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MOULDABILITY OF ANGLE INTERLOCK FABRICS

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SUMMARY: Angle interlock structures, also named warp interlock, can be widely used in many composite parts. They can be considered as a 3D multi-layer fabric linked together only with some warp yarns considered as pile yarns like in the velvet structure. Different studies have been performed to demonstrate their properties as the elastic behaviour [1] and the mouldability capacity [2]. This paper tends to better understand the mouldability aspect of an angle interlock structure. A geometrical approach has been applied to understand the different step of the global structure deformation including the filaments distribution inside the yarn and the final shape of yarns. It can be highlight that the inter ply slip and rotation of layers of the 3D fabrics encourage widely the mould property and homogeneous distribution of yarns fitting high bent curves.

KEYWORDS: mouldability property, carbon multi-layer fabric, textile reinforcement, warp interlock structure, geometrical modelling

INTRODUCTION

An increasing interest in 3D woven fabrics can be noticed because these reinforcing fibrous structures meet new requirements in terms of costs reduction with the same level of performance. These new textile materials are designed to be directly mould and produced in a single step closer to the final composite material shape. At the same time, processing techniques such as RTM (Resin Transfer Moulding) allows their use and development.

Multi-layer fabrics are composed of warp, weft and sometimes binding yarns. The yarn stiffness in one set during weaving will influence the bending behaviour of the yarn in the other sets. When two yarns from two sets meet to interlace, it is the flexible one, which bends more. Furthermore, the path of the yarn in the fabric is another factor which controls the yarn bending characteristics [3].
Among all the different 3D fabrics structure, a special focus is directed to warp interlock fabrics, a specific family of multi-layer fabrics. The main spelling warp interlock comes from the fact that

the interlacing yarn linking all the layers of fabrics is oriented in warp direction. Thus, different types of fibre rearrangement can be designed in order to place in the space volume the needed material corresponding to the mechanical constraint. In the main literature [4, 5], warp interlock structure can be divided into three main types:

- orthogonal when Z-yarns go through the whole fabric between only two columns of weft yarns,
- through-the-thickness angle interlock when Z-yarns go through the whole fabric across more than two columns of weft yarns,
- angle interlock when Z-yarns connect separate layers of the fabric

These different interlock types lead to different positions of pile yarns inside the multi-layer fabrics. A mere review of these structures by a geometric description may help to identify the good candidate with respect to the drape behaviour and the mouldability capacity.

REVIEW OF THE DIFFERENT INTERLOCK STRUCTURES

Orthogonal Structure

In Fig. 1, one of an orthogonal-Interlock structure is represented with four warp yarns (ends) which are lying straight inside each weft yarn layers and two ends (they act as the binding yarn) which are passing through the thickness of the fabric to stitch all the layers together. The non constant crimp warp interlock is defined by 2 warp yarns interlacing with 5 weft yarn layers and 4 unidirectional warp yarns.

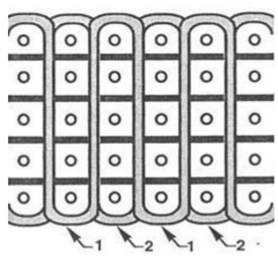


Fig. 1 Orthogonal interlock (4 warps/5 wefts/2 warp “stitching” yarns).

This structure is mainly considered to replace the multi-fabrics stitched together which tend to have the same compactness properties and high compression resistance. This configuration encourages the rigidity of the final structure in the thickness direction and thus would not be a good candidate for the bending and more over for the drape of a complex surface with convex and concave curves.

Through-Thickness Angle Interlock

In Fig. 2, one of the through-thickness angle interlock is represented and made of 9 warp yarns linking with 8 weft yarn layers.

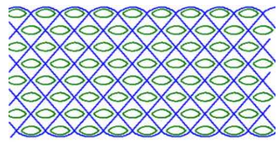


Fig. 2 Constant crimp warp interlock (9 warps/8 wefts).

This type of structure includes a constant value of the warp crimp which can be an important parameter to improve the mouldability. The geometric modelling of a given structure with TexGen© software [6, 7] provides a better understanding of the yarn path of the different warp yarns inside the interlock structure. It can be noticed that this geometric doesn’t integrate the shape deformation of yarns at the crossover points between warp and weft.

Fig. 3 Left: cross-section of the through-thickness angle interlock. Right: 3D modeling view with 9 warp yarns and 8 layers of weft yarns.

During the bending test, the through-the-thickness angle interlock can be easily deformed with high displacement of yarns inside the structure. Thus, the distribution of weft yarns along the thickness of the bent material will not be homogeneous due to the high tension applied on the warp yarns. To reduce the warp tension of all the pile yarns which are linking every plies of the multi-layer fabric, unidirectional warp yarns can be inserted between each layers. In Fig 4, considering one of the through-the-thickness angle interlock, only two crimp values are to be considered, one for the 10 warp yarns interlacing with the 5 weft yarn layers and the other for the 4 unidirectional warp yarns.

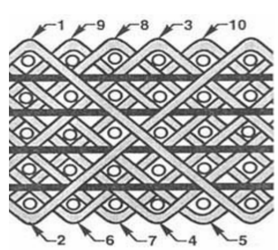
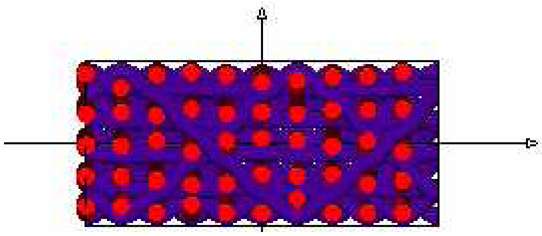


Fig. 4 Non constant crimp warp interlock (10 warp stitching yarns/4 unidirectional warp yarns/5 weft layers).

In Fig. 5, the same kind of non constant crimp warp interlock is used to show the different consumption of warp yarns inside the fabric, obtained with WiseTex© [8, [9]10]. A special focus is directed to yarn path and its shape inside the structure which depends on the type of weave diagram, warp and weft densities and yarns yields. The combination of these parameters leads to different properties in terms of mouldability.



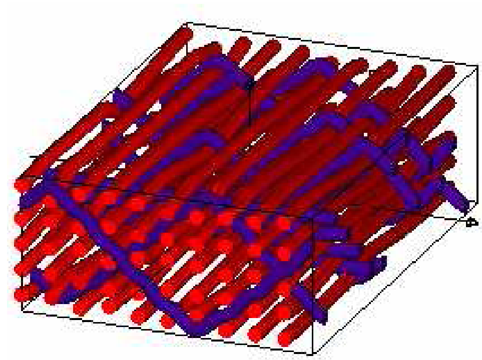
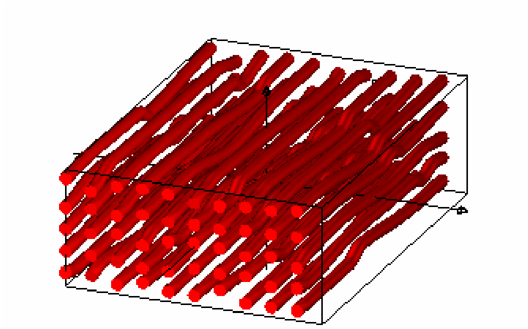


Fig. 5 Left: Cross-sectional view of the interlock fabric. Right: 3D modelling view of the warp and weft yarn paths.

In Fig. 6, the decomposition of the interlock structure on two parts, one for the weft yarns and the deformed shape by the crossover points and the other one with the two types of warp yarns.



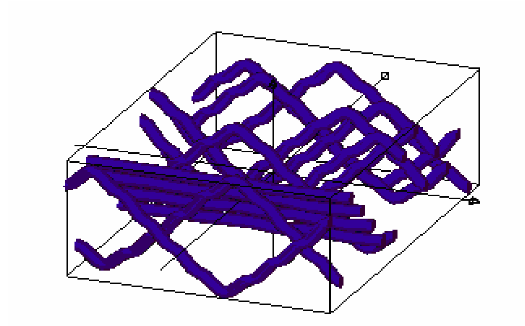


Fig. 6 Left: oblique view of the weft yarns. Right: oblique view of the warp yarns.

Awaiting results on a bending have revealed the difficulty to drape this kind of structure mainly due to the huge difference of warp shrinkage between the unidirectional and interlocking warp yarns. Thus the thickness of the multi-layer is not constant all along a bent curve and thus lead to non homogenous distribution of weft yarns inside the interlock structure.

Angle Interlock

In Fig 7, the warp interlock is composed of 16 warp yarns and 8 weft yarn layers. The 16 warp yarns can be divided into two groups of 8 threads involving one crimp value for the top (respectively bottom) of the fabric and another value for all seven remaining yarns. It can be shown that this specific structure is closer to a multi-layer construction of plain weave fabrics linked side by side. This angle interlock structure seems to be the good candidate material as a compromise between the drape capability and the yarns distribution inside the structure to ensure a constant value of the thickness.

DESCRIPTION OF THE GEOMETRIC APPROACH

The main goal of the study lies in the better understanding of the fabric behaviour as regards the mouldability of the multi-layer structure. At the first sight, it can be noticed that the mouldability of woven fabrics depends mainly on fabric shear rigidity. However, it can be assumed that the deformation mechanisms which occurred at the mesoscopic scale could affect the shape of the yarn at a macro scale, which means a certain capacity to be deformed in order to improve the final drape of the material. Assuming this phenomenon, the yarn shape modification can lead to a local re-arrangement of the filaments distribution at a micro scale.

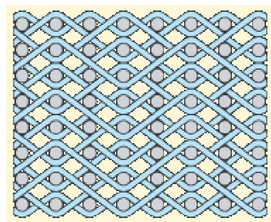


Fig. 7 Non constant crimp warp interlock 2 x (1+7) warps / 8 wefts.

Mouldability Criterion

At present, there is no standard test method for the mouldability of woven fabrics. Thus, there is not a clear definition of the mouldability of a fabric. The drape method, which consists in the measurement of a certain angle between the straight part of the fabric and the bent part under its own weight, is often considered as a mouldability test. It means that the only value interesting to measure is the internal shear resistance of the material without taking into account the shape deformation of yarns due to some compression and tensile internal constraints. In a sense, the mouldability criterion can be considered as the capacity to a material to fit or to "glue" the largest surface of material on the mould with different types of complex curves by optimizing a homogenous distribution of yarns reinforcement of the multi-layer fabric.

Geometrical Approach

Having defined a mouldability criterion, the geometric approach proposed in this paper tends to identify the behaviour laws of the interlock fabric interacting at different scales. Thanks to these laws, it can be helpful to design new interlock structure to optimize the mouldability criterion and then find local optimum with respect to the fabric parameters. In Fig. 8, the geometric is exposed into different steps.

First, the interlock fabric is deformed under a constant constraint in a static mode. At each determined position, one block of the dry material is fixed with a resin and different slices of the structure are produced to be observed. Measurements are achieved with the different parameters as the length and the diameter shape of yarns. Second, all these slices are observed at different scale to understand the deformation of yarn and filaments re-arrangement. At final, a statistical treatment of the data helps to determine the average rules of material behaviour and also the correlation between the interlock fabric deformation and the yarns paths, also the yarns shape and the filaments distribution.

MOULDABILITY RESULTS

An angle interlock fabric with 8 layers of warp and weft yarns has been used to produce structure slices to be observed. This multi-layer fabric has been performed on a specific weaving loom equipped to handle carbon fibres with multi warp beams. The same carbon yarn of 8k filaments is used in the warp and weft directions.

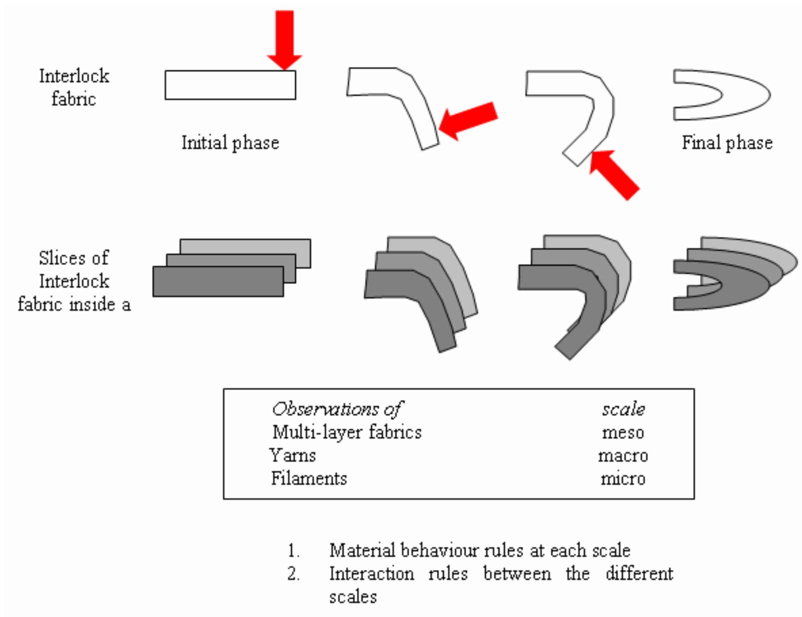


Fig. 8 Geometric approach of interlock fabric modelling.

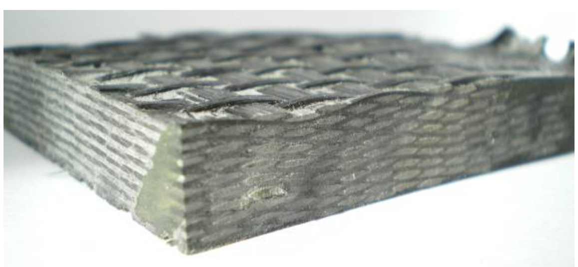


Fig. 9 Angle interlock of carbon fibres.

In Fig. 10, the first slice of the non-deformed angle interlock shows the path of all the 8 warp yarns and it can be distinguished alternatively by the column of 8 (red colour) or 9 (blue colour) weft yarns. The elliptic shapes of the multi-filament carbon fibres are quite conserved for all the layers, corresponding to a good quality of production as regards the constant value of the warp and weft tension.

In Fig. 11, the angle interlock is straight with no constraint and different measurements are done as the average spaces between the different columns of weft yarns and the exact dimension of all weft yarns (elliptic shape).

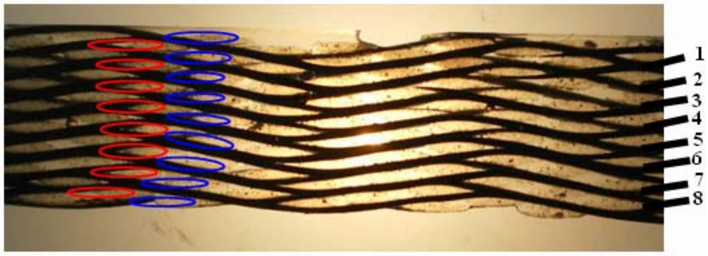


Fig. 10 Slice of angle interlock with 8 warp yarns and alternatively 8 and 9 weft yarns.

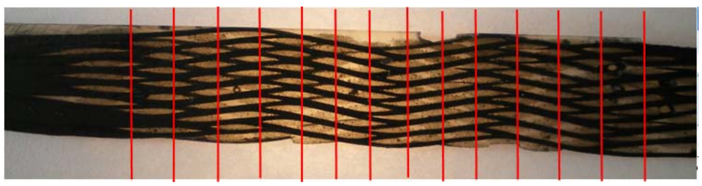


Fig. 11 Initial phase and localization of column of weft yarns layers.

In Fig. 12, the angle interlock is deformed to a given position and the same measurements are achieved and stored to be compute later to recover the dynamic rule of deformation at each scales (meso and macro). Only some yarns are selected to observe theirs filaments distributions at the micro-scale in order to avoid huge time consumption.

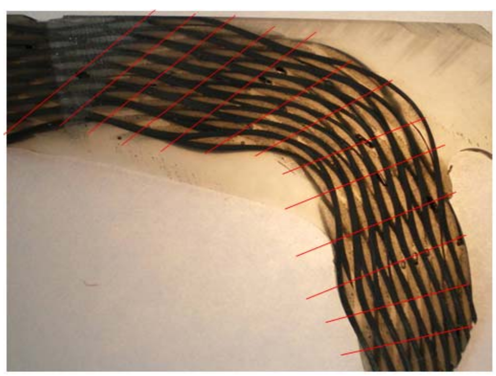


Fig. 12 Intermediate phase of observation of angle interlock fabric.

In Fig. 13, it can be noticed the difference of paths between the warp yarn due to the inner shear of the total structure and the different tension resulting from the inter-ply slip mode.

In Fig. 14, the angle interlock structure has reached its final position and the maximum value is obtained for the inter-ply slip motion, yarn shape deformation and its filaments re-arrangement.

In Fig.15, the distribution of carbon filaments inside a given yarn is observed at different deformed position of the angle interlock fabric. In the left picture, the tensile of the warp yarns leads to a curve where the distribution of filaments allows a certain number of “holes” with different sizes. On the contrary, the right picture shows the same yarn with a closer distribution of filaments inside. Thanks to a statistical treatment of data, given by the filaments distribution of different weft yarns into a precise location of the different phase of the angle interlock fabric, it will be possible to recover the average value of empty space comparing to the space occupied by all the filaments for a given shape (also necessary to well determined its boundaries). Thus, a distribution rule can be given which helps to fast compute the final shape of each yarn and recover their estimated positions to give the final shape of the angle interlock fabric model.

Fig. 13 Intermediate phase of angle interlock deformation.

Fig. 14 Final phase of the total deformation of angle interlock.

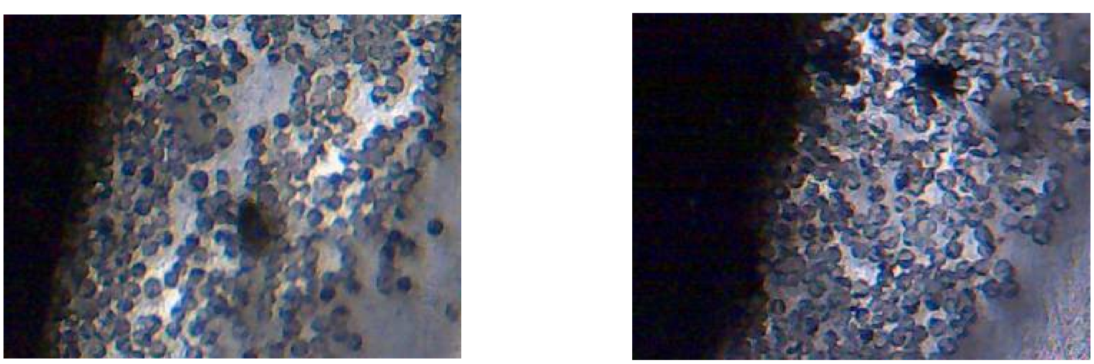


Fig. 15 Microscopic scale observation of one weft yarn inside the fabric and the different distributions of filaments: left, cross-section for the last intermediate position of angle interlock; right: cross-section of the same yarn for the final position.

Considering the elementary volume reference to observe, the proposed geometric approach requires a great number of samples in order to give more data points for the behaviour rules of the angle interlock fabric. The precision of these rules depends directly on the number of deformed shape of the multi-layer structure. Thus, experiments on this angle interlock are still in progress, but the number of measurements is not yet large enough for satisfactory statistical analysis.

CONCLUSION

Every material, made with fibres reinforcement, can be mould inside a composite according to the shape and the process used. Thus, the only interest to measure a mouldability index is to classify the material on a scale where it can be range from the easy-to-mould to the hard-to-mould values. The proposed geometric approach of this paper attempts to understand the multi layer fabric (meso-scale) deformation effects on the yarn shapes (macro scale) inside the structure which contribute to its filaments re-arrangement (micro scale). The angle interlock chosen helps to keep the same thickness of all the structure from the initial to the final phases. Weft yarns columns, corresponding to the total number of layers, have been widely deformed to ensure the inter ply slip of layers. However, the slicing process is time consuming and no sufficient measurements are available to safely engage a statistical data analysis. In the future works, the samples slicing step could be replace by a 3D scanner of angle interlock to improve the data acquisition of all the parameters of the angle interlock fabric.

REFERENCES

1 Byun J H, Chou T W., “Elastic Properties of Three-Dimensional Angle Interlock Fabric Preform”, *Journal of the Textile institute*, 81(4), pp 538-548, 1990.

2 Chen X., Lo W.-Y., Tayyar A.E., Day R.J., “Mouldability of Angle-Interlock Woven Fabrics for Technical Applications”, *Textile Research Journal*, 72, pp 195-200, 2002.

3 Gu H., Zhili Z., “Tensile Behavior of 3D Woven Composites by Using Different Fabric Structures”, *Materials and Design*, 23, pp 671–674, 2002.

4 Boussu F., Legrand X., Serret A., “General Clustering of Warp Interlock Structures”, *1st International Conference – Intelligent Textiles and Mass Customization, ITMC*, Casablanca, Morocco, pp 83-90, November 15 – 17, 2007.

5 Hearle J.W.S, Chen X., “Orthogonal Structure and Angle-Interlock Structure”, TexEng Software Ltd, http://www.texeng.co.uk/index.php, last access on April 20th 2008.

6 Sherburn M., “TexGen Software v3”, http://texgen.sourceforge.net/index.php/Main_Page, last access on April 26th 2008.

7 Sherburn M., “Geometric and Mechanical Modelling of Textiles”, Ph.D Thesis submitted to The University of Nottingham for the degree of Doctor of Philosophy, July 2007.

8 Lomov S.V., Gusakov A.V., Huysmans G., “Textile Geometry Pre-processor for Meso-Mechanical Models of Woven Composites”, *Composites Science and Technology*, 60(11), pp 2083–2095, 2000.

9 Lomov S.V., Huysmans G., Luo Y., “Textile Composites: Modelling Strategies”, *Composites (Part A)*, 32(10), pp 1379–1394, 2001.