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Assessing the Height, Width and Other Parameters of Elliptical Yarn Cross-Section Through the Thickness of Orthogonal Fabrics

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ABSTRACT

Finding the yarn cross-section parameters of woven fabric is essential to assess various fabric specifications and re-engineer it for specific end-use. This research focuses to assess the height, width, and other parameters of the elliptical yarn cross-section of woven fabrics through the new methodology. The earlier studies stated that the up and down interlacement of the yarn influences the parameters of the elliptical yarn cross-section. Hence this research studies the Elliptical Cross-Section of the yarn through the orthogonal fabric. Because in orthogonal fabric, the weft series stay straight. The samples of orthogonal weaves are produced using different counts of weft yarns. The thicknesses of orthogonal fabrics are estimated. The method of calculating the height of yarn from the thickness of the orthogonal fabric is evolved. The height of different counts of weft yarns used in weaving the orthogonal fabrics is calculated. From the height of the yarn, the width of the yarn is calculated. The height and width of the yarn are compared with the diameter. The comparison shows that the cross-section of the yarn remains elliptical in the fabric. The equations for calculating the flattening and bulging percentages are derived. It is observed that these two percentages are equal. It shows that when the yarn cross-section becomes elliptical in the fabric, the amount of flattening makes the yarn get bulge to the same amount in its width. The constant of height and constant of width are also derived. These constants are equated with the constants of diameter. The study also derived the equation to calculate the height and width of the elliptical cross-section of the given yarn count using the constants. The height, width, and diameter of different yarn counts are compared. The increase/decrease in flattening percentage between the coarser-finer yarns, single–2 ply yarns, and single-folded yarns are examined. The interpretation of the results gives practical proof for many theoretical concepts. The study also evolved the method of calculating the unknown parameters of the given yarn from the known parameters of another yarn, by weaving the orthogonal fabric using both the yarns. It is suggested that the height and width of yarn assessed from the thickness are used to assess the other specifications viz. crimp percentage, cover percentage, and GSM of the fabrics. From all these specifications, the performance of multi-layer orthogonal structures can be ascertained to produce stack reinforced composite industrial preforms with desired tensile stiffness, thickness and strength.

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1. INTRODUCTION

There are many studies about the theoretical parameters of various yarn cross-sections with respect to the interlacement of yarn in the fabrics of basic weaves. The three cross-sections are: Circular Cross-Section (CC-S), Elliptical Cross-Section (EC-S), and Race-Track Cross-Section (R-TC-S). The first study was about the yarn diameter assuming the circular cross-section of yarn. The diameter of the given Tex count of cotton yarn of specific volume 1.1 cm^3 / gram was derived as . The crimp percentage of yarn in plain weave was calculated using the yarn diameter and the thread spacing density [1]. It was studied that because of the system of forces acting between the warp and weft yarns after weaving, the yarn can never be incompressible. This inter-yarn pressure results in considerable yarn flattening normal to the plane of the cloth even in a highly twisted yarn. Therefore, many researchers have tried to correct Peirce's original relationship by assuming various shapes for the cross-section of yarn. Researchers were proposing an elliptical cross-section and race-track cross-section of yarn, as being closer to the actual appearance of yarn in a cloth. Change of elliptical yarn cross-section, parameters of maximally compressed yarn, cover factor, and thickness in plain weave was also studied by the researchers [2]. It was expressed that the next step in developing more exact methods for assessing parameters of woven fabric need a complex mechanical model, with numerical methods for calculations. The study of yarn cross-section was mostly discussed based on plain twill and its derivatives. It was stated that the yarn cross-section measurement is a difficult and time taking task for the textile technologist. In the elliptical cross-section of yarn, the interaction between the levels of twists and eccentricity plays an important role in characterizing the surface properties of the fabrics [3]. A study was also conducted to investigate the cross-sectional shape and size variation of the yarn in fabric woven with different weave types and at different weft settings. The variation in the cross-section of the yarn was evaluated by using the flattening ratio and it was observed that the weave type and setting, affect the cross-sectional properties of the yarn along the yarn path [4]. The relation between the circular cross-section, elliptical cross-section, and race track cross-section was also equated for the plain interlacement [5]. It was also studied that the twist level affects the shape of yarn cross-section parameters in the plain fabric [6]. Automated geometry modelling process of common fabrics, such as plain weave, 2/1 twill, 3/3 twill, 5/3 satin, and double layer weave fabrics based on the ellipse, power ellipse, and a lenticular shapes of yarn have been investigated [7-9]. In the plain fabric, the increase in ellipticity ratio of the yarns as the yarn twist factor increases was studied [10]. It was expressed by researchers that the next step in developing more exact methods for predicting parameters of woven fabric need complex mechanical model, with implemented numerical methods for calculations [11]. It has been observed that the structural factors which determine the geometry of the fabric, such as weave type and setting, affect the cross-sectional properties of the yarn along the yarn path [12]. The major and minor radii of elliptical yarn cross-sections were also related theoretically to yarn linear density, twist factor, warp and weft cover [13].

After reviewing the findings, it is understood that the theoretical specifications of the different cross-sections of yarn was mostly derived in relation to the interlacement of yarns in the fabrics woven with basic weaves and their derivatives, where both the up and down movement of warp and weft yarn influences the results. Hence, a new thought has been given to study the elliptical cross-section of yarn of such a woven fabric in which the yarn of one series lies straight without moving up and down of the other series. This enables to study the parameters of yarn cross-section independently without the influence of interlacement.

When studying the different fabric structures, it is found that the 'Orthogonal Weave' (OW) has a unique character. The orthogonal fabric contains more layers of weft yarns lay in parallel, separated by warp layers lay in parallel [14]. Another set of warp yarns are used to stitch the weft layers which form the face and back layers. This stitching warp gets crimped more as it travels bottom to top and top to bottom [15]. Hence double beams (DB) are required to weave this type of orthogonal fabric and named as 'Orthogonal Double Beam Fabric'. The thickness of fabrics woven by these weaves increases as the number of layers increases. Hence, the fabric produced by OW is called as '3-Dimensional fabric' (3Dm) woven by '2D-Weaving' [16]. As the layer increases in the orthogonal structure of 3Dm fabrics, their performance also increases, but the ratio of binder warp to separating warp should be optimum. Multi-layer orthogonal structures are used to produce stack reinforced composite industrial preforms with high tensile stiffness and strength [17]. It was stated that the 4-layers structure is more compact, rigid, and stable than the rest of the 3D fabric samples [17]. The 4 layers OW structure is shown in Figure 1 in which 'se' indicates separating warp layer, 'st' indicates stitching warp layer, and 'we' indicates weft layer. In each layer, the picks and the separating ends are packed in parallel without having any crimp and interlacement. Only the stitching warp goes up and down and has the crimp according to the number of layers. Figure 2 shows the cross-section and the respective weave graph of 2 picks (2P), 3 picks (3P), and 4 picks (4P) OWs taken for the study [18]. 2 picks, 3 picks and 4 picks OWs produce orthogonal fabrics of 2 layers, 3 layers and 4 layers of weft respectively and denoted as 2L-OF, 3L-OF and 4L-OF in this study.

In the study, initially orthogonal fabrics of 2L, 3L and 4L are woven using the same count of yarn for both st, se and weft series. By calculating and comparing the thickness of these three fabrics, it become possible to caculate the average height of the yarn count used. From the height, the width of yarn is calculated. Again, taking this yarn (whose height and width are known), for st and se warp, other samples are woven by changing only the weft counts. From the known height of st and se yarn, the height of the weft yarn is calculated.

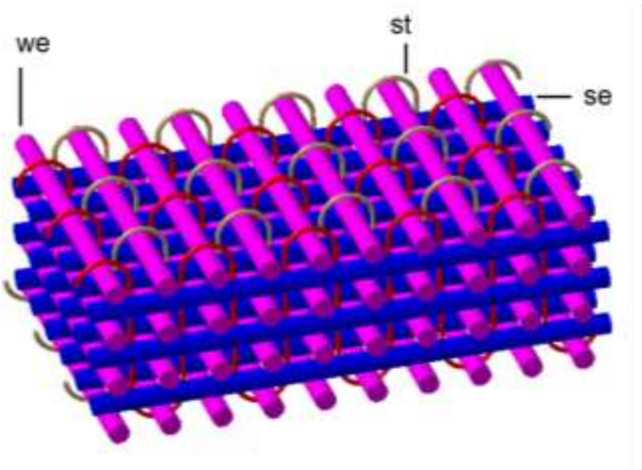

Figure 1. 4 picks (4 layers) OW structure

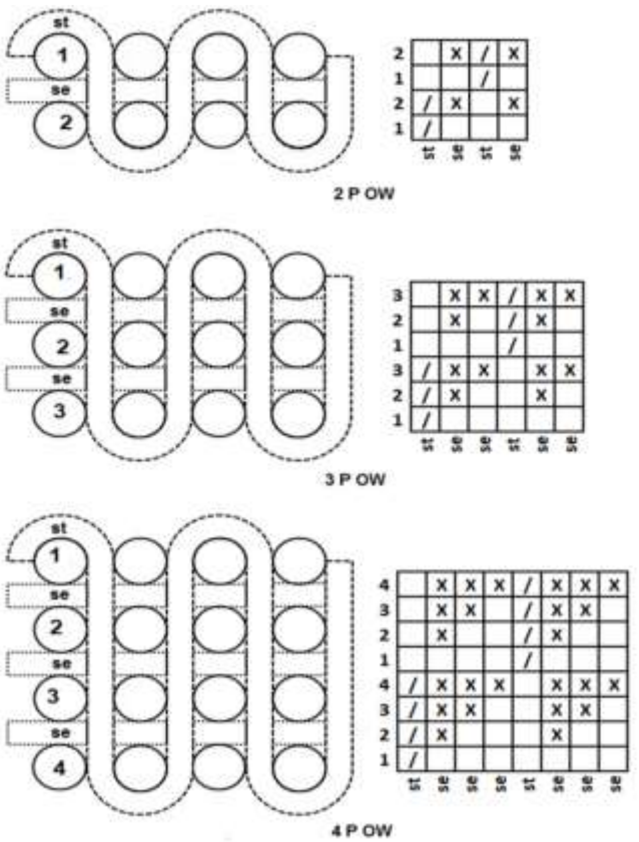

Figure 2. Cross-section and weave graph of 2P, 3P, and 4P OW structures

For the study, the orthogonal fabrics of these three different OWs are produced by keeping the warp count constant but using the six different cotton wefts ranging from 60 to 336 Tex (10^S to 2^S Ne) coarser counts. In total, 18 samples are produced (3 weaves x 6 counts). The first technical specifications taken for the study is the thickness of the fabric. With this perspective, the paper aims to study, derive, calculate, and compare the following:

- Developing the samples of orthogonal fabrics
- Testing the fabrics produced and estimating the actual thickness of fabrics
- Deriving the equations and calculating the Height (h) of yarn from the thickness of fabric and the Width (w) of yarn from the height of yarn
- Compare the height, width and diameter to prove that the yarn cross-section remains elliptical in the fabric
- Deriving the equation and calculating the Flattening Percentage (Fp) and Bulging Percentage (Bp) from the height and width of the yarn
- Proving that Flattening Percentage (Fp) and Bulging Percentage (Bp) are equal
- Deriving the equation and calculating the Constant of Height (Ch) and Constant of width (Cw) from the count, height, width of the yarn
- Equating the constant of height and constant of width with the constant of diameter.
- Comparing the flattening percentage of different counts of yarn
- Evolving the method of calculating the unknown parameters of the given yarn from the known parameters of another yarn, by weaving the orthogonal fabric using both the yarns

2. MATERIAL AND METHOD

2.1. Developing orthogonal fabric samples

A loom is set up to weave all the samples of 2P, 3P, and 4P OWs. 60 Tex (2/20S Ne) count is used for the two series of warp namely, stitching warp (st) and separating warp (se), taken in two separate beams. The tension of the stitching warp beam is kept moderately loose so that the warp is let loose with optimum level as per the thickness of weft woven. The separating warp beam is kept in normal tension. The loom is set to weave 1-meter width of the fabric. Table 1 gives the details of the total number of st. and se. ends taken for weaving one-meter width of fabric (excluding the selvedges) for all three weaves.

Six different weft counts (Ne) taken for weaving samples of each weave are I) $2/20^S$ II) 6^S III) 4^S, IV) 3^S, V) 4^S – 2ply and VI) $3/6^S$. The actual count of these yarns is estimated in Tex count by measuring the weight of the definite length of each yarn. Ten tests are carried and their average is calculated. The theoretical and actual counts estimated are given in Table 2. The first three samples are woven using $2/20^S$in stitching warp, separating warp, and weft. By this, all the counts in the first three samples are the same.

Table 1. Details of warp used for weavingorthogonal fabrics

Description	2L-OF	3L-OF	4L-OF
Reed Count	48^S Stockport	48^S Stockport	48^S Stockport
Ends per dent	2	3	4
Ratio of st : se	1 : 1	1 : 2	1 : 3
Ends per inch	24 st+ 24 se (48)	24 st+ 48 se (72)	24 st+ 72 se (96)
Ends per 100 mm	189	284	378
Ends in 1 Meter width	945 st + 945 se	945st + 1890 se	945st + 2835 se

Table 2. Theoretical and actual count of warp and weft used

Description / Samples	I	II	III	IV	V	VI
Count (Ct.) of Stitching warp (st.) and Separating warp (se.)						
Theoretical Ct. in Ne	$2/20^S$	$2/20^S$	$2/20^S$	$2/20^S$	$2/20^S$	$2/20^S$
Actual Ct. in Ne	$2/22^S$	$2/22^S$	$2/22^S$	$2/22^S$	$2/22^S$	$2/22^S$
Actual Resultant Ct. in Tex	54	54	54	54	54	54
Count (Ct.) of Weft						
Theoretical Ct. in Ne	$2/20^S$	6^S	4^S	3^S	4^S– 2 ply	$3/6^S$
Actual Ct. in Ne	$2/22^S$	6^S	4^S	2.6^S	4^S– 2 ply	$3/5.4^S$
Actual Resultant Ct. in Tex	54	98	146	227	306	336

2.2 Estimating the actual thickness

Figure 3 shows the different views of 2L, 3L, and 4L orthogonal fabrics. Figure 3(a) shows the brown color picks woven straight without any bending and stitched by white stitching ends in alternate order. In Figure 3(b), the cross-section of 2L-OF is given, where two layers of weft are laid one above the other. In Figure 3(c), the cross-section of 3L-OF is given, where three layers of weft are laid one above the other. This Figure also shows two sets of white separating ends in between the three layers. Figure 3(d) shows the up and down movement of the stitching end, stitching the alternate picks in the top and bottom layers of the 3L-OF cross-section. Figure 3I shows the cross-section of 4L-OF with four layers of weft one above the other.

After completing the weaving of 18 samples as above, the actual thickness in mm of orthogonal fabrics is tested, using a thickness tester. In each sample, the thickness is tested in 10 different places and their average is calculated. Table 3 gives the list of actual thickness in mm of all the three orthogonal fabrics.

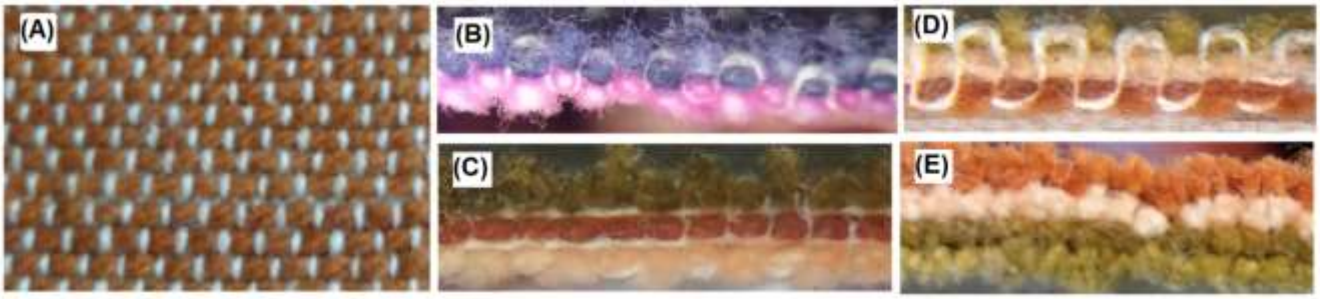

Figure 3. (A) 2L orthogonal fabric with alternate white stitching ends,(B) cross-section of 2L-OF, (C) white separating ends seen in the cross-section of 3L-OF, and (D) white stitching end seen in the cross-section of 3L-OF, andI cross-section of 4L-OF

Table 3. Actual thickness of orthogonal fabrics

Description / Sample	**I**	**II**	**III**	**IV**	**V**	**VI**
Ct. of st., se. in Tex	54	54	54	54	54	54
Ct. of weft in Tex	54	98	146	227	306	336
Actual Thickness in mm						
2L-OF	0.90	1.09	1.27	1.52	1.76	1.95
3L-OF	1.24	1.55	1.87	2.19	2.48	2.75
4L-OF	1.56	1.88	2.20	2.65	3.00	3.20

3. RESULTS AND DISCUSSION

3.1 Calculating the height of EC-S yarn

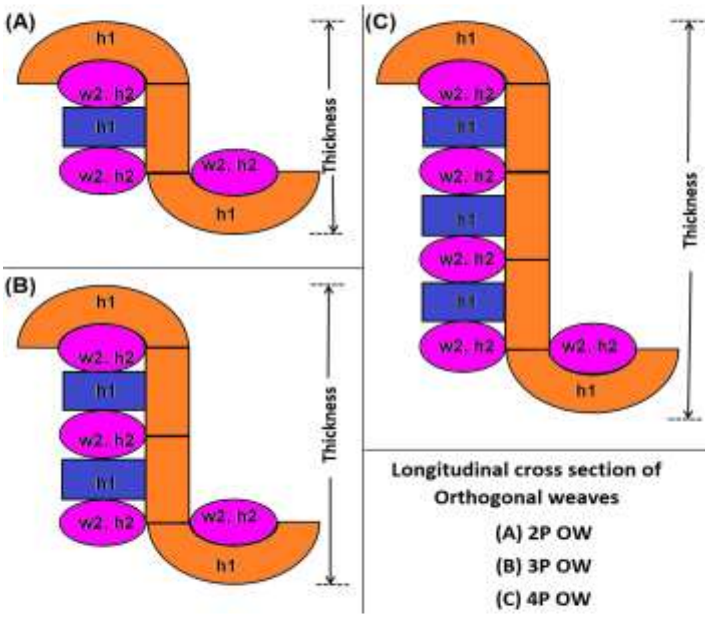

Figure 4. Cross-section of 2P, 3P, and 4P orthogonal weaves based on EC-S

Figure 4 shows the cross-section of OWs considering the cross-section of yarn is elliptical. When the cross-section of yarn is elliptical (Figure 4), the thickness of the orthogonal fabric is equal to the sum of the heights of yarns used in the given weave. ‘h1’ is the height of st.end (orange), ‘h1’ is the height of se. end (blue). ‘h2’ is the height of pick (purple). Hence based on the height of EC-S of yarn,

Thickness of 2L-OW = {(3 x h1) + (2 x h2)} (1)

Thickness of 3L-OW={(4 x h1) + (3 x h2)} (2)

Thickness of 4L-OW={(5 x h1) + (4 x h2)} (3)

The actual thickness of the fabric varies proportionately to the height of the warp and weft used. The first three samples are woven in 2P, 3P, and 4P OW using 54 Tex yarn ($2/22^S$) both in warp and weft (stitching ends, separating ends, and weft). Hence, the height of 54 Tex yarn is calculated first from the thickness of these three samples.

Thickness of 2L-OW = {(3 x h1) + (2 x h2)}

When the count of st., se., and weft are same (That is h2 = h1)

Thickness of 2L-OW = {(3 x h1) + (2 x h1)} = 5h1 (4)

Thickness of 3L-OW = {(4 x h1) + (3 x h1)} = 7h1 (5)

Thickness of 4L-OW = {(4 x h1) + (4 x h1)} = 9h1 (6)

Table 4 shows the calculation of height of 54 Tex yarn.

The height (h1) of 54 Tex yarn is 0.177 mm. Keeping this height (h1) of yarn, and the total thickness (Total height) of 2L, 3L, and 4L OW fabrics, the height of other weft yarns (h2) used in weaving these fabrics is calculated as given below.

Thickness of 2L-OW = {(3x h1) + (2 x h2)}

Height of weft yarn used in 2L – OW (h2) = $[[\{[\text{Thickness of 2L} - \text{OW}) - (3 \text{ x h1})\}\})/2)$ … (7)

Similarly, Thickness of 3L-OW = {(4 x h1) + (3 x h2)}

Height of weft yarn used in 3L – OW (h2)= $\left(\frac{\{(\text{Thickness of 3L} - \text{OW}) - (4 \text{ x h1})\}}{3}\right)$…………… (8)

Again, Thickness of 4L-OW = {(5 x h1) + (4 x h2)}

Height of weft yarn used in 4L – OW (h2)= $\left(\frac{\{(\text{Thickness of 4L} - \text{OW}) - (5 \text{ x h1})\}}{4}\right)$…………… (9)

Table 5 shows the calculation of the average height of 98 Tex, 146Tex, 227Tex, 306Tex, and 336Tex yarns from the thickness of different OW fabrics woven using these yarn counts. At the end of the Table, the calculated diameters of these yarns are also given.

From the thickness of the samples, the height of different counts of the yarn is calculated as 54 Tex yarn is 0.177 mm, 98 Tex yarn is 0.270 mm, 146 Tex yarn is 0.362 mm, 227 Tex yarn is 0.477 mm, 306 Tex yarn is 0.578 mm, and 336 Tex yarn is 0.657 mm. It is noted from the Table that the height of each weft yarn is lesser than its diameter. The width of each weft yarn is more than its diameter. It shows that the yarn cross-section in the fabric did not remain circular. It flattened and has become elliptical in cross-section.

Table 4. Calculation of height of 54 Tex yarn from the OW fabrics woven with all 54 Tex count

Fabric	2L – OW	3L – OW	4L – OW
Thickness, when h2 = h1	5h1	7h1	9h1
Thickness in mm – from Table 3	0.90	1.24	1.56
h1	0.90 / 5	1.24/7	1.56/9
h1	0.180	0.177	0.173
Average h1	0.180 + 0.177 + 0.173 = 0.530; 0.530/3 = 0.177		
Height of 54 Tex yarn	0.177 mm		

Table 5. Calculation of the height of different weft yarns from the thickness of OW fabrics

Description / Sample	II	III	IV	V	VI
Ct. of st., se. in Ne	$2/22^S$	$2/22^S$	$2/22^S$	$2/22^S$	$2/22^S$
Ct. of weft in Ne	6^S	4^S	2.6^S	4^S– 2 ply	$3/5.4^S$
Ct. of st., se. in Tex	54	54	54	54	54
Ct. of weft in Tex	98	146	227	306	336
All values in mm					
Height of st., se. yarn (h1) – from Table 4	0.177	0.177	0.177	0.177	0.177
Thickness of 2L – OW = {(3 x h1) + (2 x h2)} – from Table 3	1.090	1.270	1.520	1.760	1.950
(3 x h1)	0.531	0.531	0.531	0.531	0.531
(2 x h2) = {(Thickness of 2L-OW) – (3 x h1)}	0.559	0.739	0.989	1.229	1.419
h2 = (2 x h2) / 2	0.280	0.370	0.495	0.615	0.710
Thickness of 3L – OW = {(4 x h1) + (3 x h2)} – from Table 3	1.550	1.870	2.190	2.480	2.750
(4 x h1)	0.708	0.708	0.708	0.708	0.708
(3 x h2) = {(Thickness of 3L-OW) – (4 x h1)}	0.842	1.162	1.482	1.772	2.042
h2 from = (3 x h2) / 3	0.281	0.387	0.494	0.591	0.681
Thickness of 4L – OW = {(5 x h1) + (4 x h2)} – from Table 3	1.880	2.200	2.650	3.000	3.200
(5 x h1)	0.885	0.885	0.885	0.885	0.885
(4 x h2) = {(Thickness of 4L-OW) – (5 x h1)}	0.995	1.315	1.765	2.115	2.315
h2 = (4 x h2) / 4	0.249	0.329	0.441	0.529	0.579
Total height of weft yarn (from 3 samples)	0.810	1.086	1.430	1.735	1.970
Average height of weft yarn (h2)	0.270	0.362	0.477	0.578	0.657
Calculated Diameter of weft yarn (d) = $\left(\frac{\sqrt{N}}{26}.7\right)$	0.371	0.453	0.564	0.655	0.687

3.2 Calculating the width of EC-S yarn from the height

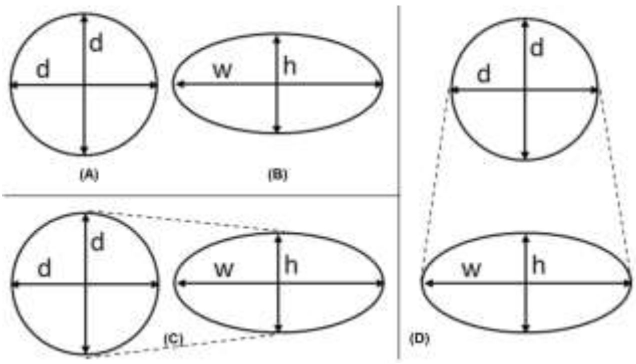

Figure 5. (A) Circular Cross- Section, (B) Elliptical Cross-Section, (C) Flattening of vertical diameter, and (D) Bulging of horizontal diameter

Figure 5 (a) and (b) shows the circular and the elliptical cross-sections of yarn respectively. Let the diameter of CC-S yarn is 'd' whose count is N Tex. 'w' denotes the major axis – the width and 'h' denotes the minor axis – the height of EC-S yarn. The area of the circular cross-section of yarn takes the shape of an ellipse in the orthogonal fabric. Taking that the area of CC-S of the given yarn is equal to the area of EC-S of that yarn, it is possible to calculate the width of EC-S of yarn from the height, or vice-versa as per the equation derived below.

Diameter of the yarn (d) = $\left(\frac{\sqrt{N}}{26}.7\right)$; $d^2 = \left(\frac{N}{26.7 \times 26.7}\right)$

Area of Circle = $\pi r^2 = \pi\left(\frac{d}{2}\right)\left(\frac{d}{2}\right)$; Area of Ellipse = $\pi\left(\frac{w}{2}\right)\left(\frac{h}{2}\right)$

Area of Circle = Area of Ellipse

$\pi\left(\frac{d}{2}\right)\left(\frac{d}{2}\right) = \pi\left(\frac{w}{2}\right)\left(\frac{h}{2}\right)$; Then $\left(\frac{d^2}{4}\right) = \left(\frac{wh}{4}\right)$; $d^2 = (w \times h)$; Th

$$(w \times h) = \left(\frac{N}{26.7 \times 26.7}\right) \qquad (10)$$

$$w = \left(\frac{N}{h \times 26.7 \times 26.7}\right) \text{ OR } \left(\frac{d^2}{h}\right) \text{.........} \qquad (11)$$

$$h = \left(\frac{N}{w \times 26.7 \times 26.7}\right) \text{ OR } \left(\frac{d^2}{w}\right) \qquad (12)$$

Proof:

Let the Diameter (d)of the CC-S yarn = 14 units

Area of the CC-S yarn = $\pi r^2 = \pi \left(\frac{d}{2}\right)\left(\frac{d}{2}\right) = \left(\frac{22}{7}\right)\left(\frac{14}{2}\right)\left(\frac{14}{2}\right)$ = 154 units

Considering that when the CC-S of yarn becomes EC-S, the height is 9.8 units (less than 14 units). Then the width of EC-S yarn is calculated

Width of the EC-S yarn (w) = $\left(\frac{d^2}{h}\right)$ = = 20 units (more than 14 units)

Area of the EC-S yarn = $\pi \left(\frac{w}{2}\right)\left(\frac{h}{2}\right) = \left(\frac{22}{7}\right)\left(\frac{20}{2}\right)\left(9.\frac{8}{2}\right)$ = 154 sq. units

Area of the CC-S yarn = Area of EC-S yarn

Similarly, Circumference of Circle = π d; Circumference of Ellipse = π {√ (w x h)}

Diameter (d) of the CC-S yarn = 14 units

Circumference of the CC-S yarn = π d = x 14 = 44 units

Height (h) of the EC-S yarn = 9.8 units

Width (w) of the EC-S yarn = 20 units

Circumference of EC-S yarn = π (√w x h) = x {√ (20 x 9.8)} = 44 units

Circumference of the CC-S yarn = Circumference of the EC-S yarn

3.3 Calculating the Flattening and Bulging Ratio / Percentage of EC-S yarn

When it is taken that the yarn cross-section becomes elliptical in the fabric, the vertical diameter (d) of the circular yarn get flattened and becomes the height (h) of the elliptical yarn (Figure 5C). The horizontal diameter (d) of the circular yarn get bulged and becomes the width (w) of the elliptical yarn (Figure 5D). The ratio of the difference between the diameter and height to the diameter is called as Flattening Ratio (Fr). Flattening Percentage (Fp) is equal to Fr x 100. Similarly, the ratio of the difference between the width and diameter to the width is called as Bulging Ratio (Br). Bulging Percentage (Bp) is equal to Br x 100. The calculation of flattening and bulging ratios/percentages are as follows.

$$\text{Flattening Ratio (Fr)} = \left(\frac{(d-h)}{d}\right) \quad (13)$$

$$\text{Bulging Ratio (Br)} = \left(\frac{(w-d)}{w}\right) \quad (14)$$

$$\text{Flattening Percentage (Fp)} = \left(\frac{(d-h)}{d} \text{ x } 100\right) \quad (15)$$

$$\text{Bulging Percentage (Bp)} = \left(\frac{(w-d)}{w} \text{ x } 100\right) \quad (16)$$

It is obvious that the Flattening Ratio (Fr) is equal to Bulging Ratio (Br). This is proved by:

We have, $d^2 = wh$; which is $(-wh) = (-d^2)$.

Adding dw on both sides

$(dw - wh) = (dw - d^2)$; $w(d-h) = d(w-d)$

$$\left(\frac{(d-h)}{d}\right) = \left(\frac{(w-d)}{w}\right)$$

Flattening Ratio (Fr) = Bulging Ratio (Br) (17)

Flattening Percentage (Fp) = Bulging Percentage (Bp) (18)

3.4 Calculating the Constants of Height and Width of EC-S yarn from the given Count

Diameter of the yarn (d) = $\left(\frac{\sqrt{N}}{26}.7\right)$; Constant of Diameter (Cd) = 26.7;

$$(\text{width x height}) = \left(\frac{N}{26.7 \text{ x } 26.7}\right) \quad (10)$$

$$\left(\frac{\sqrt{N} \text{ x } \sqrt{N}}{\text{width x height}}\right) = (26.7 \text{ x } 26.7)$$

$$[(\sqrt{N})/\text{height}) \text{ x } ((\sqrt{N})/\text{width}) = (26.7 \text{ x } 26.7)$$

$$\text{Constant height (Ch)} = \left(\frac{\sqrt{N}}{\text{height}}\right) \quad (19)$$

$$\text{Constant width (Cw)} = \left(\frac{\sqrt{N}}{\text{width}}\right) \quad (20)$$

{Constant height (Ch) x Constant width (Cw)}= (26.7 x 26.7)

√{Constant height (Ch) x Constant width (Cw)} = √ (26.7 x 26.7)

√{Constant height (Ch) x Constant width (Cw)} = 26.7(21)

$$\text{Height (h)} = \left(\frac{\sqrt{N}}{\text{Constant height (Ch)}}\right) \quad (22)$$

$$\text{Width (w)} = \left(\frac{\sqrt{N}}{\text{Constant Width (Cw)}}\right) \quad (23)$$

Table 6 shows the diameter (d) and height of different yarns taken from Table 5. The width (w) of different yarns calculated from the height (h) is also shown. From the height and width, the flattening ratio is also calculated. Then, from the height and count, the constant of height (Ch) is calculated. Similarly, from the width and count, the constant of width (Cw) is calculated. Finally, √{Constant height (Ch) x Constant width (Cw)} is also calculated.

3.5 Calculations of other samples

3.5.1 Sample No. 19

The thickness of a three-layered orthogonal fabric is 1.284 mm. It is woven using $2/22^S$ (54Tex) for stitching, separating warp and 10^S (60 Tex) for weft. The height, diameterand width of $2/22^S$ yarn derived from the other sample is 0.177 mm, 0.275 mm, and 0.428 mm. Table 7 shows the steps to calculate the parameters of 10^S (60 Tex) yarn and the thickness of 2 layered and 4 layered orthogonal fabrics woven using $2/22^S$ warp and 10^S (60 Tex) weft.

3.5.2 Sample No. 20

The thickness of a two layered orthogonal fabric is 1.455 mm. It is woven using $2/10^S$ (118 Tex) for stitching and separating warp. The weft is 6^S (98 Tex). The diameter, height and width of 6^S yarn derived from the other sample is 0.371 mm, 0.270 mm, and 0.510 mm respectively.

Table 8 shows the steps to calculate the parameters of $2/10^S$ (118 Tex) and the thickness of other fabrics woven using the same from the given particulars.

Table 6. Calculation of Diameter (d), Height (h), Width (w), Flattening Percentage (Fp), Bulging Percentage (Bp), Constant of Height (Ch), Constant of Width (Cw),and √(Ch x Cw) of different yarns

Description / Sample	I	II	III	IV	V	VI
Ct. of st., se. in Ne	$2/22^S$	$2/22^S$	$2/22^S$	$2/22^S$	$2/22^S$	$2/22^S$
Ct. of weft in Ne	$2/22^S$	6^S	4^S	2.6^S	4^S– 2 ply	$3/5.4^S$
Ct. of st., se. in Tex	54	54	54	54	54	54
Ct. of weft in Tex	54	98	146	227	306	336
All values in mm						
Diameter of weft yarn (d) = $\left(\frac{\sqrt{N}}{26}.7\right)$	0.275	0.371	0.453	0.564	0.655	0.687
Height of weft yarn (h2), from Table 5	0.177	0.270	0.362	0.477	0.578	0.657
Width of weft yarn (w)= $\left(\frac{d^2}{h}\right)$	0.427	0.510	0.567	0.667	0.742	0.718
Flattening Ratio (Fr) = $\left(\frac{(d-h)}{d}\right)$	0. 36	0.27	0.20	0.16	0.12	0.04
BulgingRatio (Br) = $\left(\frac{(w-d)}{w}\right)$	0.36	0.27	0.20	0.16	0.12	0.04
Flattening Percentage (Fp) = $\left(\frac{(d-h)}{d}\ x\ 100\right)$	36	27	20	16	12	4
Bulging Percentage (Bp) = $\left(\frac{(w-d)}{w}\ x\ 100\right)$	36	27	20	16	12	4
Constant of height (Ch) = $\left(\frac{\sqrt{N}}{height}\right)$	41.52	36.66	33.38	31.59	30.26	27.90
Constant of width (Cw) = $\left(\frac{\sqrt{N}}{width}\right)$	17.21	19.41	21.31	22.59	23.57	25.53
√{(Ch) x (Cw)}	26.7	26.7	26.7	26.7	26.7	26.7
Constant of Diameter (Cd)	26.7	26.7	26.7	26.7	26.7	26.7

Table 7. Calculation of parameters of 10^S (60 Tex) and thickness of OW fabrics

Description and given details	Equation No., Equation and calculation		Result
Thickness of 3L-OW	2	{(4 x h1) + (3 x h2)}	1.284 mm
St. Se. Warp Yarn			$2/22^S$ (54 Tex)
Diameter of $2/22^S$ (54 Tex) (d)			0.275 mm
Height of $2/22^S$ (54 Tex) (h1)			0.177 mm
Width of $2/22^S$ (54 Tex) (w)			0.427 mm
Weft Yarn			10^S (60 Tex)
Diameter of 10^S (60 Tex) (d)		$\left(\frac{\sqrt{N}}{26}.7\right) = \left(\frac{\sqrt{60}}{26.7}\right)$	0.290 mm
Height of 10^S (60 Tex) (h2) used in 3L-OW	8	$\left(\frac{[(\text{Thickness of 3L} - \text{OW}) - (4 \times h1)]}{3}\right) = \left(\frac{[(1.284) - (4 \times 0.177)]}{3}\right)$	0.192 mm
Width of 10^S (60 Tex) (w)	11	$\left(\frac{d^2}{h}\right) = \left(\frac{0.290 \times 0.290}{0.192}\right)$	0.438 mm
Flattening Percentage (Fp)	15	$\left(\frac{(d-h)}{d} \times 100\right) = \left(\frac{(0.290 - 0.192)}{0.290} \times 100\right)$	34
Bulging Percentage (Fp)	16	$\left(\frac{(w-d)}{w} \times 100\right) = \left(\frac{(0.438 - 0.290)}{0.438} \times 100\right)$	34
Constant height (Ch)	19	$\left(\frac{\sqrt{N}}{\text{height}}\right) = \left(\frac{\sqrt{60}}{0}.192\right)$	40.34
Constant width (Cw)	20	$\left(\frac{\sqrt{N}}{\text{width}}\right) = \left(\frac{\sqrt{60}}{0}.438\right)$	17.68
√{Constant height (Ch) x Constant width (Cw)} = 26.7	21	√{(40.34) x (17.68)}	26.7
Thickness of 2L-OW	1	{(3 x h1) + (2 x h2)} = {(3 x 0.177) + (2 x 0.192)}	0.915 mm
Thickness of 4L-OW	3	{(5 x h1) + (4 x h2)} = {(5 x 0.177) + (4 x 0.192)}	1.653

Table 8. Calculation of parameters of $2/10^S$ (118 Tex) and thickness of OW fabrics

Description and given details	Equation No. Equation and calculation		Result
Thickness of 2L-OW	1	{(3 x h1) + (2 x h2)}	1.455 mm
St. Se. Warp Yarn			$2/10^S$ (118 Tex)
Weft Yarn			6^S (98 Tex)
Diameter of 6^S (98 Tex) (d)			0.371 mm
Height of 6^S (98 Tex) (h2)			0.270 mm
Width of 6^S (98 Tex) (w)			0.510 mm
Diameter of $2/10^S$ (118 Tex) (d)		$\left(\frac{\sqrt{N}}{26}.7\right) = \left(\frac{\sqrt{118}}{26.7}\right)$	0.407 mm
Height of $2/10^S$ (118 Tex) (h1) used in 2L-OW	7	$\left(\frac{[(\text{Thickness of 2L} - \text{OW}) - (2 \times h2)]}{3}\right) = \left(\frac{[(1.455) - (2 \times 0.270)]}{3}\right)$	0.305 mm
Width of $2/10^S$ (118 Tex) (w)	11	$\left(\frac{d^2}{h}\right) = \left(\frac{0.407 \times 0.407}{0.305}\right)$	0.543 mm
Flattening Percentage (Fp)	15	$\left(\frac{(d-h)}{d} \times 100\right) = \left(\frac{(0.407 - 0.305)}{0.407} \times 100\right)$	25
Bulging Percentage (Fp)	16	$\left(\frac{(w-d)}{w} \times 100\right) = \left(\frac{(0.543 - 0.407)}{0.543} \times 100\right)$	25
Constant height (Ch)	19	$\left(\frac{\sqrt{N}}{\text{height}}\right) = \left(\frac{\sqrt{118}}{0}.305\right)$	35.61
Constant width (Cw)	20	$\left(\frac{\sqrt{N}}{\text{width}}\right) = \left(\frac{\sqrt{118}}{0}.543\right)$	20.0
√{Constant height (Ch) x Constant width (Cw)} = 26.7	21	√{(35.61) x (20.0)}	26.7
Thickness of 3L-OW	2	{(4 x h1) + (3 x h2)} = {(4 x 0.305) + (3 x 0.270)}	2.03 mm
Thickness of 4L-OW	3	{(5 x h1) + (4 x h2)} = {(5 x 0.305) + (4 x 0.270)}	2.6 mm

The Height, Width, Flattening (Bulging) Percentage, Constant of Height, and Constant of Width of all the different counts of yarn is consolidated and given in Table 9.

3.6 Summary and interpretation of the EC-S Yarn Parameters

From the above calculations and derivations, the following summary of results has been made. The interpretation of the results gives practical proof for many theoretical concepts.

- From the orthogonal fabric woven from the given yarn count, it is possible to find the height of the given yarn count. Then, the width is calculated from the height. The flattening percentage is calculated from the height and width. The constant of height and constant of width are also calculated.
- Subsequently, these constants are used to calculate the height and width of the given yarn count having the same flattening percentage. The thickness of the fabric woven in different weaves using this selected yarn count can be assessed before actual weaving.
- Table 9 shows the actual height (h) actual width (w), and the calculated diameter of the yarn counts used in the samples. The line chart given in Figure 6(A) compares the diameter, height, and width of different yarns used in the samples. The comparison shows that the height of each weft yarn is lesser than its diameter. The width of each weft yarn is more than its diameter. It shows that the yarn cross-section in the fabric did not remain circular. It flattened and has become elliptical in cross-section.
- In Table 6, it is observed that the values of Flattening Percentage (Fp) and Bulging Percentage (Bp) of each yarn count are the same. It shows that when the yarn cross-section becomes elliptical in the fabric, the amount of flattening in the height makes the yarn get bulge to the same amount in its width.
- The line chart in Figure 6(B) shows the Flattening Percentage (Bulging Percentage) of different yarn counts. The Fp of 54 Tex ($2/22^S$) is 36 shows that this yarn count has become flattened almost one-third (1/3) from its diameter. The Fp of 98 Tex (10^S) is 27, Fp of 146 Tex (4^S) is 20, and the Fp of 227 Tex (2.6^S) is 16. It shows that the Flattening Percentage reduces gradually as the yarn count increases (become coarser).
- The Fp of 146 Tex (4^S – Single yarn) is 20. Whereas the Fp of 306 Tex (4^S – Two-ply yarn) is 12. It shows that the Flattening Percentage of two-ply yarn is lesser than the Flattening Percentage of single yarn from which it is prepared.
- The Fp of 60 Tex (10^S – Single yarn) is 34. Whereas, the Fp of 118 Tex ($2/10^S$ – Folded yarn) is 25. It shows that the Flattening Percentage of folded yarn is lesser than the Flattening Percentage of the single yarn from which it is twisted.
- The Fp of 98 Tex (6^S – Single yarn) is 27, Whereas, the Fp of 336 Tex ($3/5.4^S$) is 4%. It shows that the Flattening Percentage of three-fold yarn is too less when compared to the Flattening Percentage of a single yarn from which it is twisted.
- The Fp of 336 Tex ($3/5.4^S$) is 4. It shows that this yarn count has become flattened too less from its diameter and the yarn remained almost cylindrical in the fabric.
- The line chart given in Figure 6(C) compares the Constant of Diameter (Cd), Constant of Height (Ch), and Constant of width (Cw) of different yarns used in the samples.
- In Table 9, it is to note that the square root of the multiplication of the Constant of height and the Constant of width is equal to 26.7 (Constant of Diameter). It shows that the equation derived for calculating the parameters of given yarn count is in order.

Table 9. Height, Width, Flattening (Bulging) Percentage, Constant of Height, and Constant of Width of different counts of yarn

Count	**54 T($2/22^S$)**	**60 T (10^S)**	**98 T (6^S)**	**118 T ($2/10^S$)**	**146 T (4^S)**	**227 T (2.6^S)**	**306 T (4s -2 ply)**	**336 T ($3/5.4^S$)**
Height in mm	0.177	0.192	0.270	0.305	0.362	0.477	0.578	0.657
Diameter in mm	0.275	0.290	0.371	0.407	0.453	0.564	0.655	0.687
Width	0.427	0.438	0.510	0.543	0.567	0.667	0.742	0.718
Flattening (Bulging) Percentage	36	34s	27	25	20	16	12	4
Constant Height	41.52	40.34	36.66	35.61	33.38	31.59	30.26	27.90
Constant Width	17.21	17.68	19.41	20.00	21.31	22.59	23.57	25.53
√ (Ch x Cw)	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7

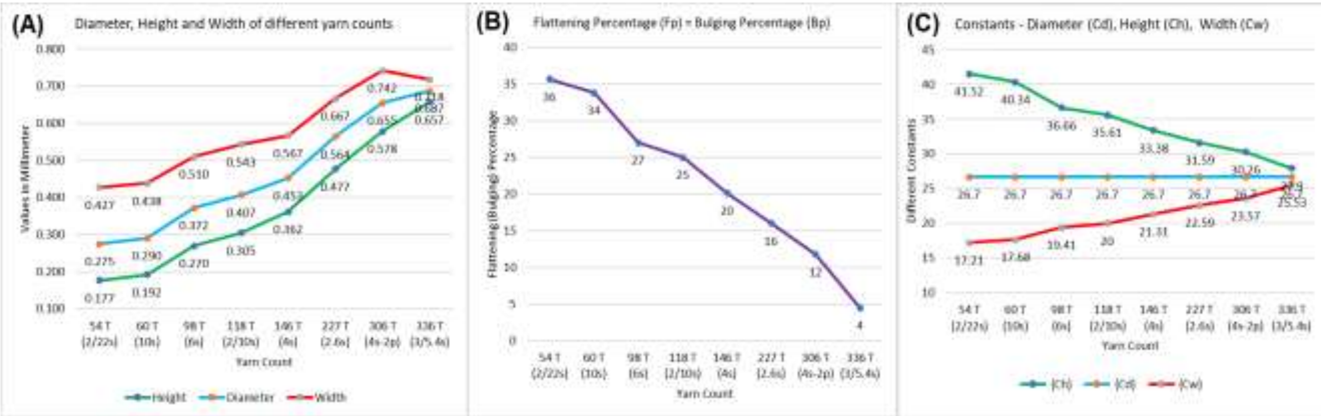

Figure 6. Line charts comparing the different parameters of EC-S of different yarn counts. (A) Comparison of Diameter, Height and Width, (B) Flattening (Bulging) Percentage, and (C) Comparison of Constant of Diameter, Constant of Height, and Constant of Width

3.7 Future Study

The present study evolved the height, width and other parameters of the given yarn count from the thickness of orthogonal fabrics. Future study is also taken up to assess the following parameters and specifications from the height, width, and flattening percentage of yarn.

- The thickness of other orthogonal fabrics and other fabrics woven using basic weaves.
- The crimp percentage of stitching end used in orthogonal fabric.
- The optimum/maximum picks per inch and the cover factor of the fabric.
- The GSM of the fabric.

In total, the fabric specifications viz. the thickness, the crimp percentage, the cover factor, and the GSM of any fabric can be assessed before taking up the actual weaving, where the cross-section of yarn remains elliptical in the fabric.

4. CONCLUSION

In this research, a new thought has been given to study the elliptical cross-section of yarn through the orthogonal fabric. in which the yarn of one series laid straight without moving up and down of the other series. This enables to study the cross-section independently without the influence of interlacement. For the study, the orthogonal fabrics of 2 Picks, 3 Picks, and 4 Picks Orthogonal Weaves are produced. The actual thicknesses of these fabrics are tested. Different equations are derived to calculate the Height, Width, Flattening Percentage, Bulging Percentage, Constant of Height, and Constant of Width of given yarn count. First, the height and width are estimated using the equations. The comparison of height and width with the diameter of the given yarn count proves that the yarn cross-section remains elliptical in the fabric. It is also noted that when the yarn cross-section becomes elliptical in the fabric, the amount of flattening in the height makes the yarn get bulge to the same amount in its width. The constant of height and constant of width are also derived. These constants are equated with the constants of diameter. The study also derived the equation to calculate the height and width of the elliptical cross-section of the given yarn count using the constants. It is also estimated that the square root of the multiplication of Constant of Height and Constant of Width is equal to 26.7 (Constant of Diameter). The height, width, and diameter of different yarn counts are compared. The increase/decrease in flattening percentage between the coarser-finer yarns, single–2 ply yarns, and single-folded yarns are examined. The interpretation of the results gives practical proof for many theoretical concepts. The study also evolved the method of calculating the unknown parameters of the given yarn from the known parameters of another yarn, by weaving the orthogonal fabric using both the yarns. The research also suggests that the height and width of yarn count derived from the thickness of fabric can be used to calculate the other specifications of fabrics viz. crimp percentage, optimum/maximum picks per inch, cover fraction, and GSM. These specifications are useful to assess the performance of multi-layer orthogonal structures to produce stack reinforced composite industrial preforms with the desired tensile stiffness, thickness and strength.

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