MESO-FE MODELS OF TIGHT 3D WOVEN STRUCTURES

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Abstract

The aim of this work is to produce a realistic description of fabric topology and internal geometry of two warp interlock 3D textile architectures: orthogonal interlock/through-thickness (O/T) and angle interlock/through-thickness (A/T). The solid models are intended for finite element simulations of fabric behaviour. The first step in modelling is approximate description of geometry provided by the WiseTex tool, which reproduces fabric topology and position of warp/weft/Z-yarn families, but does not account for the lateral interactions of the warp yarns in tight fabrics and variation of cross-section shape along the yarn midlines. The initial model is then processed to create solid models with non-intersecting yarn volumes and to tune parameters for correspondence with real micro geometry.

1 Introduction

The challenges and solutions of modelling three-dimensional (3D) woven fabrics and reinforced composites have been described in [1]. The current paper illustrates one of the possible paths for generation models on examples of two dense weave architectures.

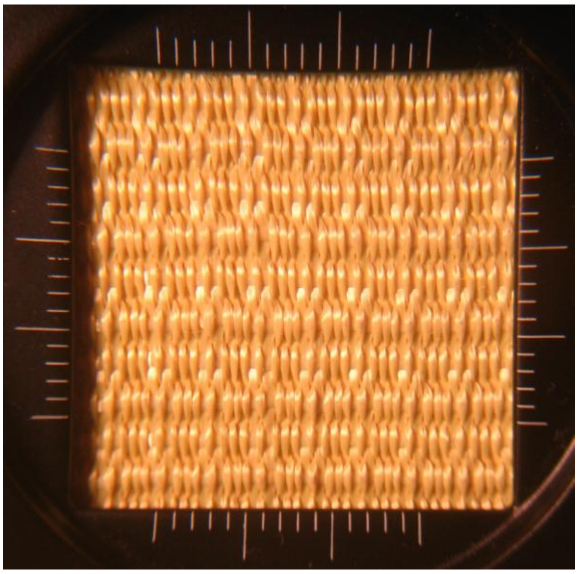
Textile topology and geometry is coded in WiseTex geometric preprocessor [2], which is based on the energy optimisation of a system of interacting yarns. Yarn pattern, spacing, cross-section dimensions enter the software as input data. The model presents yarn as a midline path and a set of cross-sections “stringed” onto the path in the plane normal to the path direction. The key assumptions and simplifications of WiseTex are: (1) constant cross-section shape and (2) interaction of orthogonal yarns of the same layer at their crossovers. These assumptions lead to the following limitations: lateral interactions of the warp yarns in tight fabrics are not taken into account; nesting of a fabric cannot be modeled. In the case of a tight fabric, yarns can penetrate through several layers of the other yarns and/or to be squeezed in between the yarns of the same direction. To match realistic thickness and areal density, one needs to construct a model with either overestimated fabric thickness or with an intersection of yarn volumes. Hence, there is a need for operation of the yarn volumes to approach a realistic and non-contradictory 3D geometry.

The following procedure has been used for solid modelling of the 3D tight fabrics:

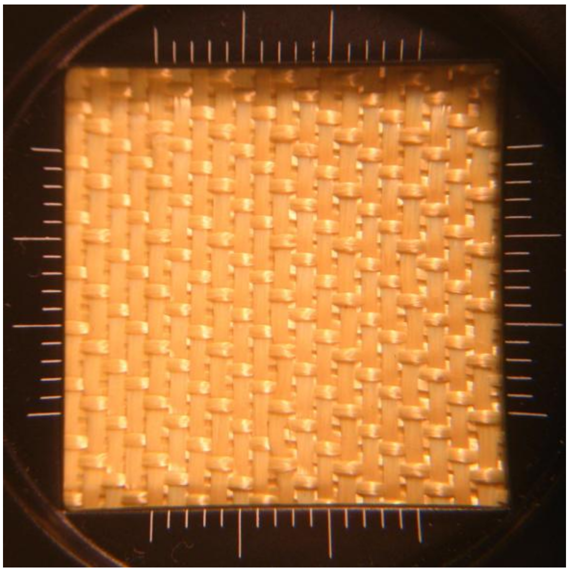
- WiseTex model is built based on parameters of yarn width, yarn spacing, and unit cell dimensions measured on the surface of a fabric.
- The intersections of the yarns are detected by an automatic algorithm. Then internal fabric geometry is operated and tuned to exclude these intersections.

2 Topology and geometry of interlock textile structures with WiseTex software

Various 3D fabrics are candidates for use as polymer composite reinforcements. In this paper two warp interlock 3D textile structures designed in ENSAIT [3] are investigated: orthogonal interlock/through-thickness (O/T) and angle interlock/through-thickness (A/T). The out-of-plane views of fabric are shown in Figure 1.



a)



b)

Figure 1. a)**:**Orthogonal interlock/through-thickness (O/T) fabric;

b): **A**ngle interlock/through-thickness (A/T) fabric.

The basic parameters of the two 3D woven fabrics specified by manufacturer are given in Table 1.

	O/T fabric	**A/T fabric**
Yarn type	Twaron1000	Twaron2000
Linear density	840dTex	1100dTex
Warp, yarns/cm	54	60
Weft, yarns/cm	18	38
Areal density, g/m^2	~720	~1180

Table 1. Parameters of the 3D fabrics

2.1 WiseTex model of O/T fabric

In the O/T fabric (also called “pseudoorthogonal”) 5 layers of weft yarns are stacked in the regular periodic order. Warp through-the-thickness Z-yarns envelopes the upper yarn of the first weft column and dives under the bottom weft yarn of the next column. The neighbouring Z-yarn is shifted by half period in the warp direction. Every couple of the Z-yarns is suppressed by two “straight” non-interlaced warp yarns (S-yarns) on both the sides. The columns of two S-yarns are inserted either between the top three weft yarns, or between the bottom three ones. The 3-D image of WiseTex model of O/T fabric is shown in Figure 2.

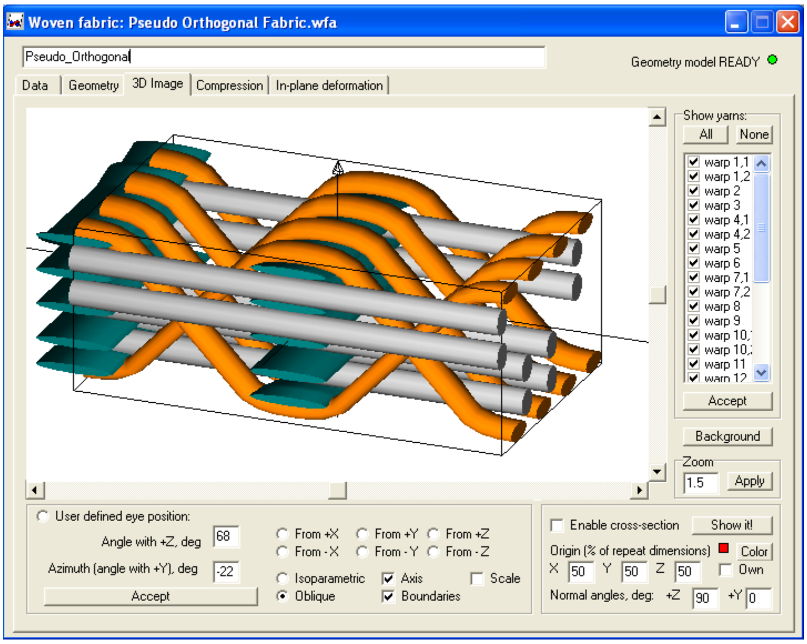


Figure 2. 3-D image for the WiseTex model of orthogonal/through-thickness (O/T) fabric. Orange – for warp Z-yarns, grey – "straight" warp yarns, green – weft yarns.

2.2 WiseTex model of A/T fabric

The WiseTex model of the fabric is shown in Figure 3.

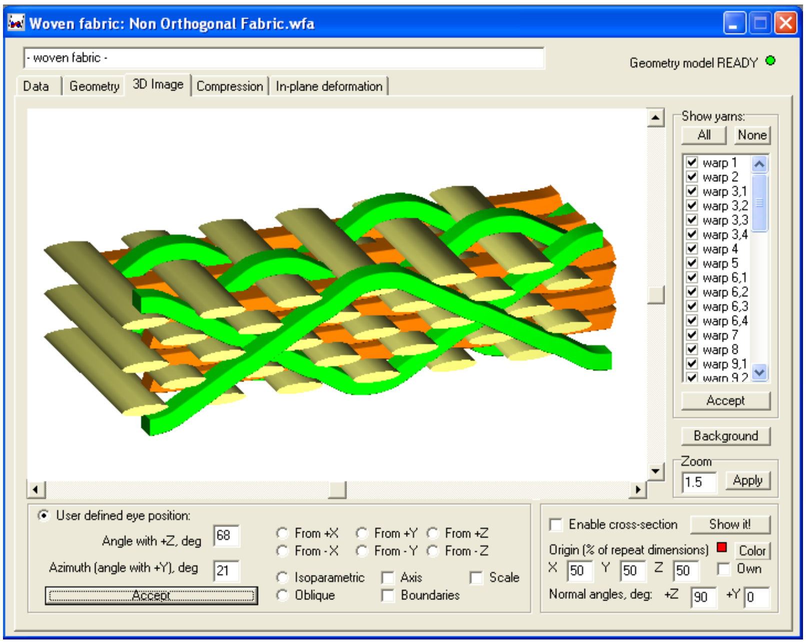


Figure 3. WiseTex model of A/T fabric; warp Z-yarns (green), warp S-yarns (orange) weft yarns (yellow).

In the A/T fabric 5 layers of weft yarns are grouped in two columns. The first group consists of three yarns placed one on top of the other. The other two yarns are placed between them in z-direction and shifted in the warp direction to half a distance between the weft yarns of the same layer – see Figure 3. Warp through-the-thickness Z-yarn envelopes the upper yarn, passes through the shifted yarns and dives under the bottom weft yarn of the fourth outer weft column. Each two Z-yarns are followed by the column of 4 non-interlacing S- yarns. The unit cell of the considered fabric has 6 Z-yarns, 12 S-yarns and 30 weft yarns. Unlike the O/T fabric, the A/T one does not exhibit internal mirror symmetry. The fabric is denser than the previous one.

3 Microstructural analysis of interlock textile structure geometry

3.1 Microstructural analysis of O/T fabric

For microstructural analysis the fabric samples have been impregnated by an epoxy resin. The cross-sections have been made perpendicular to the weft and the warp directions of a fabric. This cross-sections have been examined with optical microscope. Typical cross-sections are shown in Figures 4–6. The yarn contours on these images are highlighted because of the poor contrast. Analysis of the fabric structures has shown that for some yarns there is an essential side crimp and/or changing of the yarn cross-section shape along the yarn length. The Z-yarns are compressed laterally inside the fabrics due to the specifics of the manufacturing process – Figure 4.

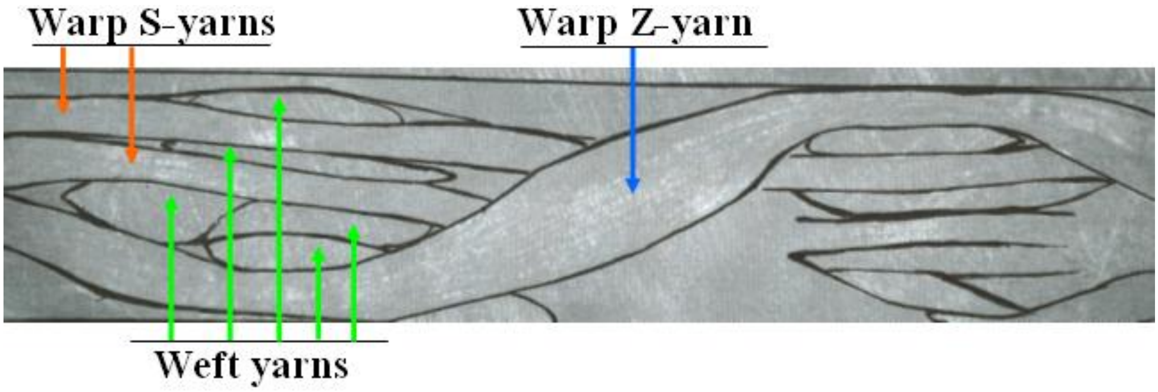


Figure 4. Cross-section of O/T fabric along the warp yarns. The figure shows strong lateral compression of the Z-yarn at the location where two Z-yarns meet.

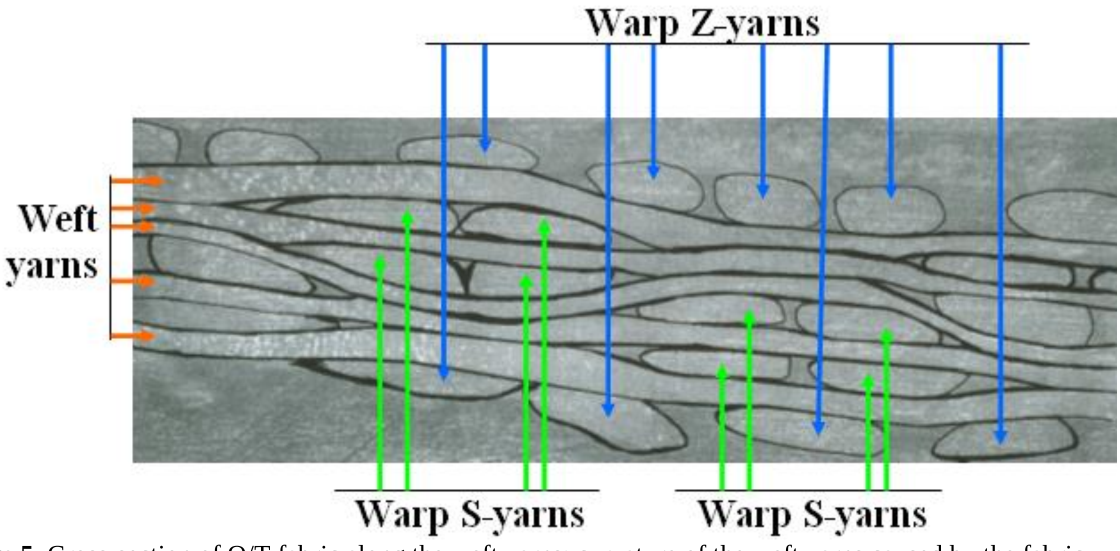


Figure 5. Cross-section of O/T fabric along the weft yarns: curvature of the weft yarns caused by the fabric nesting.

There are two fundamental geometrical factors that WiseTex cannot handle:

(1) Every column of the straight warps counts only 2 yarns, whereas every weft column contains 5 yarns. Thus, there is a local misbalance in the architecture.

(2) Tension applied to the Z-yarns squeezes the structure and forces the "straight" S-warp yarns to bend and to rest upon the yarns of another layer – see Figure 5. This nesting of the fabric occurs at the locations where the other warp layers are missing. The nesting strongly decreases the fabric thickness in comparison with a theoretical configuration where the non-interlaced warp yarns are assumed to be straight.

(3) The straight warp yarns squeeze the Z-warps across their direction – Figure 6. Hence, at the location where two Z-yarns meet each other their lateral dimensions are strongly reduced. On the contrary, the local thickness of the yarn exceeds the yarn width at the surface.

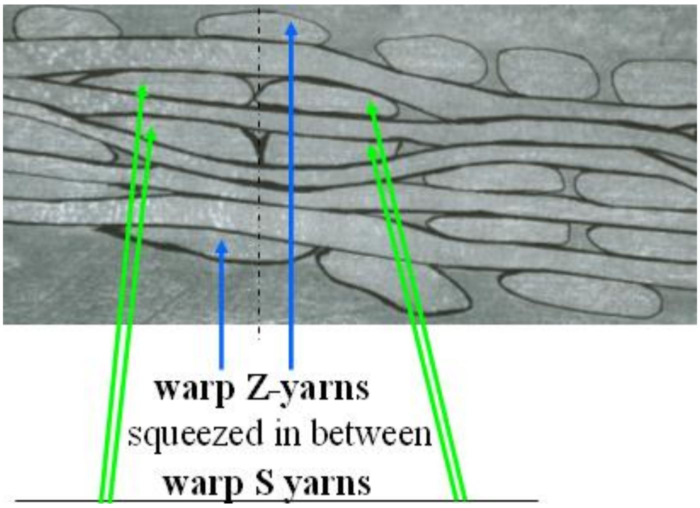


Figure 6. Cross-section of O/T fabric along the weft yarns: columns of "straight"/non-interlaced warp yarns (S-yarns) come together locking the space for the two Z-yarns running in between the columns..

3.2 Microstructural analysis of A/T fabric

The cross-sections of the fabric reveal the following:

1. Unlike the case of the orthogonal textile, both the S-warp and the weft yarns appear to be relatively straight – see Figures 7–8. A low crimp is present as local regular fluctuations of the yarn path. The fabric nesting is much less pronounced than in the previous case.
2. The Z-warp yarns are less squeezed, because they are constrained by the columns of the shifted weft yarns.
3. There is a pronounced side crimp of the Z-yarns: the neighbouring yarns nearly interweave around each other due to the peculiarities of the weaving process – Figure 8.
4. A warp yarn cross-section can be well approximated by a stadium shape, whereas the weft yarn cross-section can be better described by an elliptical shape.

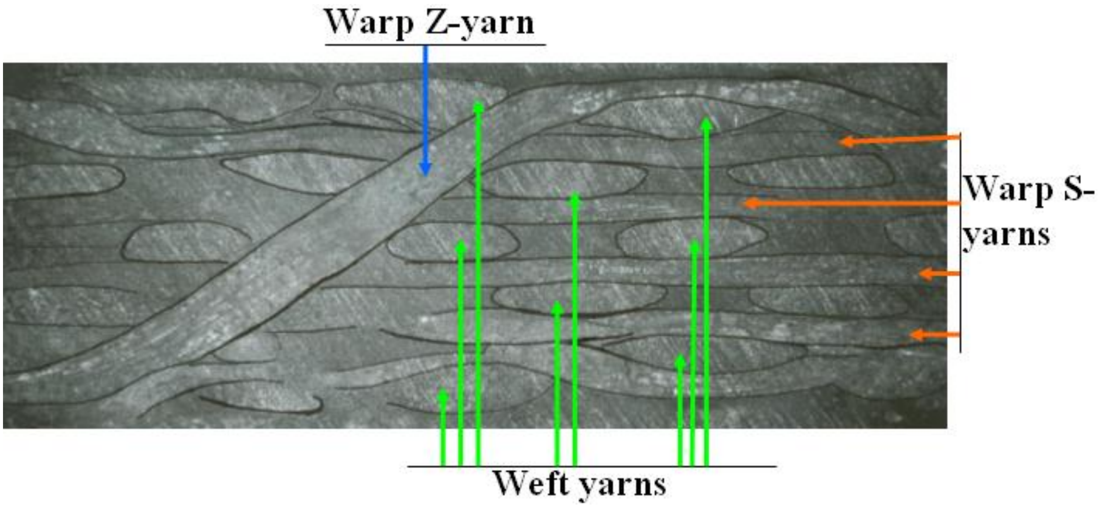


Figure 7. Cross-section of the A/T fabric: view in the warp direction

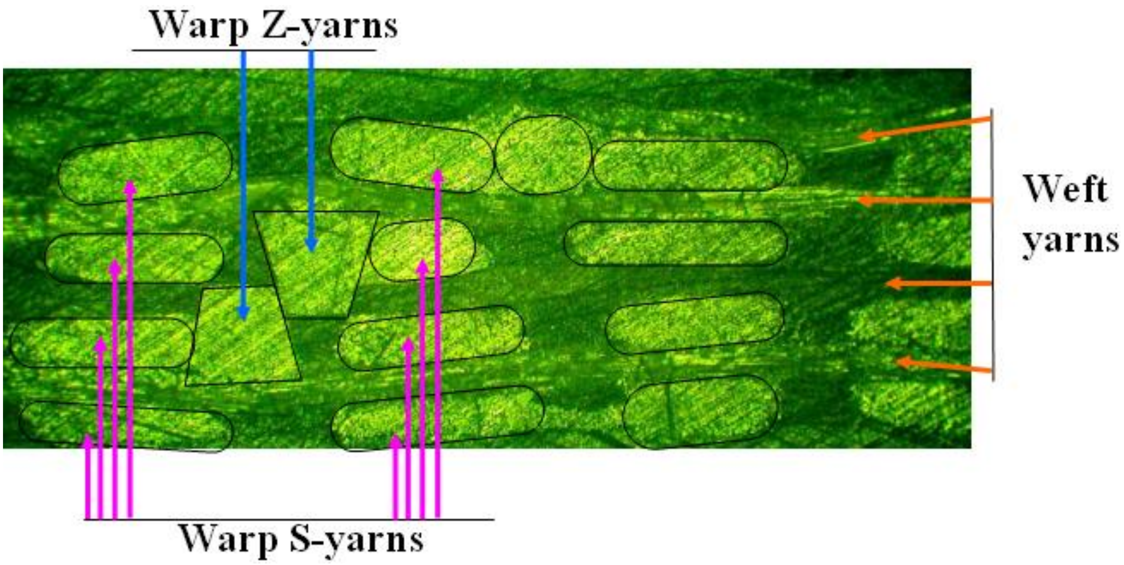


Figure 8. Cross-section of A/T fabric. View in the weft direction. Yarn highlighting approximates yarn shapes with simple geometrical primitives: stadiums and trapeziums.

4 Examples of interlock textile solid models

An efficient modelling approach demands a set of simplifications and assumptions on the yarn interaction, variation of the cross-section shapes and the yarn path. These assumptions should both preserve the basic features of the fabrics and keep the model simple enough. The main challenges are to create a model (1) with an appropriate thickness, (2) with non-excessive fibre volume fraction in yarns, (3) fitting to the unit cell box, (4) with regular mesh, which should preferably be coarse as requested for the computationally heavy impact modelling, (5) with non-intersecting volumes.

The developed routines are used to transform the initial geometric primitives supplied by WiseTex to a non-contradictory geometry. The yarn surgery is performed in a semi-automated fashion. The main features of the fabric are recorded from the cross-section (such as basic yarn shapes, side crimp, lateral contact features), parameterized and expressed as functions of the yarn spacing, yarn dimensions and location within the fabric unit cell. Hence a different fabric with the same topology can be created automatically. The main operations used for the surgery are:

- Introduction of the side crimp of the yarns. Yarn cross-sections are shifted in the lateral direction if an intersection is detected. This creates local deviations of the yarn path.
- Changing of the yarn cross-section size and orientation. This includes: (a) creating lateral squeezing and vertical spreading of the yarns based on the space available within the unit cell; (b) spreading the yarns at the unit cell surface to reduce the fabric thickness in a way that the top yarn surface remains flat. During these operations the area of the cross-section is preserved so that the fibre volume fraction remains realistic.
- Correction of the yarn path by means of analytical functions. To handle the tangent intersections at the crossovers, the yarn path and orientation of the cross-section in the enveloping yarn are calculated analytically. The resultant cross-sections do not intersect the elliptical boundary of the orthogonal yarns. The procedure also allows to introduce a gap between the yarns if necessary.
- Inserting additional cross-sections to smooth the path trajectory at highly curved locations.

The obtained geometry model is fitted into a unit cell box. The local fiber coordinate systems are created with respect to corrections of yarn paths.

An example of the simplified solid model of O/T fabric built in ANSYS software after processing in MatLAB software is shown in Figure 9. The resultant model does not have any interpenetration, it realistically reproduces the shape of the warp yarns, and it keeps the original thickness inherited from the WiseTEX model. The main drawback of the model is the absence of crimp in the weft yarns and, consequently, absence of nesting in the fabric. Introducing the nesting can further improve the model and result in a more realistic thickness of the textile. Another possible approach is to compress the obtained model in a contact problem, which will automatically adjust the appropriate thickness and yarn configuration.

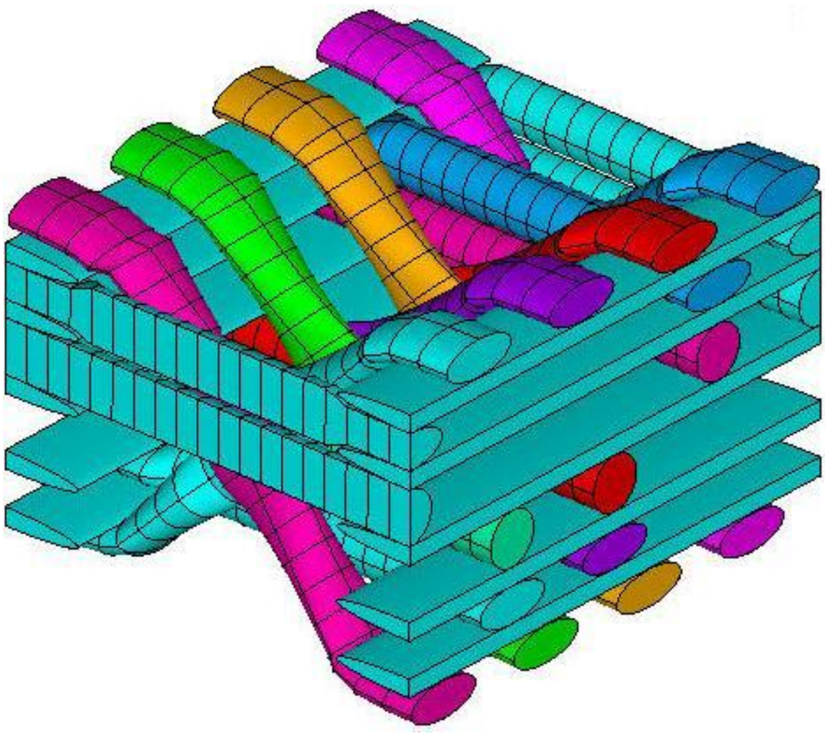


Figure 9. The solid model of O/T fabric obtained on the base of WiseTex model and additional volume processing:

An example of the simplified solid model of A/T fabric built in ANSYS software after processing in MatLAB software is shown in Figure 10. Despite the operations, the obtained model still have a minor excessive thickness (within 5% of the actual one). However the designed models can be used for further simulation of fabric compression or subjected to more complex geometrical considerations.

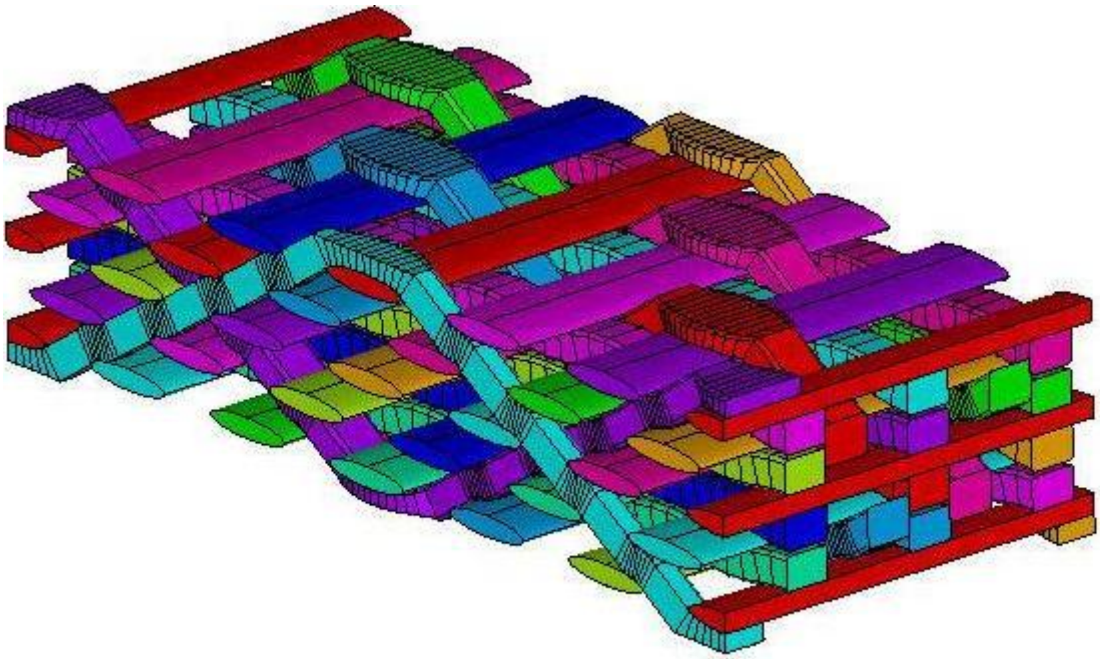


Figure 10. A result of solid modelling of the A/T fabric.

5 Conclusions

Two different configurations of fabrics have been modelled via WiseTex geometric tool and additional processing of the raw geometrical data to create solid models of complex fabric configurations. The developed for solid modelling routines complement the WiseTex tool.

The high diversity of the yarn configuration creates difficulty for constructing a model with regular geometric primitives (such as the cross-section shape). However, it is very important to create the simple models of the fabric for it ensures a computational efficiency (coarse mesh) and easy handling of the unit cell model.

The assumption on regular shapes of the yarns and simplified yarn path may result in the excessive thickness of the fabric. This drawback can be either naturally handled in the simulation of the fabric compression, or subjected to more complex geometrical considerations if necessary.

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