GEOMETRICAL MODELLING OF 3D INTERLOCK FABRIC

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ABSTRACT

In order to better predict the composite material behaviour, mechanical engineers need software tools to model the textile structure, which requires precise geometrical description of the textile reinforcement. It is also important to have a clear description of the textile structure at each scale. Realising the importance of geometrical description, this research focuses on establishing and defining a model for geometrical description of 3D Interlock fabrics having layer to layer binding. Most of the literature found on the subject focuses on so called 2D fabrics. When these models are applied on 3D architectures they tend to distort the geometry and often interpenetrations are resulted. In order to define the geometry of 3D interlock fabrics, certain new notions of geometry have been introduced. These new notions of geometry described here are advantageous for the modelling of 3D structures.

Our observations of photomicrographs have revealed that these notions provide a generic strategy for modelling of 3D layer to layer Interlock fabrics. These new notions have been applied to model the geometry of warp interlock structure. The visualisation of the modelling approach is realised in VRML (Virtual reality Modelling language).The model is compared with the results obtained from another modelling tool.

1. INTRODUCTION

The geometric models of fabric structure can be classified into three groups [1].The microscopic scale models involve the filaments position and their distribution, which influence the geometry and mechanical properties of yarns. The mesoscopic scale attempts to model the yarn paths and shapes inside the woven geometry and the mechanical parameters of yarns at crossover points of the fabric. The continuum models describe certain properties averaged over the fabric surface or the unit cell and thus compromise precision. The global approach of Textile modelling proposed by Lomov et al. [2] is mainly based on the analysis of hierarchy of textile structures(micro-meso-macro).The modelling approach takes into account the non linear and non conservative behaviour of yarns in compression and bending. The continuum models have been studied by Steigmann [3] for filaments, Reese [4] to integrate anisotropic and elastic properties, and by Xue et al [5] while models proposed by Shockey et al [6][7][8][9][10] describe woven structures. A simple meso-structural model was first proposed by Peirce [11] to give a mathematical geometric formulation of the crossover points in woven and knitted fabrics. This model was modified by various researchers such as Warren [12] and Sagar et al [13] who proposed non circular cross sections of yarns. Kawabata [14][15][16] has proposed analytical models of the fabric geometry based on bi-axial tensile and shear behaviours. On the basis of Kawabata's geometry, modified models have been proposed by Kato et al [17] who describes the lattice geometry of a unit cell, by Realff et al [18] whose model includes compressive properties of yarns, by Boisse et al. [19] and Rattensperger et al. [20] who integrate bending and shearing behaviour of yarns in their model. The numerical models such as the models proposed by Ng et al. [21] and Boisse et al. [22], help to describe all the fabric buckling mechanisms through a precise description of mechanical parameters acting on yarns.

Although geometrical description alone is not enough to explain completely the behaviour of all the fibres and yarns in a fabric structure, it is important to have at least statistical estimates of the yarn geometry in order to develop a non empirical model. The internal geometry of the textile reinforcement is an important factor that affects the properties of the composite during its fabrication and later on during its performance. For the former impregnation of the reinforcement by resin is affected by porosity (size, distribution and connectivity of pores).For the later, fibre orientation plays an important role in determining the transfer of stress from the matrix to the reinforcement and its rigidity. Areas of stress-deformation concentration are correlated with the resin rich zones and resin-matrix interfaces, which are distributed throughout the volume according to the geometry of the reinforcement.

2. DEFINITIONS

Traditionally a multi-layer fabric is considered as consisting of various layers of weft threads placed more or less parallel to one another, i.e. one over another. Each layer of weft threads basically defines fabric layer in the same fashion as in multilayer laminates. The warp threads in warp interlock structures that traverse between different layers and bind weft yarns are thought to keep these fabric layers parallel. Since this approach of viewing the 3D structures is a source of trouble in subsequent modelling of geometry, we have introduced certain new notions of geometry; block, Interblock crimp and Interblock displacement, in order to be able to better describe the multilayer nature of interlock architecture. These and other important definitions appear in the following

1. Block and Layer
2. Interblock Crimp
3. Interblock Displacement
4. Crimp Angle
5. Trajectory of the warp yarn

2.1. Block and Layer

A layer is same as traditionally thought of i.e. horizontal layers of weft threads placed one over another. But the block of weft thread is the vertical arrangement of weft threads placed one over another so that a block and a layer are always mutually perpendicular. (Figure 1 and Figure 5(a))

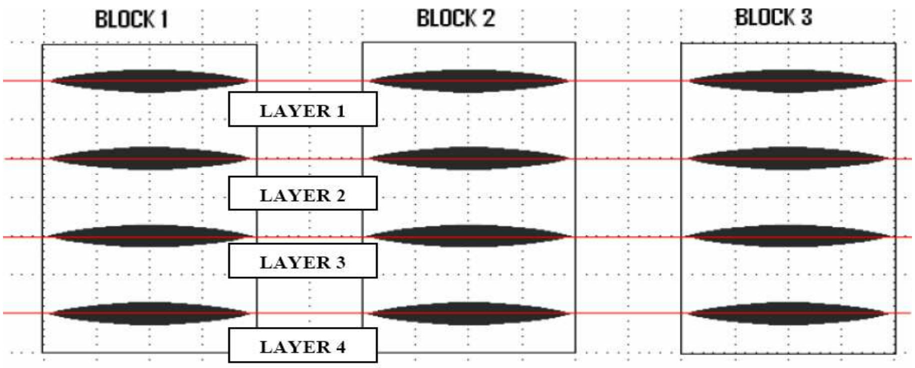

Fig. 1: Definition of block and layer

2.2. Interblock Crimp

Individual blocks of weft threads displace in vertical direction due to the tension that the binding threads (warp) apply on different layers, while these layers are being bound together by this thread. Due to this phenomenon each layer will assume a wave pattern, and this displacement of weft thread blocks in vertical direction will give rise to 'Interblock crimp'. (Figures 2,4 and 5(b))

Interblock crimp will depend upon crimp angle and relative compressibility of warp and weft threads. Crimp angle depends upon various factors. These factors which, in turn affect Interblock crimp, will be discussed in a later section.

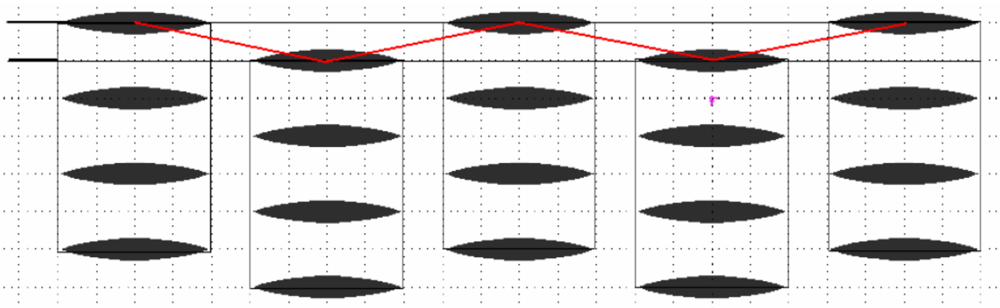
Fig. 2: Definition of Interblock Crimp

2.3. Interblock Displacement

Due to the tension applied on weft threads by the warp thread going through different layers, the blocks displace in horizontal direction (in addition to the Interblock crimp). Interblock displacement will largely depend upon crimp angle. (Figures 3, 4 and 5(c))

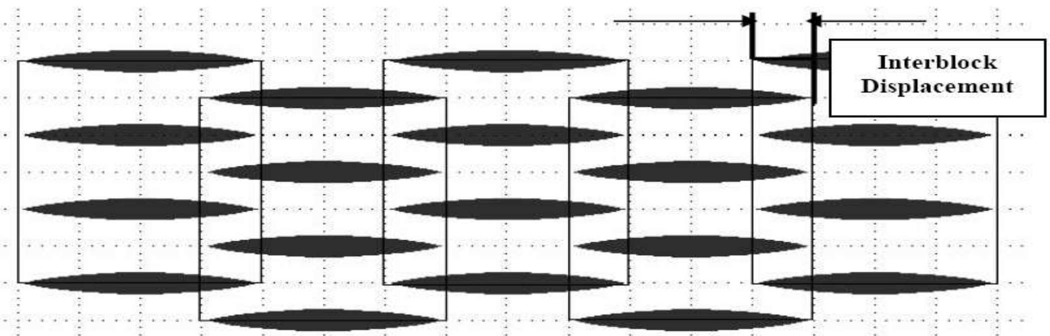

Fig. 3: Definition of Interblock Displacement

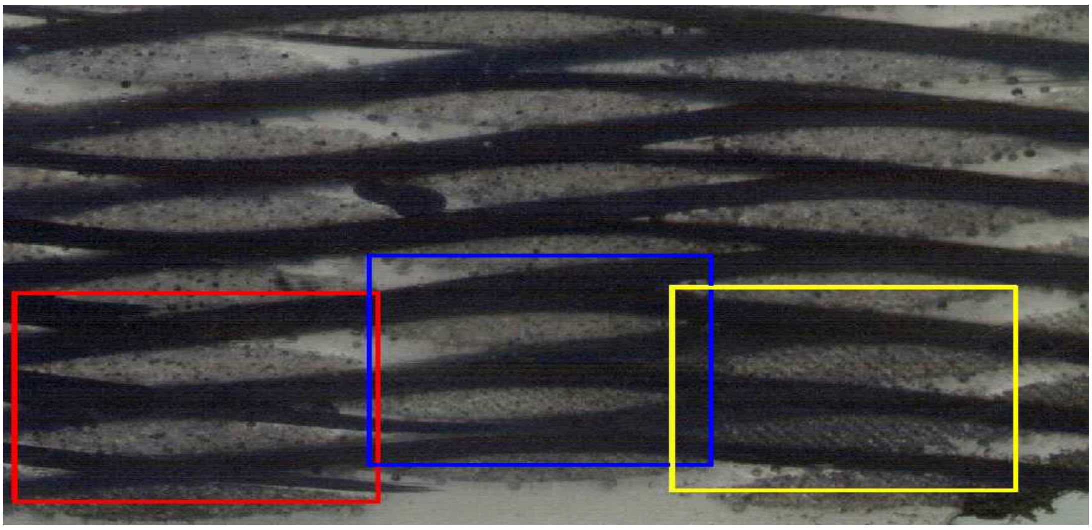

Fig. 4: Photomicrograph of a warp interlock fabric made of carbon fibres. The three rectangles represent three blocks exhibiting Interblock Crimp and Interblock Displacement.

During the weaving process of the warp interlock fabric, it can be assumed that these three consecutive steps occurred by the different motions of heddles and the beating of the weaving reed. (Figure 5)

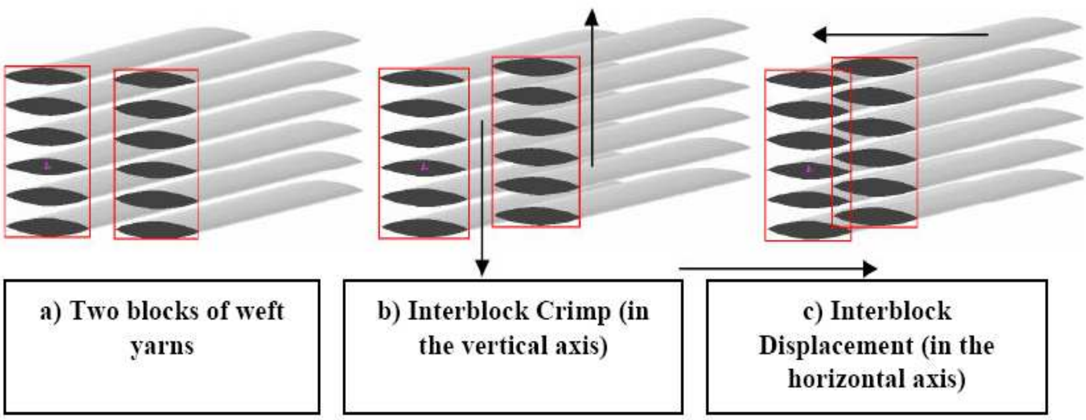

Fig. 5: Schematic diagram showing the phenomena of Interblock crimp and Interblock displacement in two blocks of weft yarns

2.4. Crimp Angle

Crimp angle is the angle that the trajectory of a yarn makes with the horizontal axis (Figure 6). Crimp angle depends upon

- Weave architecture i.e. number of layers linked by the interlocking warp thread
- Tension applied during the weaving process
- Weft yarn density i.e. number of blocks of weft threads/cm

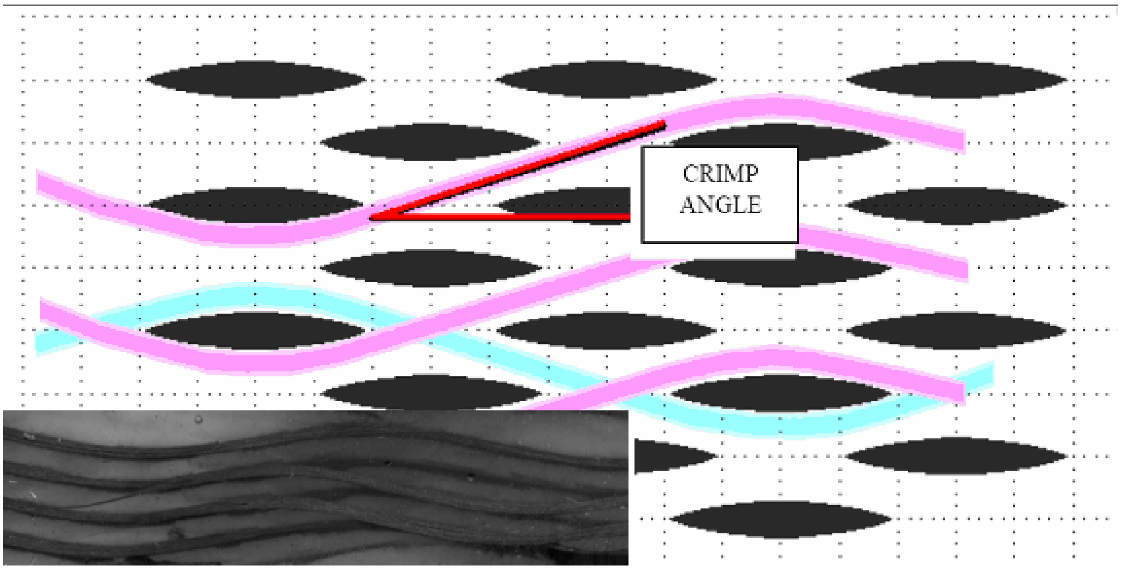

Fig. 6: Definition and real description of crimp angle

It can be concluded that Interblock crimp and Interblock displacement vary directly with crimp angle. From photomicrographs it was observed that the individual weft yarns remain straight and the only crimp in the weft direction is Interblock crimp.

2.5. Trajectory of the Warp Yarn

We have used the approach developed by Shang and Shuong [23] (Figure 7), who have described the warp yarn trajectory as a combination of elliptical and straight line segments. The warp yarns are assumed to follow an elliptical path under the pressure of weft yarns (and blocks of weft yarns for 3D layer to layer Interlock structures). Between these elliptical segments, the yarns assume straight trajectory (Figure 7). The length of these straight and elliptical segments will depend upon the weave structure i.e. number of layers being linked by the warp yarn. The curvature of the elliptical segment will depend upon the weft yarn geometry and its section (elliptical, lenticular or round), and the tension that develops as a result of warp and weft yarn interactions.

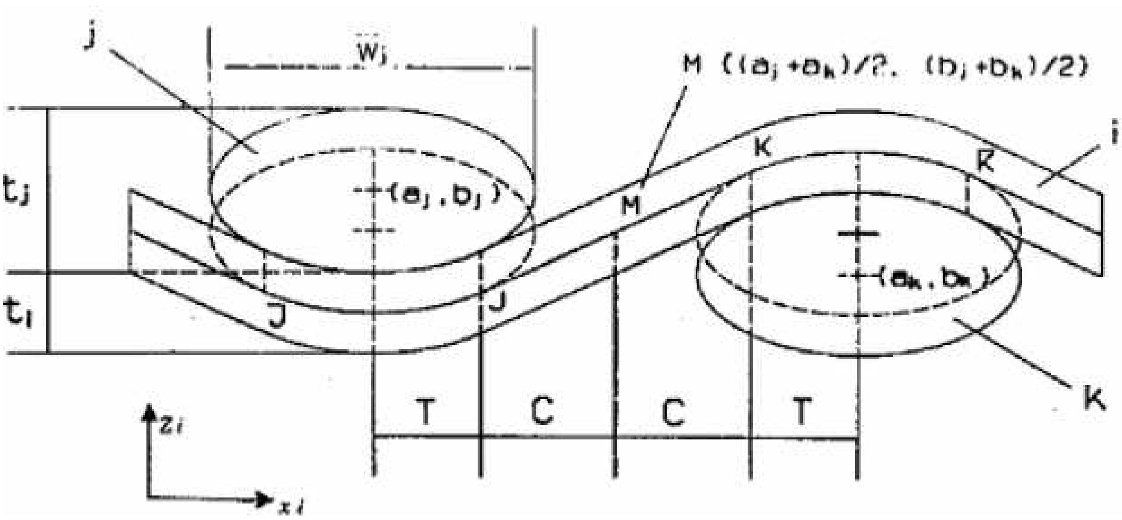

Fig. 7: The geometry proposed by Shang and Shuong [23]

3. APPLICATION OF THE PROPOSED APPROACH

3.1. The Proposed Model

Let's have a concise description of our logical scheme to apply on our modelling approach. Our proposed mathematical model will calculate the parameters of geometry already discussed, from weaving parameters that are traditionally used to describe a fabric.

DATA TO BE ENTERED

- **Weave architecture**
- **Number of warp threads in the unit cell**
- **Number of weft threads in the unit cell**
- **Number of layers of the multilayer structure**
- **Parameters describing the cross section of warp and weft yarns like thickness and width in the case of lenticular yarns**

CALCULATIONS MADE WITH MATHEMATICAL MODEL

- **Number and spatial position of elliptical segments in warp yarn trajectory**
- **Number and spatial position of straight line segments in warp yarn trajectory**
- **Interblock crimp**
- **Interblock displacement**
- **Crimp angle**

Average warp yarn trajectories, and spatial positions of weft blocks

Means for the graphical representation of 3D fabric geometry (VRML Browser)

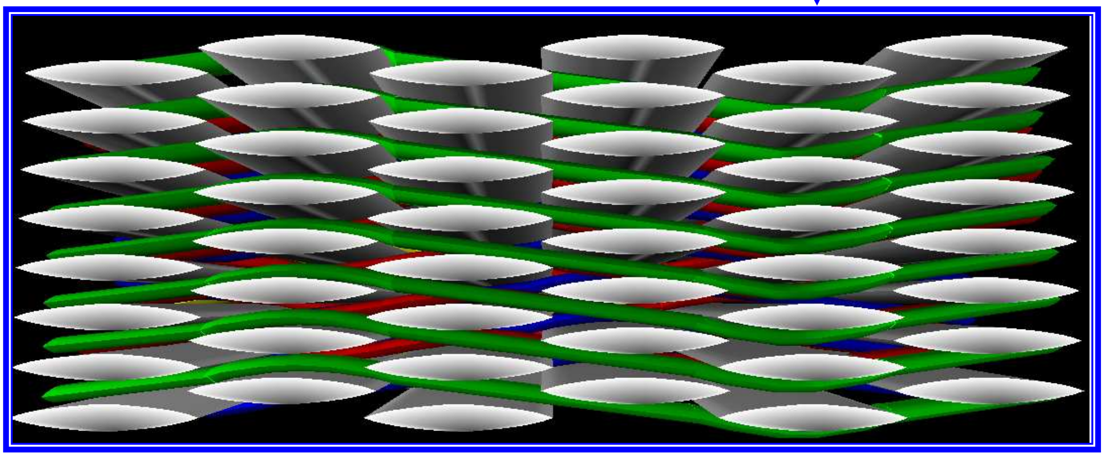

Fig 8: Geometry of 3D Interlock woven fabric structure based on the proposed approach

3.2. Advantages of the Proposed Approach

The approach proposed has following inherent advantages over traditional approaches of modelling geometry.

- One of the great advantages of this approach is that, all the parameters described in this study are related to one geometrical parameter i.e. crimp angle.
- The approach allows us to model nesting of layers and blocks. Traditional approaches give an estimate of the nesting of layers [24]. These approaches generally model nesting in 3D architecture in the same way as in laminated multilayer structures, but the introduction of new notion of block helps us to model nesting of blocks as well.
- The approach proposed allows us to avoid interpenetration of warp and weft yarns as weft yarns behave as a collection of blocks while nesting and these blocks interact in more or less predictable manner. This interpenetration is a complex problem that arises when the traditional approaches of modelling, such as TexGen® [25] [26], are applied to model the 3D architectures (Figure 9).

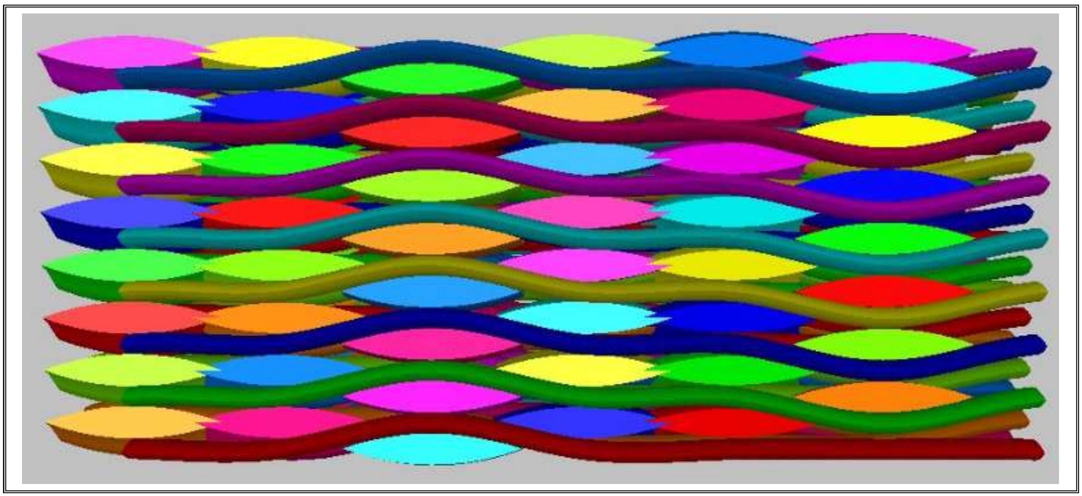

Fig 9: Interpenetrations are viewed in the geometry modelled using TexGen®

3.3. Criticism of the Model

1. It is assumed that the cross sections of warp and weft yarns are constant and undeformed.
2. Maximum Interblock crimp is limited and the ‘theoretical maximum Interblock crimp’ is achieved when the warp yarns are straight and thus the ‘theoretical maximum Interblock crimp for weft yarns can not go beyond the thickness of a warp yarn.
3. It is assumed that the 3D Interlock structures being studied are dense enough and can be safely considered to have stable geometry, in which all the stresses are in mutual equilibrium(thus we are considering stable and relaxed geometry of the structure).
4. The model considers an average constant value of Interblock crimp and Interblock displacement throughout the structure giving rise to the distribution of blocks in wave pattern. As is evident from photomicrograph (Figure 4), Interblock Crimp and Interblock displacement may not be constant.

5. We consider that the blocks of weft yarns move in two axis i.e., in vertical (Interblock crimp) and horizontal (Interblock displacement) directions. Movement in the third axis is not allowed as the structure is dense and stable. Thus warp-weft angle is perpendicular throughout the structure and no shearing is allowed.
6. Weft-weft and warp-warp distance is assumed to remain constant throughout the structure. Infact warp yarns are assumed to lie in parallel planes just touching each other without being deformed.
7. Thus the model under consideration gives the average geometry of the structure with average trajectories of undeformed warp yarns composed of straight and elliptical segments and average configuration of weft yarn blocks in space composed of undeformed weft yarns.

4. CONCLUSION

The approach proposed in this paper, for the geometric modelling of 3D architectures having layer to layer interlock binding is simple and promises further development of the meso structural models for 3D architectures of woven fabrics. The approach efficiently explains the phenomenon of nesting and it was found that the new notions of geometry introduced in this paper are helpful in the modelling of such structures. Further development of the model would include more complex phenomena and properties, such as deformable cross sections of warp and weft yarns, estimation of tension in the warp yarn and its relationship with crimp angle and shearing behaviour of the 3D structure.

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