f</math> = average float, <math>m</math> = constant empirically determined from weave.</p>  |
| Original Brierley Factor [5, 51]                  | $MS / MD = \sqrt{\frac{12}{\pi}} \cdot \frac{1}{F^m} \cdot \sqrt{\frac{T_{avg}}{\rho}} \cdot S_2^{\frac{1}{1+g\sqrt{\frac{F_1}{F_2}}}} \cdot S_1^{\frac{g\sqrt{\frac{F_1}{F_2}}}{1+g\sqrt{\frac{F_1}{F_2}}}}$ <p>where, <math>T_{avg} = \frac{S_1 T_1 + S_2 T_2}{S_1 + S_2}</math> and <math>\rho = \frac{S_1 \rho_1 + S_2 \rho_2}{S_1 + S_2}</math></p> <p>Here, <math>MS/MD</math> = maximum setting/maximum density, <math>S_1, S_2</math> = warp and weft setting respectively, <math>F^m</math> = the empirical weave factor, <math>T_1, T_2</math> = warp and weft linear density, <math>g = 2/3</math> if <math>F_1 \geq F_2</math> and <math>3/2</math> if <math>F_1 &lt; F_2</math> (for weft faced rib <math>g=2</math>), <math>F_1, F_2</math> = float lengths, <math>\rho_1, \rho_2</math> = fibre density,</p> |
| Peirce cover factor [4]                           | $K_f = C_{warp} + C_{weft} - C_{warp} \cdot C_{weft}$ <p>where, <math>C_{warp}</math> or, <math>C_{weft} = 4.44 \times 10^{-3} \times \sqrt{\frac{tex}{\rho}} \times yarn / cm</math></p>   |
| Galceran's fabric tightness factor [55-56]        | $O = \frac{\frac{S_1 \sqrt{T_1}}{\sqrt{1000}} + \frac{S_2 \sqrt{T_2}}{\sqrt{1000}}}{\frac{5\sqrt{\pi\rho_1}}{1+0.73Kl_1} + \frac{5\sqrt{\pi\rho_2}}{1+0.73Kl_2}} - 100$ , here, $Kl_{1(2)} = \frac{\sum_{i=1}^{R_{1(2)}} t_{1(2)i}}{R_1 R_2}$ <p>Here, <math>S_1, S_2</math> = warp and weft setting, <math>T_1, T_2</math> = warp and weft linear density, <math>\rho_1, \rho_2</math> = fibre density, <math>R_1, R_2</math> = warp and weft repeat, <math>t_1, t_2</math> = intersection</p>   |
| Skliannikov tenseness factor [57]                 | $C = \frac{6R_1 R_2 - \left( 2N_f + \sum_{i=1}^6 K_i N_{fi} \right)}{6R_1 R_2}$ <p>Here, <math>R_1, R_2</math> = warp and weft repeat, <math>N_f</math> = number of free fields, <math>N_{fi}</math> = number of free fields belong to group <math>i</math> (all free fields are distributed into six groups <math>K_i</math> - elimination factor of group <math>i</math>)</p>   |
| Hamilton's tightness factor [7]                   | $T = \frac{(K_1 + K_2)_{actual}}{(K_1 + K_2)_{limit}}$ , here, $K_1 = \frac{d_1}{p_1}$ and $K_2 = \frac{d_2}{p_2}$ <p>Here, <math>d_1, d_2</math> = diameter, <math>p_1, p_2</math> = distance between threads.</p>   |
| Gulaszynski coefficient of fabric tightness [58]  | $t = \frac{N_a}{N}$ , where, $N_a = N_1^{-g/g-1}$ , $N_2^{1/1-g}$ , $N = \frac{K_4 F^m}{\sqrt{T}}$ and $T = \frac{nT_1 T_2}{n_1 T_1 + n_2 T_2}$ <p>Here, <math>N_1, N_2</math> = unknown value of warp and weft setting, <math>g</math> = coefficient depend on weave, <math>K_4</math> = coefficient depend on raw material and count system, <math>F^m</math> = empirical weave factor, <math>T</math> = average yarn count, <math>T_1, T_2</math> = count of threads, <math>n</math> = total number of threads in the weave repeat, <math>n_1, n_2</math> = the numbers of threads of a defined count within the weave repeat</p>  |

| Names of factors   | Suggested mathematical relationship among different weave parameters   |
|--|--|
| Seyam and El-Shiekh tightness factors [25]                       | $TS_{1(2)} = \frac{S_{1(2)}}{F_{2(1)}} d_{1(2)} \left( \frac{\pi(F_{2(1)} - 1)}{4} + 2 \right)$  |
| Milasius new factor relating Brierley and Sliannikov factors [9] | <p>Here, <math>d_1, d_2</math> = diameter, <math>F_1, F_2</math> = float lengths, <math>S_1, S_2</math> = warp and weft setting</p> $P_{1(2)} = \frac{1}{\sqrt{C_{1(2)}}} = \sqrt{\frac{3R_1 R_2}{3R_1 R_2 - \left( 2N_{f1(2)} + \sum_{i=1}^6 K_{1(2)i} N_{f1(2)i} \right)}}$  |
| Newtons tightness factor [10]                                    | <p>Here, <math>C_1, C_2</math> = Skliannikov tenseness factor, <math>R_1, R_2</math> = warp and weft repeat, <math>N_f</math> = number of free fields, <math>N_{fi}</math> = number of free fields belong to group <math>i</math> (all free fields are distributed into six groups <math>K_i</math> - elimination factor of group <math>i</math>)</p> $L = \sqrt{(K_1 - K_1^1)^2 + (K_2 - K_2^1)^2} \text{ where, } K_{1(2)} = \frac{d_{1(2)}}{\frac{F_{2(1)}}{S_{2(1)}} - \frac{\pi d_{1(2)}}{4} (F_{2(1)} - 1)}$   |
| Milasius firmness factor [59]                                    | <p>Here, <math>d_1, d_2</math> = diameter, <math>F_1, F_2</math> = float lengths, <math>S_1, S_2</math> = warp and weft setting, <math>K_{1(2)}^1</math> can be calculated from the curve which was plotted by Peirce according to his formula of maximal setting.</p> $\phi = \sqrt{\frac{12}{\pi}} \cdot \frac{1}{P_1} \cdot \sqrt{\frac{T_{avg}}{\rho}} \cdot S_2^{\frac{1}{1+2/3\sqrt{F_1/T_2}}} \cdot S_1^{\frac{2/3\sqrt{F_1/T_2}}{1+2/3\sqrt{F_1/T_2}}}$  |
| Morino et al. CFF and FYF [60]                                   | <p>Here, <math>S_1, S_2</math> = warp and weft setting, <math>T_1, T_2</math> = warp and weft linear density, <math>T_{avg}</math> = average yarn linear density, <math>\rho</math> = fibre density, <math>p_1</math> = distance between threads</p> $CFF = \frac{\text{Number of cross over lines in the complete repeat}}{\text{Number of interlacing points in the complete repeat}}$ $FYF = \frac{(\text{Type}_{1-ix} - 1) \times (\text{Existing number of type}_{1-ix} - 1 \text{ in the complete repeat})}{\text{Number of interlacing points in the complete repeat}}$                                 |
| Milasius new weave factor [61]                                   | $P_{exp} = \frac{S_{qmax}}{S_{qmax\ plain}} = \frac{\frac{1}{1+\frac{2}{3}\sqrt{\frac{T_1}{T_2}}} \cdot \frac{2}{3\sqrt{\frac{T_1}{T_2}}}}{S_{2max}} \cdot S_1^{1+\frac{2}{3}\sqrt{\frac{T_1}{T_2}}} = \left( \frac{S_{2max}}{S_{2max\ plain}} \right)^{\frac{1}{1+\frac{2}{3}\sqrt{\frac{T_1}{T_2}}}} \cdot \left( \frac{S_1}{S_{1\ plain}} \right)^{\frac{2}{3}\sqrt{\frac{T_1}{T_2}}}$  |
| Padaki et al. Interlacement index and float index [62]           | <p>Here, <math>S_{qmax}</math> = maximum pick density of tested square weave, <math>S_{qmax\ plain}</math> = maximum pick density of square plain weave, <math>S_{2max}</math> = maximum pick density of tested weave, <math>S_{2max\ plain}</math> = maximum pick density of plain weave, <math>S_f</math> = warp density of tested weave, <math>S_{f\ plain}</math> = warp density of plain weave, <math>T_1, T_2</math> = warp and weft linear density.</p> $1 = \left( \frac{i_{wp} + i_{wf}}{R_1 R_2} \right) \text{ and, } F = \left( \frac{f_{wp} + f_{wf}}{R_1 R_2} \right) \text{ where, } 1 + F = 2$ |
| Havlova M. [67-69]   | <p>here, <math>i_{wp}, i_{wf}</math> = interlacements in warp and weft, <math>f_{wp}, f_{wf}</math> = floats in warp and weft, <math>R_1, R_2</math> = warp and weft repeat</p> $d_p = \frac{1}{2} \left[ \left( \frac{1}{D_o} - d_o \right) + \left( \frac{1}{D_u} - d_u \right) \right]$ $P_{hor} = 1 - (d_o D_o + d_u D_u \pm d_o d_u D_o D_u)$ $P_{ver} = \frac{(E_o + E_u)}{(S_{FO} + S_{FU})}$   |
|  | <p>here, <math>d_p</math> = average pore diameter, <math>d_o, d_u</math> = diameter of warp and weft, <math>D_o, D_u</math> = sets of warp and weft per m, <math>P_{hor}</math> = horizontal porosity, <math>P_{ver}</math> = vertical porosity, <math>E_o, E_u</math> = projection area of one vertical pore of warp and weft, <math>S_{FO}, S_{FU}</math> = projection area of one vertical warp and weft.</p>   |

## 5. Limitations and Possibilities of Weave Structures

It is practically possible to weave fabric to a greater sett than those estimated by Ashenhurst's formula as the estimated yarn dia is much higher than the measured value and recognised that different fibres and different systems of yarn manufacture were likely to affect the overall yarn density. These influence the yarn diameter and maximum square sett can be achieved [50].

But, it has been reported that Ashenhurst's value of yarn diameter fell between the value of yarn under uncompressed and compressed condition [54].

Armitage and Brierley's maximum square sett did not carry any direct relation to the yarn diameter. But, both showed that setts in excess of those quoted by Ashenhurst could be obtained in all weaves [5, 49-51]

For twill weave rules of maximum construction given by Brierley and Law are fairly accurate but, for satin Law would have been more accurate [52-53].

The shortcoming of Galceran weave factors is that they estimate only a single thread and do not take into account the interlacing of adjacent threads [55-56].

Galuszynski analysing weaving resistance found that Brierley's formula requires some modification of certain values of the coefficients  $m$  and  $g$  for some weft and warp faced ribs and proposed the coefficient of fabric tightness  $T_{Galuszynski}$ . For the weft-faced ribs value  $F$  is taken as an average for the weave with  $g=2/3$ . For warp-faced ribs Galuszynski proposed the value of  $m=0.35$  instead of 0.42 given by Brierley. But, it can only be applied only to few weave structures [58].

Newtons shows that it is difficult to construct the fabric according to the geometry suggested by the Seyam and El-shiekh. But, they pointed that love gave no indication as to which maximum sett fabric was to be used, and the method was not practicable. Newton gave another suggestion when he found that it is possible to have fabric with different setts, yarn counts, weaves and, cover factors which are equally tightly woven. Again, Newton found Hamilton's method is unable to determine the tightness of tow poplin fabric because of high  $K_1/K_2$  values. Hamilton's value show lower values for tighter fabrics became its major limitation in use [10, 60, 62].

The factors based on average float length or KI do not estimate exactly the weave. Hence, Brierley's and Galuszynski's factors cannot be calculated for all types of weave thought they are very easy to understand [10].

Back in the 19<sup>th</sup> century, in order to evaluate the two dimensional matrix of a weave, the average float  $F$  was proposed. Later, it is observed no reflection of all the properties of a weave which are important from a technological and end-use point of view [48].

It is well known that the weaves twill 7/1, satin 8/3 and panama 4/4 have a different tightness, but are still counted with the same value,  $F = 4$  and unbalanced weaves, whose

average warp float is different from the average weft float i.e. warp rib 4/4 and weft rib 4/4 behave very differently during weaving but still evaluated using the same value,  $F = 2.5$ . [61]

However, factor  $P$  is very good for balanced weaves but cannot evaluate the difference between unbalanced weaves – warp rib 4/4 and weft rib 4/4 have the same value,  $P = 1.205$ . Later on V. Milašius proposed factor  $P1$ , calculated in the warp direction. It covers most of the weaves used but cannot be employed for calculating very unbalanced weaves "Fig. 6" [8-9].



Figure 6. Weave structure unbalanced by value  $F$  shown by Milasius.

Finally milasius suggested a new representation of the fabric weave factor that can be used for both balanced and unbalanced weave structure without any variable experimental co-efficient. [61].

The weave factors FYF and CFF belong to Peirce group and like all the factors of this group, they do not take into account an interlacing of adjacent threads [60].

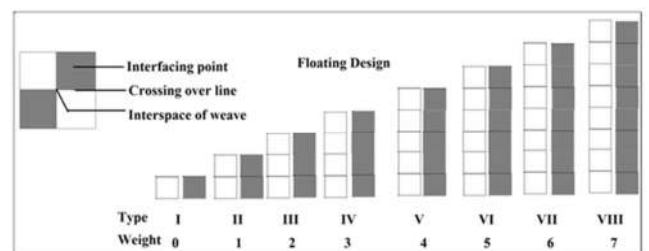


Figure 7. Details of CFF and FYF.

## 6. Conclusion

Mathematical models based on the fundamental mechanics of woven fabrics often fail to yield satisfactory results, as it is hardly possible to combine all the complexities in the model. As the application of mathematical model is very specific, it is important to introduce a different approach for the mathematical modelling of fabric constitutive equations. From predictive, descriptive and numerical models predictive is the most important where relevant factors are considered for prediction considering the other factors as assumptions. And it is based on statistical methods to an approach which is more relevant to real situations [63].

Seven parameters are considered to be important for representing fabric structure. These are namely warp and weft raw materials, warp and weft linear density, warp and



weft settings and fabric weave [45].

Due to variation of yarn structure, fabric construction, weave, methods of testing, this study is to find out the best factors to predict the fabric strength and determine the mathematical expression relating to the yarn strength and predict the woven fabric strength. As other parameters like elongation during testing, floating parameters are also change the test results. Now, we need to combine them in a mathematical formula.

The tightness factors, firmness factors, tenseness factors, floating index and so other factors are based on either yarn specification or weave design. But, other parameters like yarn elongation and bi-axial extension of fabric are still not combined. It is not a easy and simple combination of some values. They are totally variables under different testing conditions also.

As we have so many mathematical tools to combine several parameters in prediction i.e. Linear Regression Model, Taguchi Design of Experiments, Artificial Neural Network etc., it will not be difficult in the next to predict the strength of fabric comparatively more accurate than previous.

It is clear that, statistical tools always have some limitations in the biasness in the result. The information provided to the statistical tools is the main limitation in this regards. If the training like ANN can be done more precisely with all possibilities of the variations only and only then it can provide us the true prediction accuracy. Although the complexity in the mathematical relation between fabric strength and all the variables is still present, new attempts should be taken to make it more clear for the further research in this field.

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