MODELLING THE CROSS-SECTIONAL PROPERTIES OF YARN ALONG THE FABRIC

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Abstract: *Three dimensional (3-D) fabric geometry defines the fabric's physical and mechanical properties. For this reason, it is important to obtain realistic fabric models. In this study, the yarn path of the woven fabric was modeled according to structural properties of fabric using Pierce geometry. On the other hand, the cross-sectional properties of the yarn along the weave unit were modeled depending on the movement of the yarn and the interactions between adjacent and perpendicular yarns. The yarn path was divided into regions and the cross-section of the yarn was defined according to region properties. By an experimental study, the variation of the yarn dimension at each region was measurement and the flattening ratio of yarn was determined. These data were used in the cross-section model. The simulations of yarn path and cross-sectional models were obtained by using SolidWorks. These simulations present the variation of yarn cross-section along the weave unit.*

Keywords: *Yarn cross-section, yarn path, yarn diameter, woven fabric.*

1 INTRODUCTION

Three dimensional (3-D) fabric geometry was formed according to structural parameters and manufacturing processes. Raw material, yarn properties such as yarn production type, yarn linear density, twist, packing ratio, etc., and construction properties of fabric such as settings and weave type are some of the important structural parameters defined fabric geometry. The fabric geometry affects the physical properties of the fabric, such as mechanical, sensory, permeability and conductivity properties of the fabric. Therefore, the structural parameters of the fabric must be chosen well to design a special product for a defined using area. However, the relationship between structural parameters and fabric geometry and also the performance properties of a fabric is complicated. Thus, modeling studies about the fabric geometry are needed to predict the performance behaviours of product. Besides, determination of fabric properties at the designing step is important for both designers and manufacturers in terms of time and cost.

Generally, fabrics were idealized into simple geometrical forms. The yarn path along the fabric was described by circular arcs, straight lines, sinus curves, elastic forms, and the yarn cross-section was modeled as circular, elliptical, lenticular, racetrack shapes [4-9]. However, yarn cross-section varies inside the fabric due to inter-yarn compression. In recent years, irregular cross-section shapes of yarns were also studied [1-3, 10-12]. The shape of a yarn cross-section shape and size are affected by many factors such as raw material, twist degree, yarn spinning technology, weave type, settings, etc. It is important to provide an efficient modeling technique for creating the yarn cross-sections properties.

In this study, fabric geometry was modeled into two steps. First, the yarn path was defined according to structural parameters and B-spline method was used to get a smooth yarn center line along the weave unit. It is important to define the variation at the cross-sectional shape and size of the yarn into the fabric in order to create more realistic 3-D fabric geometry. In the second step, the cross-sectional properties of yarn were modelled along the yarn path according to the interactions between adjacent and perpendicular yarns. An experimental study was carried out to get data about the variation of yarn size along the yarn path. Yarn dimensions of different cotton fabrics were measured from different regions of fabric images. The fabric geometry simulations were performed by using SolidWorks 2014.

2 EXPERIMENTAL

2.1 Materials

In this study, both theoretical and experimental studies were carried out. In the experimental part of the study, four different commercial cotton woven fabrics having different structural parameters were used. The structural properties of these fabrics given in Table 1 were analyzed by related standards.

Table 1 Structural properties of measured fabrics

Fabric code	Weave type	Unit weight [g/m^2]	Warp count [tex]	Weft count [tex]	Warp setting [cm^{-1}]	Weft setting [cm^{-1}]	Thickness [cm]
P1	Plain	106	11	11	60	35	0.0228
P2	Plain	114	11	11	56	30	0.0226
P3	2/2 Twill	126	10	9	62	56	0.0256
P4	4/1 Twill	215	12	19	90	50	0.0416

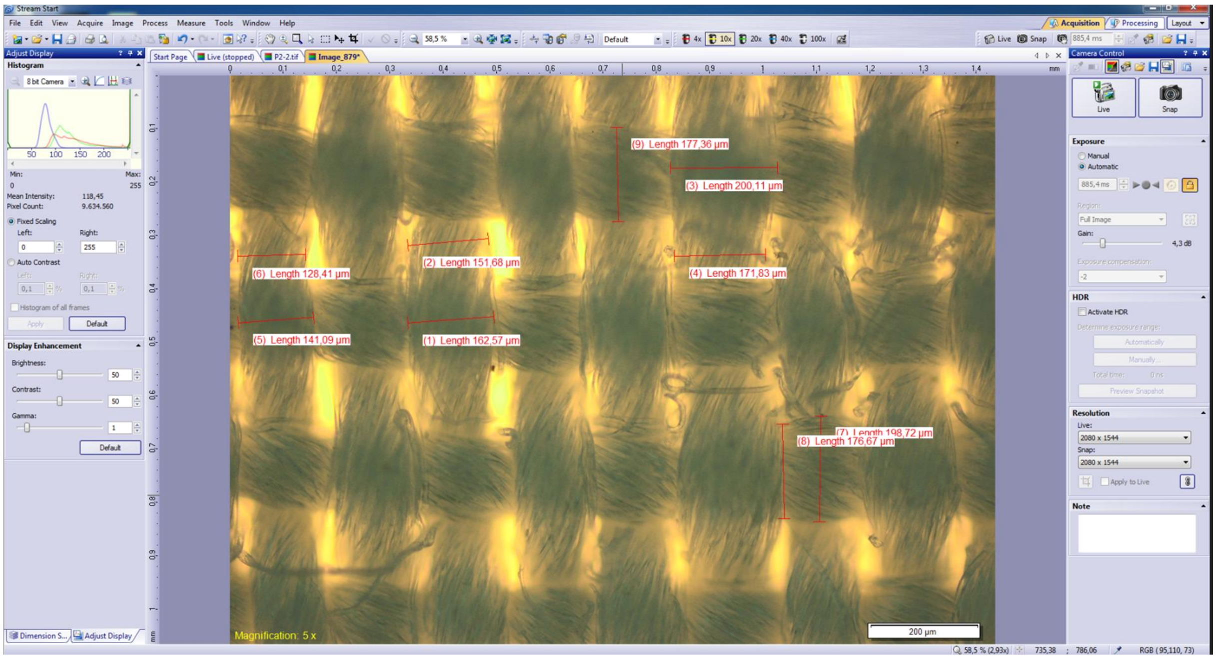

Figure 1 Measurement of yarn diameter at different regions of the yarn path

2.2 Methods

Sectioning is a more realistic method in order to obtain cross-sectional dimensions of yarn into the fabric. But this is a laborious and time-consuming method. For this reason, in this study measuring of yarn dimensions onto the 2D surface images of fabrics were preferred. The images of various cotton fabrics were observed by a camera system integrated to a microscope. The dimensions of warp and weft yarns were measured from captured images by using the application of the camera system as seen in Figure 1. Measurements were done from the different regions of the weave unit. Regions were defined as the peak point of the intersecting region and the middle point of the interchanging region, for plain weave. For twill weaves, the middle of the floating region was also measured. Ten measurements were done for each region of warp and weft yarns. The results were used to estimate the variation of the yarn dimension along the yarn path. Besides, the possible flattening ratio of different regions was predicted from the measurements.

3 THEORETICAL

In the theoretical part of the study, the yarn path and yarn cross-section were modeled in order to get realistic fabric simulations. The basic yarn path was defined depending on the structural properties of the fabric according to Pierce geometry [8]. In Peirce geometry, when weaving angle is assumed a small value then the amplitude of yarns (h) can be calculated as in Equation 1. Here, p is yarn spacing, c is crimp factor. Subtitles 1 and 2 were used for warp and weft yarns, respectively. This formula was defined according to plain fabric in Peirce geometry. Some modifications were done and the crimp factor of 2/2 twill and 4/1 twill weaves were calculated in order to use this equation for these weave types, too.

$$h1 = p2\frac{\sqrt{2c_1}}{1-c_1} \quad (1)$$

B-spline curve method was used in order to obtain yarn path as a smooth curve. The open non-uniform cubic B-spline curves with a continuity of the order 2 were used. First, a linear control polygon was defined, for each weave types. The B-spline curve generally follows the shape of control polygon. Seven control points were defined for each weave unit, as seen in Figure 2. The coordinates of these points were calculated by using the Peirce geometry. Appling B-spline method, 21 new points confirmed yarn path were calculated. Yarn paths were obtained individually for warp and weft yarns.

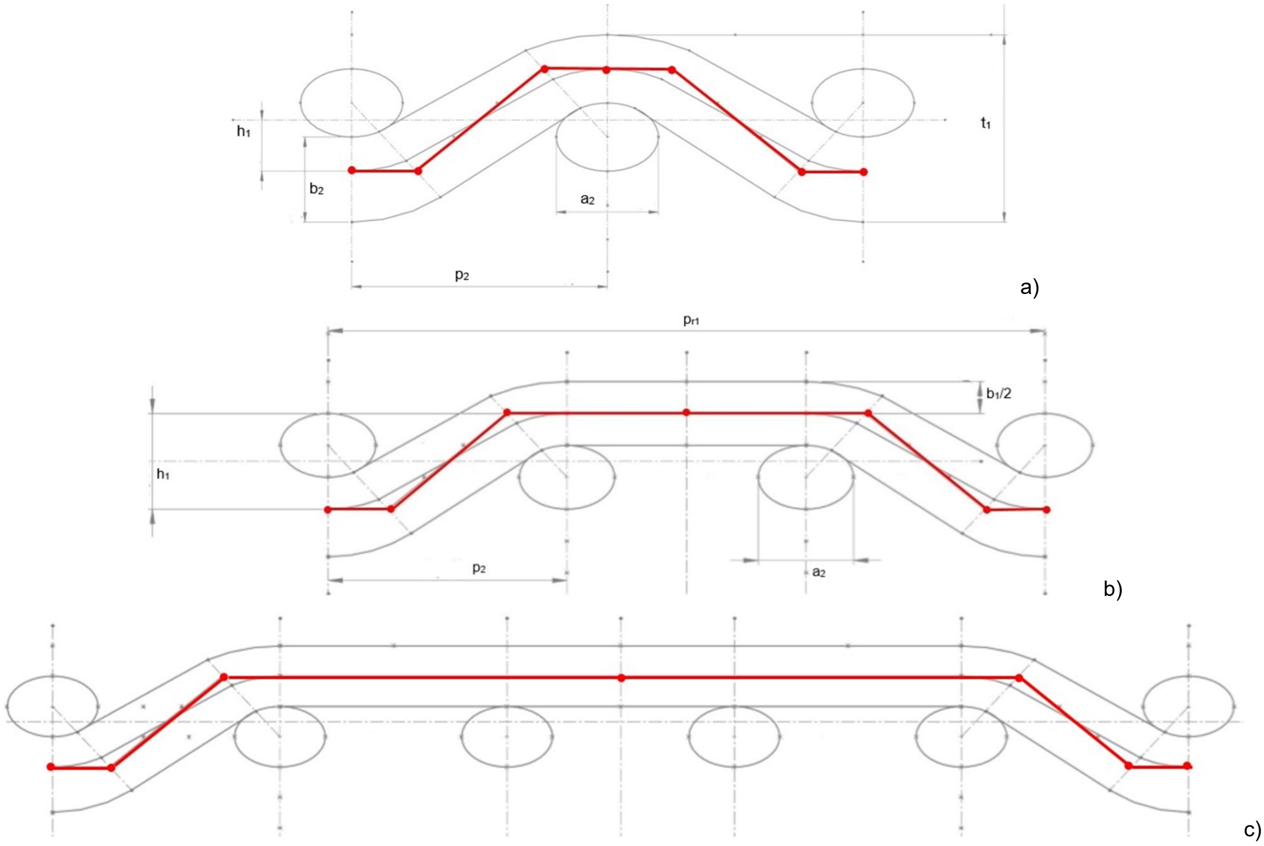

Figure 2 B-Spline control polygon and control points for a) Plain, b) 2/1 Twill, c) 4/1 Twill weave units

In many studies, the cross-sectional shape of yarn in the woven fabric was modeled as circular. However, it was known that the shape and dimension of yarn changed along the yarn path because of interactions between adjacent and perpendicular yarns. In this study, the dimensions of yarn cross-section were defined by using theoretical calculations and experimental measurements. Theoretical yarn diameter was accepted as the real circular diameter of the yarn before weaving. The theoretical circular yarn diameter depending on yarn count was calculated by Ashenhurst theory (13) given in Equation 2. But, from previous studies and literature, it was known that the cross-sectional shape of the yarn is changed during weaving and this shape is not constant along the yarn path. Therefore, in this study, it was accepted that this circular yarn shape became elliptical during the weaving. The dimensions of an ellipse having the same perimeter with a circle were calculated by Equation 3. Here, *a* is the major and *b* is the minor diameter. Besides, flattening ratio (*e*) is defined as being the ratio of the minor diameter to the major (*e=b/a*). In the theoretical study, the minor dimension of the ellipse could be calculated by using the relation between fabric thickness (*t*) and the amplitude of warp yarn (h_1) as given in Equation 4. So, the value of major diameter could be calculated theoretically.

In addition, in the experimental study, the dimension of major diameter was be measured by using surface pictures of fabrics. Thus, the minor diameter of the yarn was predicted by using the relationship between theoretical circular diameter and major diameter.

$$h1 = p2\frac{\sqrt{2c_1}}{1-c_1} \tag{1}$$

$$d = \frac{1}{K\sqrt{N}} \tag{2}$$

$$d = \frac{a+b}{2} \tag{3}$$

$$t = h1 + b1 \tag{4}$$

The variation of major diameter was measured along the yarn path, in the experimental study. Flattening ratio of yarn was calculated for different regions. Using these values, the yarn cross-sectional shape and size of yarn along the yarn path were defined for each region. Thus, a realistic yarn geometry which does not accept a constant cross-sectional shape and size was formed.

4 RESULTS AND DISCUSSION

In Table 2, theoretical circular yarn diameter and mean value of the measured major diameter of elliptical yarn cross sections were summarized. Measurement of yarn dimension was done in different regions of weave unit onto the fabric images. In Table 2, a_{p-m} denotes major diameter at the peak point of intersecting region, a_{i-m} is major diameter at the middle point of the interchanging region, a_{c-m} is major diameter at the middle point of floating region (for twill weaves). It was found that differences of major diameter between different regions of yarn path are significant according to statistical analysis.

Table 2 Calculated circular yarn diameter and measured major diameters

Fabric Code		d_t [cm]	a_{p-m} [cm]	a_{i-m} [cm]	a_{c-m} [cm]
Warp	P1	0.0129	0.0163	0.0148	x
	P2	0.0126	0.0161	0.0140	x
	P3	0.0118	0.0157	0.0126	0.0142
	P4	0.0131	0.0173	0.0133	0.0144
Weft	P1	0.0129	0.0171	0.0148	x
	P2	0.0129	0.0174	0.0154	x
	P3	0.0116	0.0139	0.0124	0.0128
	P4	0.0167	0.0198	0.0169	0.0211

a_{p-m} - major diameter at the peak point, a_{i-m} - major diameter at interchanging region, a_{c-m} - major diameter at middle of floating (for twill weaves)

Minor diameter at the peak point of the intersecting region was calculated by using Equation 4, depending on fabric measured fabric thickness (t) and calculated amplitude of warp yarn (h_1). Here, the thickness was accepted forming by warp yarns. In addition, minor diameter at the different regions was calculated by using Equation 3, depending on the relation between theoretically calculated circular diameter and experimentally measured major diameter. In plain fabrics, the minor diameter values at the peak point of the intersecting region were found similar for both calculations. But in twill weaves, especially in 4/1 twill weave, real thickness (measured) was formed differently from the theoretical aspect because of long floating. So the minor dimension value calculated from fabric thickness was bigger. In order to eliminate this problem, a certain flattening ratio at the peak point of 4/1 twill was used to define yarn dimensions as being 0.6.

Flattening ratio of yarn for different regions was calculated. Maximum flattening was found at the peak of intersecting region in which warp and weft yarns contact each other. The flattening ratio was found nearly 0.5-0.6 at that region. At the interchanging region, the flattening ratio was increased because of the pore region. It was nearly between 0.7-0.85 for different weave types. At the midpoint of the floating region (twill weaves), *e* was calculated nearly 0.6-0.7.

Table 3 Theoretical calculated yarn dimensions and experimental calculated minor diameter

Fabric Code		a_{p-t}	b_{p-t} [cm]	b_{p-m} [cm]	b_{i-m} [cm]	b_{c-m} [cm]
Warp	P1	0.0164	0.0095	0.0095	0.0110	X
	P2	0.0149	0.0103	0.0092	0.0113	X
	P3	0-0143	0.0093	0.0079	0.0110	0.0094
	P4	0.0084	0.0117	0.0088	0.0128	0.0117

In the theoretical study, the yarn path was defined by using B-spline curve method. The control points of B-spline polygon were calculated depending on structural properties of fabric such as fabric thickness (t), settings, yarn count, crimp ratio. Then the B-spline method was applied by an algorithm written in Visual Basic 2010. Fabric unit weight area (w) and crimp ratios (k) of yarns were calculated as control factors as given in Table 4. This geometrical model is achieved for plain fabrics. But, because of interactions between long floating, the theoretical results of 4/1 twill weave was found different from experimental results.

Table 4 Structural fabric properties calculated by B-spline method

Fabric Code	W	k_1	k_2
P1	121	1.11	1.09
P2	104	1.07	1.11
P3	132	1.2	1.16
P4	246	1.19	1.26

The fabric geometry simulations were performed by using SolidWorks. In Figure 3, some steps of SolidWorks drawing were shown. First, the yarn path was defined as a spline curve using 21 points. Then the planes for cross-sections were defined along the yarn path depending on the region. Five different plains were defined for each weave units. Flattening ratio of different regions was found different and in this study, the cross-sectional dimensions were defined individually for all planes. Then, loft property of SolidWorks was used and different cross-sections at different planes were connected along the yarn path. By this simulation, the variation of the yarn cross-section was reflected, realistically. Both warp and weft yarns were modelled depending on the structural properties of fabrics. In the end, drawn solid yarn simulations were repeated and 3D fabric simulations were acquired as given in Figure 4. In addition, B-spline curve based on control points could be obtained in SolidWorks. Yarn path could be drawn automatically after determined the number and coordinates of control points. This is a faster way to obtain yarn path geometry in SolidWorks. But, the calculation of spline points was chosen in that study in order to define some structural properties of the fabric. Thus, the experimental and the theoretical properties of fabrics could be calculated.

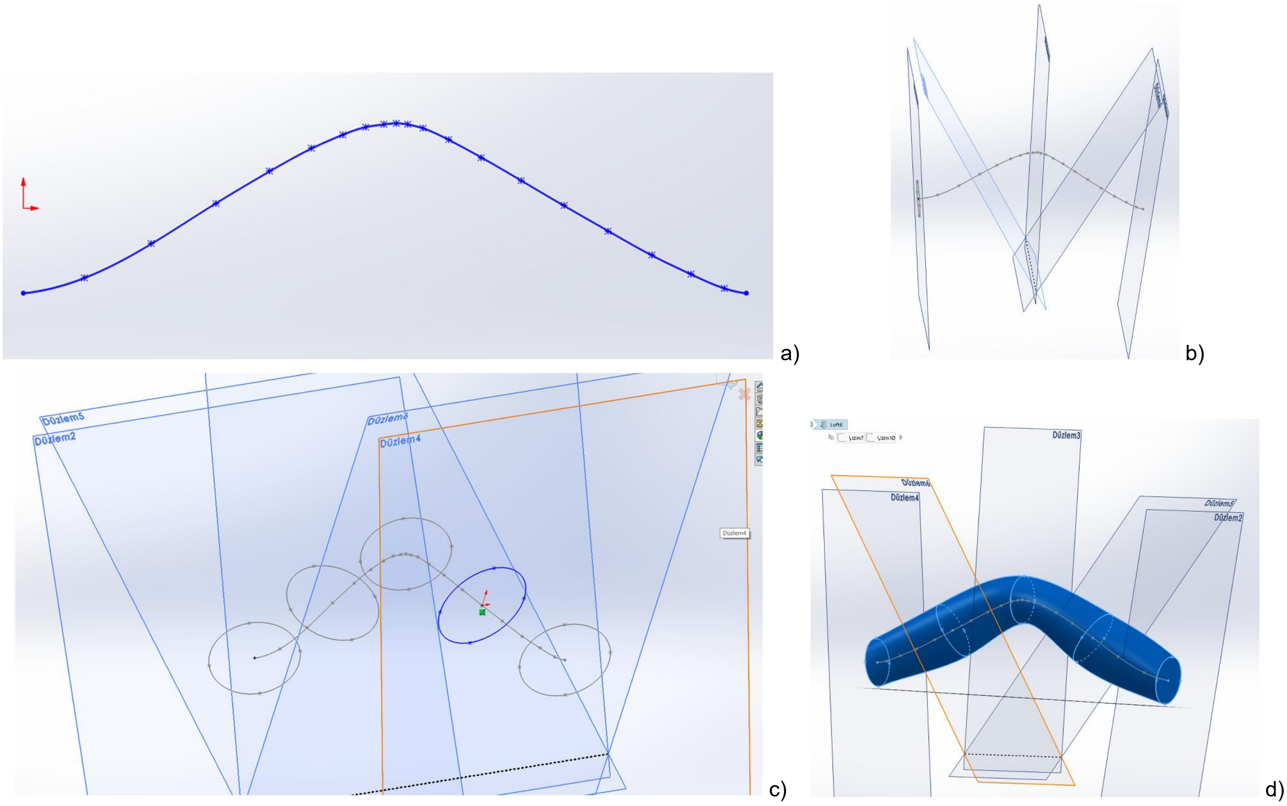

Figure 3 The B-spline curve of yarn path (a), definition of planes for different regions of yarn path (b), various cross-sections in different planes (c), simulation of solid yarn model having various cross-section along the yarn path (d)

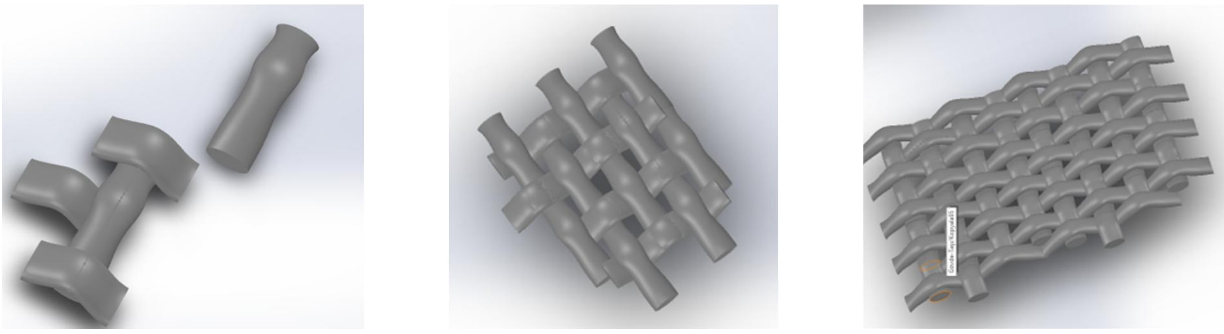

Figure 4 The simulation of fabric (for P1)

5 CONCLUSIONS

In this study, first, yarn path was modeled according to structural parameters of fabric such as weave type, settings, yarn counts, fabric thickness.

The B-spline method was used to get a smooth yarn curve. Then, the yarn cross-section was modelled depending on the yarn path.

The experimental results were used in order to get the flattening ratio of yarn cross-section at different regions of yarn path. After defining the cross-sectional properties of each region on the yarn path the yarn geometry of fabric weave unit was obtained. The performed fabric simulations were more realistic because of reflecting the variation of yarn cross section along the yarn path. This would help more realistic mechanical models with CAD system. The only disadvantage of using this program is the material selection. In further studies, it is aimed to generate 3-D fabric geometry with multifilament yarns and to use these fabric models in the prediction of performance properties of fabrics. Besides, an exhaustive experimental study contained different raw materials and structural parameters were planned.

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