STRUCTURAL DESIGN ENGINEERING OF WOVEN FABRIC BY SOFT COMPUTING: PART I - PLAIN WEAVE

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Abstract:

An attempt has been made to optimise the engineering attributes of a plain weave fabric according to certain requirements. A simplified algorithm was used to solve fabric geometrical model equations, and relationships were obtained between useful fabric parameters such as thread spacing and crimp, fabric cover and crimp, warp and weft cover. Such relationships help in guiding the direction for moderating fabric parameters. The full potential of the Peirce fabric geometrical model for plain weave has been exploited by soft computing. The inter-relationships between different fabric parameters for jammed structures, non-jammed structures and special cases in which the cross-threads are straight were obtained using a suitable algorithm. It is hoped that the fabric designer will benefit from the flexibility in choosing fabric parameters for achieving any end use with the desired fabric properties.

Key words:

Design engineering, geometrical model, jammed structure, soft computing.

Introduction

Fabric properties are greatly affected by the choice of fabric parameters, since the choice of fabric parameters influences the structure. The behaviour and relationship between fabric parameters is a precursor to the optimal solution for fabric engineering problems. Many features of the cloth are essentially dependent on geometrical relationships. The geometrical model of fabric provides some simplified formulae to facilitate calculations and specific constants which are of value for cloth engineering, structural problems and mechanical properties [1]. These fabric parameters are tools for an innovative fabric designer in creating fabrics for diverse applications. The theoretical relationship between fabric parameters enables the fabric designer to play with different fibres, yarn tex, threads/cm and weave to vary texture and fabric properties.

The first study of fabric structural design was started in 1937 by Peirce [1], which led to Peirce's model of plain-weave fabrics with a circular yarn cross-section. He also proposed a fabric model with an elliptical yarn cross-section. In 1958, Kemp proposed a racetrack model [2]. Hearle and Amirbayat proposed lenticular geometry for calculations in fabric mechanics by the energy method in 1988 [3]. Many studies related to fabric mechanical properties on the basis of the fabric structural model were carried out by Grosberg [4], Backer [5] and Postle [6]. Lindberg [7] extensively studied fabric mechanical behaviour related to tailorability. Subsequently, a sophisticated measurement system of fabric mechanical properties was developed by Kawabata and Niwa [8], which is called the KES-FB system. Another fabric mechanical measurement system called FAST was developed by CSIRO in Australia [9]. Recently, new objective measurement systems [10] such as the Virtual Image Display System (VIDS) and the Fabric Surface Analysis System (FabricEye(r)) have been developed for the analysis of fabric geometrical properties. On the other hand, there are currently many CAD systems [11] related to fabric design such as weave construction, colour and pattern. There is also a pattern design CAD [12,13], including a visual wearing system (VWS) for garment designers. However, there is no fabric structural design system related to the decision on fabric density according to fibre materials, yarn linear density and weave pattern. Therefore, a database system which can easily calculate warp and weft densities according to the various yarn counts, weave constructions and materials is required through the analysis of a design plan for nylon and polyester fabrics [14,15].

It is possible to predict the fabric parameters and their effect on the fabric properties by soft computing. This information is helpful in making a decision regarding a specific buyer's need. A simplified algorithm is used to solve these equations and to obtain relationships between useful fabric parameters such as thread spacing and crimp, fabric cover and crimp, as well as warp and weft cover. Such relationships help in guiding the direction for moderating fabric parameters. For example, the parameters of a fabric requiring a certain crimp in the warp and weft even in the jammed state can be calculated. Alternatively, it may be desirable to make a non-jammed fabric with a certain amount of warp and weft. Even fabrics with maximum crimp in either the warp or weft direction can be estimated. In this work, an attempt has been made to optimise the engineering attributes of a plain weave fabric according to certain requirements.

Methodology

Approach to develop soft computing algorithm

It is needless to mention that the pioneering work of Peirce on the geometrical model provides the basic platform for fabric engineering. Many basic fabric dimensional parameters can be worked out from the geometrical model by use of modern soft computing methods. Fabric parameters for any relationship between warp and weft cover can be evaluated. Last but not least, the relationship between fabric mass and fabric cover can also be evaluated. This is the strength of soft computing which cannot be achieved by any other means, including the graphical or monogram methods. The basic equations derived from the geometrical model are not easy to handle. In fact, it is difficult to solve these equations on many occasions. Many researchers have tried to solve these equations and found some simplified relationships. However, the best method so far has been found to be the graphical method. It was therefore decided to develop a simple algorithm from the Peirce geometrical model to establish the relationship between various fabric parameters through soft computing.

Programming

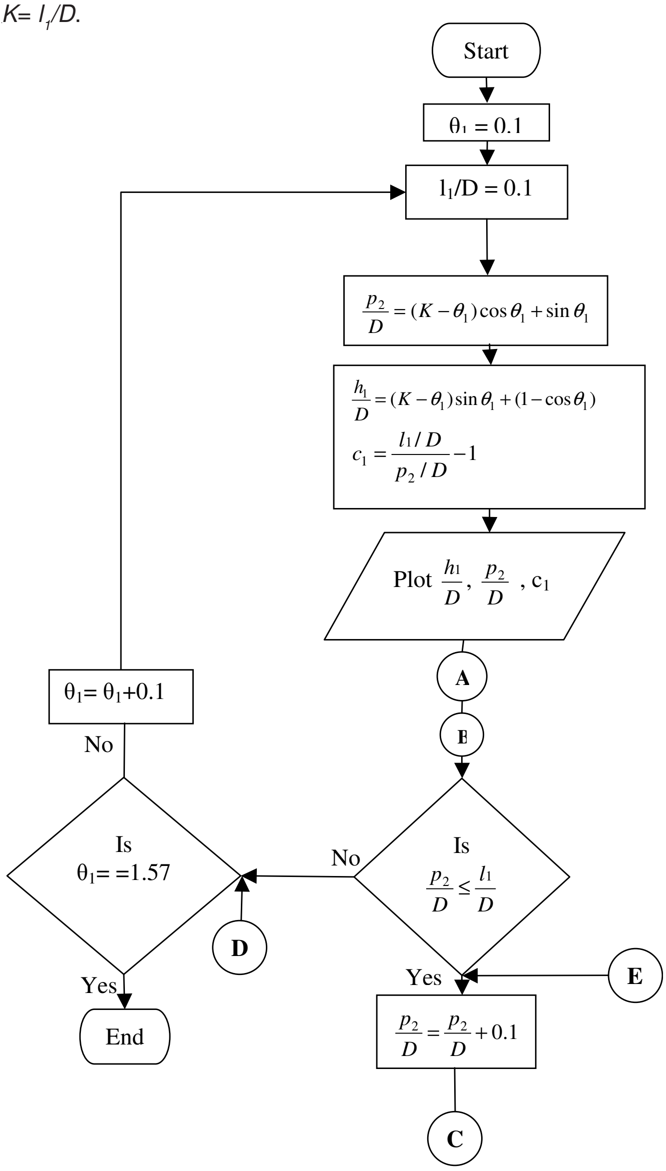
Computer programs were developed for establishing relationships between various fabric parameters originating from the Peirce geometrical model using MATLAB-7.

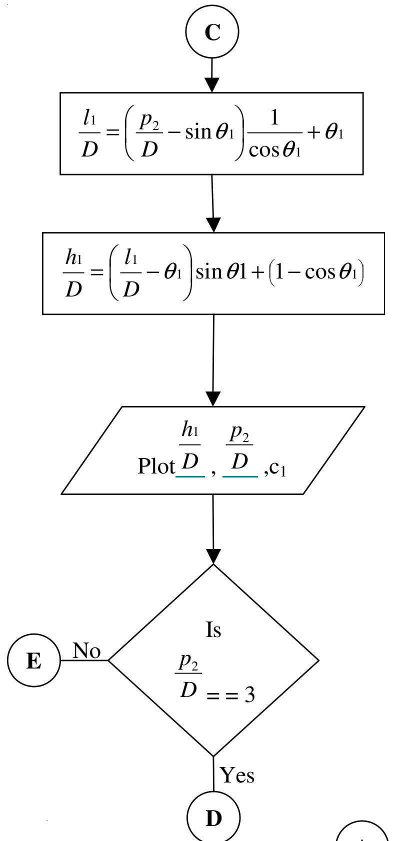
Peirce's geometrical relationships can be written in the following form:

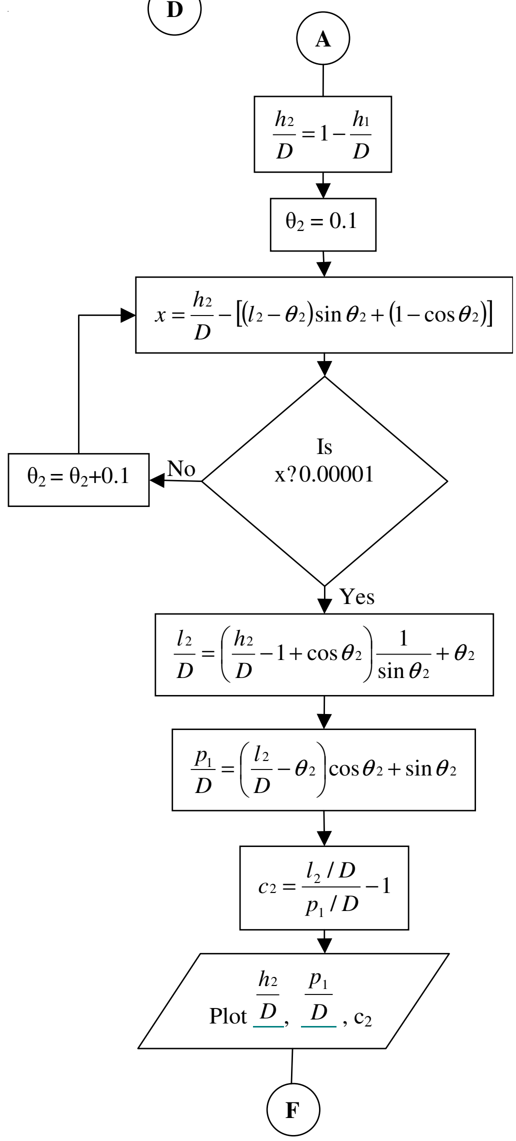
$$\frac{p_2}{D} = (K - \theta_1)\cos\theta_1 + \sin\theta_1 \quad [1]$$

$$\frac{h_1}{D} = (K - \theta_1)\sin\theta_1 + (1 - \cos\theta_1) \quad [2]$$

where:
p = thread spacing,
h = crimp height,
$D = d_1 + d_2$,
d = yarn diameter,
l = modular length,
θ = weave angle,
$K = l_1/D$.







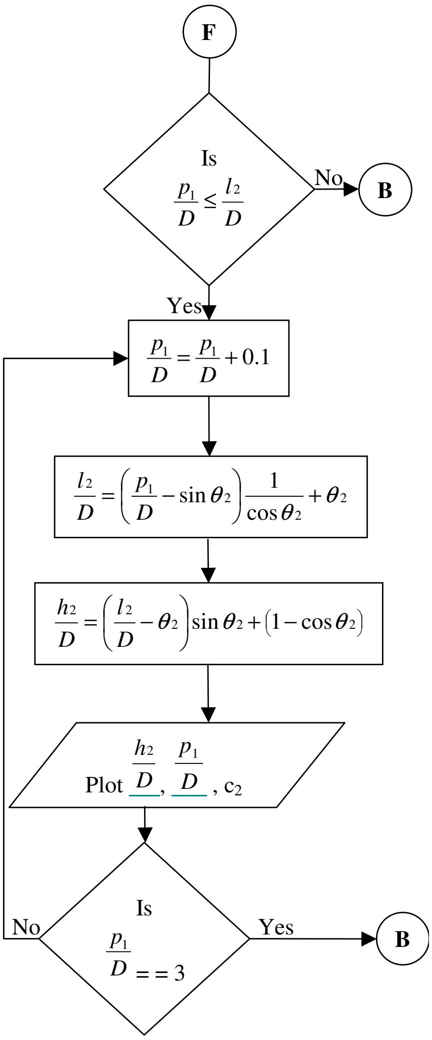


Figure 1. Flowchart for solving Peirce's basic geometrical equations

Suffix 1 and 2 represent warp and weft yarn, respectively.

Two similar equations for the weft direction can be obtained by interchanging suffix 1 with 2 and vice-versa. The relationships between fabric parameters were graphically obtained for various constructions like jammed structures, non-jammed structures and also for fabric when the cross-threads are straight. The flow chart for this algorithm is shown in Figure 1.

Results and discussion

The solution of p_2/D and h_1/D was obtained for different values of θ (warp crimp angle) ranging from 0.1 - $\pi/2$ radians. Such a relationship is shown in Figure 2. The Figure is similar to that given by Peirce. It is a very useful relationship between fabric parameters for engineering desired fabric constructions. One can see its utility for the following three cases:

- Jammed structures,
- Non-jammed fabrics,
- Special case in which cross-threads are straight.

Jammed structures

Figure 2 shows the non-linear relationship between the two fabric parameters p and h on the extreme left. In fact, this curve is for jamming in the warp direction. It can be seen that the jamming curve shows different values of p_2/D for increasing

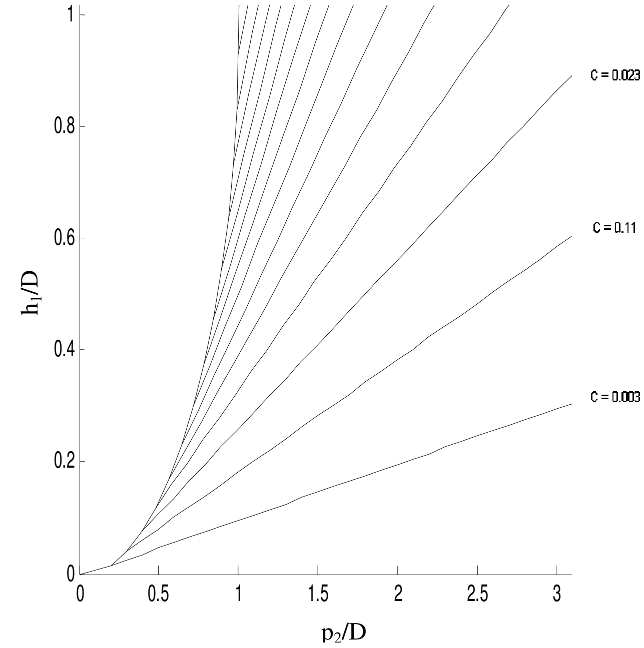


Figure 2. Relationship between thread spacing and crimp height

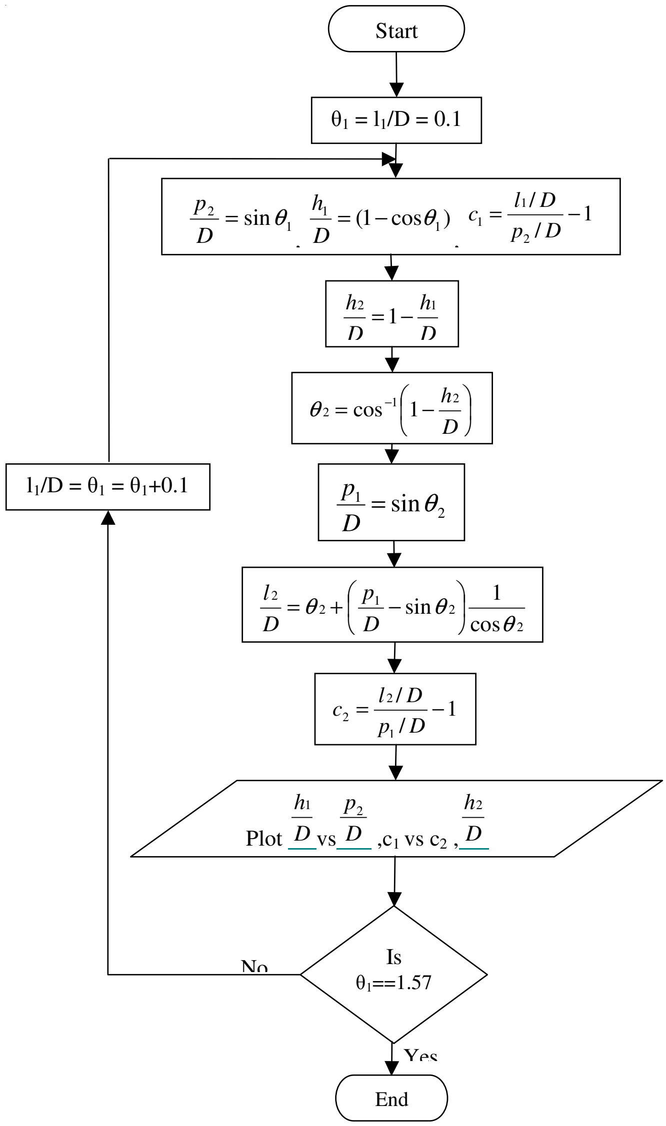


Figure 3. Flowchart for fabric parameters in jammed structures

crimp. Interestingly this curve is a part of a circle and its equation is:

$$\left(\frac{p_2}{D}\right)^2 + \left(\frac{h_1}{D} - 1\right)^2 = 1 \qquad [3]$$

With the centre at (0, 1) and a radius equal to 1.

For jamming in the warp direction of the fabric, the parameters p_2/D and corresponding h_1/D can be obtained either from this figure or from the equation above.

The relationship between the fabric parameters over the whole domain of the structure being jammed in both directions can be obtained by the algorithm given in Figure 3.

Yarn spacing *p* and crimp amplitude *h* depend upon both yarn diameters and weave angle:

$$p_2 = D\sin\theta_1 = D\sin\frac{l_1}{D}$$
$$h_1 = D(1-\cos\theta_1) = D\left(1-\cos\frac{l_1}{D}\right) \qquad [4]$$

We know that $(h_1 + h_2) = (d_1 + d_2) = D$, or in other words, $\frac{h_2}{D} = 1 - \frac{h_1}{D}$.

From Peirce's equations,

$$p_1 = D\sin\theta_2 = D\sin\frac{l_2}{D}$$
$$h_2 = D(1-\cos\theta_2) = D\left(1-\cos\frac{l_2}{D}\right) \qquad [5]$$

From the above computation, the relationship between different useful fabric parameters can be obtained and are given in Figure 4 to Figure 8. Figure 4 gives the relationship between p_2/D and p_1/D. This figure shows that the relationship between these parameters is less sensitive at the two extreme ends, while the relationship is sensitive in a *p/D* range closer to 1. In fact, this sensitive range corresponds to maximum crimp in one direction only. The scope for change in p_2 and p_1 lies between 0.6 to 0.9 for both parameters. Beyond this range, a change in thread spacing is possible in only one direction.

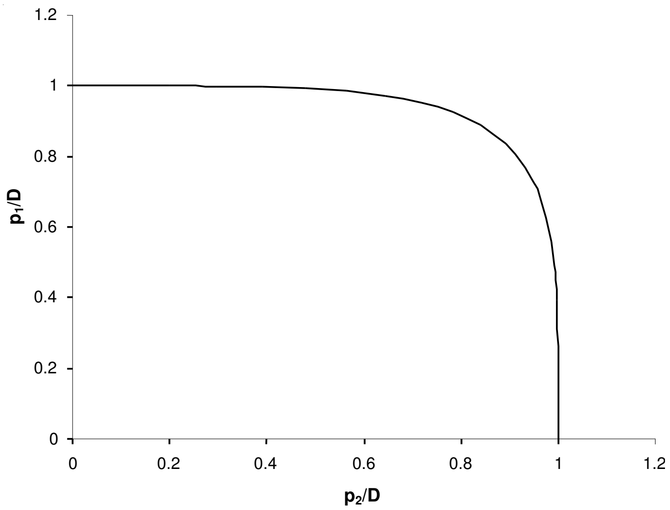


Figure 4. Relationship between warp and weft thread spacing for jammed fabric

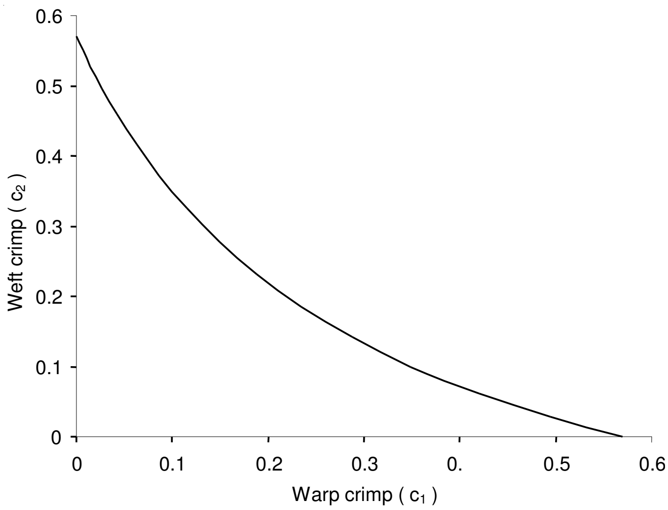


Figure 5. Relationship between fraction warp and weft crimp for jammed fabric

A useful relationship between the crimps in the two directions is shown in Figure 5. It indicates an inverse non-linear relationship between c_1 and c_2. The intercepts on the axis give maximum crimp values with zero crimp in the cross direction. This is a fabric configuration in which cross-threads are straight and all the bending is done by the intersecting threads. It may be concluded here that at either end, a small change in the crimp in one direction can permit a large change in the crimp in the other direction.

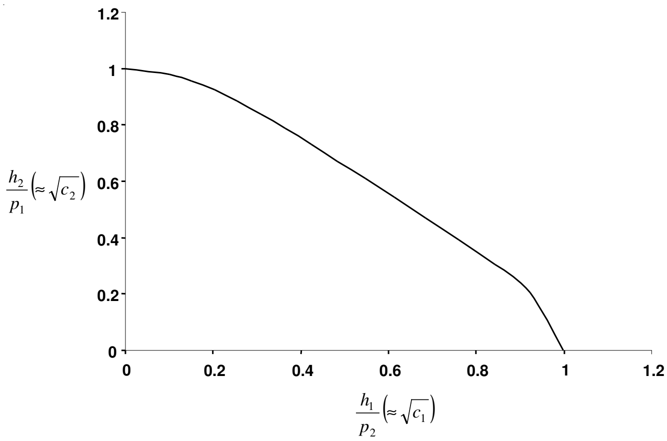


Figure 6. Relationship between $\sqrt{c_1}$ and $\sqrt{c_2}$ for jammed fabric

Figure 6 shows the relationship between h_1/p_2 and h_2/p_1 with linearity between the parameters except at the two extremes. This behaviour is in fact the relationship between the square root of the crimp in two directions; the constant is fixed for any jammed fabric. Other practical relationships are obtained between the warp and weft cover factor and between the cloth cover factor and fabric mass (gsm).

Figure 7 gives the relationship between warp and weft cover factor for different ratios of weft to warp yarn diameters (ß). The relationship between the cover factors in two directions is sensitive only in a narrow range for all values of ß. The relationship between the cover factors in two directions are inter-dependent for jammed structures. Maximum threads in the warp/weft direction depend on the yarn count and weave. Maximum threads in one direction of the fabric will give unique maximum threads in the cross-direction. The change in the value of ß causes a distinct shift in the curve. A comparatively coarse yarn in one direction, with respect to the other direction,

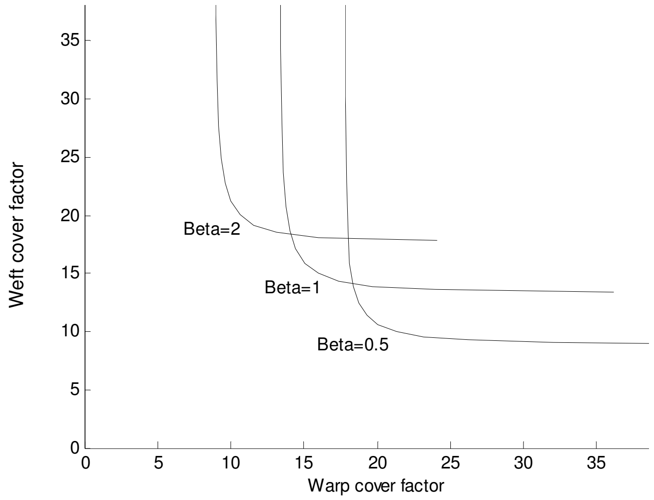


Figure 7. Relationship between warp and weft cover factor for different ß for jammed fabric.

helps in increasing the cover factor. For ß=0.5, the warp yarn is coarser than the weft, which causes an increase in the warp cover factor and a decrease in the weft cover factor. A similar effect can be noted for ß =2, in which the weft yarn is coarser than the warp yarn.

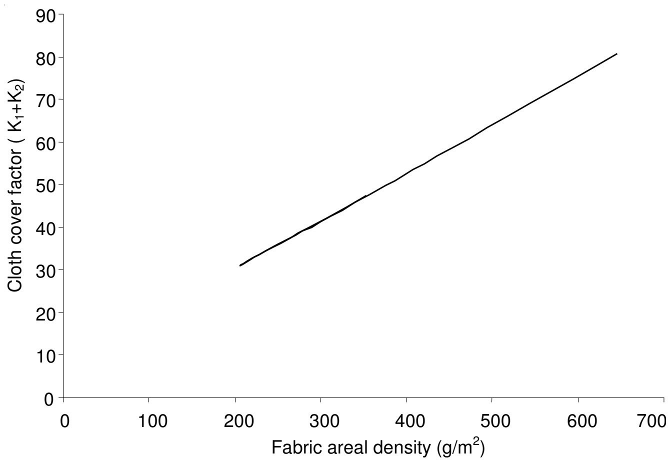


Figure 8. Relationship between fabric cover factor and fabric mass for jammed structures

The relationship between fabric mass in gsm with cloth cover (K_1+K_2) is positively linear as shown in Figure 8. The trend may appear to be self-explanatory. Practically, an increase in fabric mass and cloth cover factor for jammed fabrics can be achieved in several ways, such as zero crimp in the warp direction and maximum crimp in the weft direction, zero crimp in the weft direction and maximum crimp in the warp direction, equal crimp in both directions and dissimilar crimp in both directions. This explanation can be understood by referring to the non-linear part of the curve in Figure 2.

Non-jammed structures

It can be seen that the relationship between p_2/D and corresponding h_1/D is linear for different values of crimp. This relationship is useful for engineering non-jammed structures for a range of values of crimp. The fabric parameters can be calculated from the above non-jammed linear relationship between p_2/D and h_1/D for any desired value of warp crimp. Then, h2/D can be obtained from ($1-h_1/D$), and for this value of h_2/D, one can obtain the value of p1/D for the desired value of weft crimp. Thus, all fabric parameters can be obtained for a desired value of p_2/D, picks/cm, warp and weft yarn tex, as well as warp and weft crimp. One can choose any other four parameters to obtain all fabric parameters. The algorithm described in Figure 1 can be used to obtain several solutions for non-jammed fabric.

Straight cross-threads

In the Figure 2, the intersection of the horizontal line corresponding to h_1/D =1 gives all possible structures ranging from relatively open to jammed configurations. In this case, h_2=0, h_1=D. The fabric designer is allowed the option to choose the possible fabric construction. These options include jamming and other loose constructions.

Using the above logic, it is also possible to obtain fabric parameters for:
– A fabric jammed in both directions,
– A fabric with maximum crimp in one direction and straight cross-threads,
– A fabric which is neither jammed nor has zero crimp in the cross-threads.

Conclusion

The full potential of the Peirce fabric geometric model for plain weave has been exploited by soft computing. The inter-relationships between different fabric parameters as shown for jammed structures can be obtained for the other two cases using the algorithm. It is hoped that the fabric designer will benefit from the flexibility in choosing fabric parameters for achieving any end use with the desired fabric properties.

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