ANALYSES OF THE DRAPABILITY OF BIAXIAL REINFORCED WEFT-KNITTED FABRICS BY MEANS OF FEM MESO-SCALE MODELS

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ABSTRACT

The bending and shearing properties have a major influence on the drapability of 2D fabrics while forming 3D preforms for composites. The bending and shearing behaviour are dependent on the yarn bending stiffness, the interaction between the yarn systems, and the density of the yarn systems in the textile structure. Weft-knitted fabrics are known for their excellent drapability due to their internal structure. Meso-scale models of two biaxial reinforced weft-knitted fabrics with different configurations of the yarn systems are used to predict the forming behaviour of the fabrics. Results show an excellent agreement of the simulations compared to experimental trials, thus, making the model a valid tool for further analyses of the preforms.

Key Words: composite, draping, finite element method, meso-scale model, weft-knitted fabric

1. INTRODUCTION

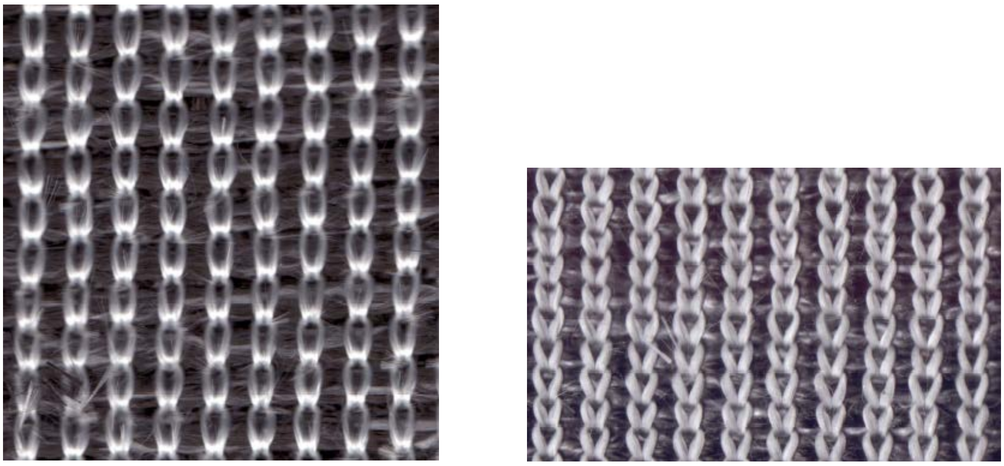
In the composite production process, the forming of 3D preforms plays a decisive role on the quality of the final component. Wrinkling is one of the most frequently occurring defects during the forming process. Drapability is defined as the ability of 2D fabrics to be deep drawn into 3D preforms without developing wrinkles. Many researchers focused on investigating the influence of bending and shear behaviour on the wrinkle formation [1-3]. In the classical shell theories, the in-plane tensile and bending characteristics are coupled [4]. But due to the fibrous architecture, the classical shell theories cannot be applied to fabrics, because the textile material has a significant smaller bending stiffness in comparison to other continuum materials with similar tensile strength, such as metals. Döbrich et al. [5] introduced a method to describe the mechanical behaviour of textiles correctly by decoupling the bending and the membrane properties of finite shell elements. In a recent development, a meso-scale model based on beam element was introduced to describe the structure of biaxial reinforced weft-knitted fabrics [6]. The mechanical behaviour of the whole structure during forming process can be simulated by a separate description of tensile strength, bending rigidity, and friction of the beam elements, which are used to model the knitting and reinforcing yarns.
Biaxial reinforced weft-knitted fabrics consist of two reinforcing yarn systems (in warp and weft direction) and a knitting yarn system, which fixes the two reinforcing yarn systems in the structure. The loop length of the knitting yarn system is the main factor influencing the magnitude of interaction between the three yarn systems. Therefore, the loop length affects bending and shear properties of the whole textile structure. Thanks to the adjustment of the knitting parameter, the loop length could be configured to meet the targeted application. However, this adjustment requires enormous time by using trial-and-error methods. Fabrics have to be produced and tested to assure they meet the requirements. Therefore, a numerical approach will significantly reduce the development time. In this paper, the mechanical behaviour of the biaxial reinforced weft-knitted fabrics is further investigated. Two fabric variants are produced, tested and modelled exhibiting different loop length and density of the reinforcing yarns.

2. MATERIAL AND TESTING

The reinforcing yarns are commingling hybrid yarns from carbon fiber 300 tex (CF) and polyamide 6.6 fiber 94 tex (PA 6.6). The knitting yarn are folded from glass fiber 2 x 68 tex (GF) and PA 6.6 94 tex. The production of the biaxial reinforced weft-knitted fabrics were carried out on a modified flat knitting machine. The configuration of two variants of the biaxial reinforced weft-knitted fabrics are shown in Table 1. The right sides of the two fabric variants are shown in Figure 1. The bending of the fabrics was tested on a cantilever machine (Figure 2a) according to the standard DIN 53362 [7]. The results of cantilever test are shown in Table 2. The shearing resistance was tested on a tensile machine with a picture frame of 200 x 200 mm (Figure 2b). The force-displacement data of the machine was recorded and a 3D scanner (Artec Eva 3D) was used to scan the surface of the textile at the end of the test.

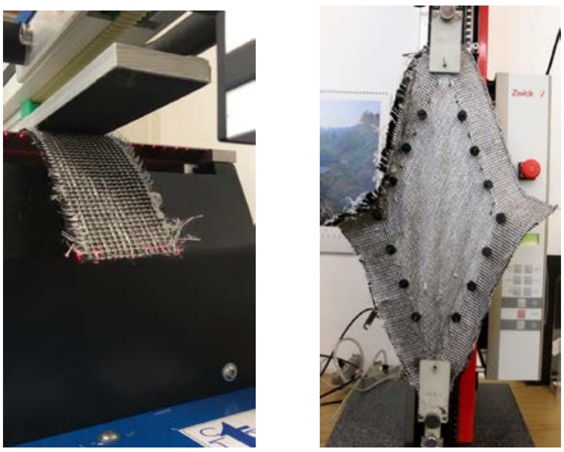
Table 1. Configuration of the two fabric variants

Variant	Warp yarn density [yarn/100mm]	Weft yarn density [yarn/100mm]	Loop length [mm]	Thickness of fabrics [mm]
1	28	28	14,4	2.22 ± 0.08
2	28	41	13,4	2.63 ± 0.15



(a) (b)

Figure 1. Right side of two fabric variants with 10 warp and 10 weft reinforcing yarns on the same scale: (a) Variant 1 (b) Variant 2



(a) (b)

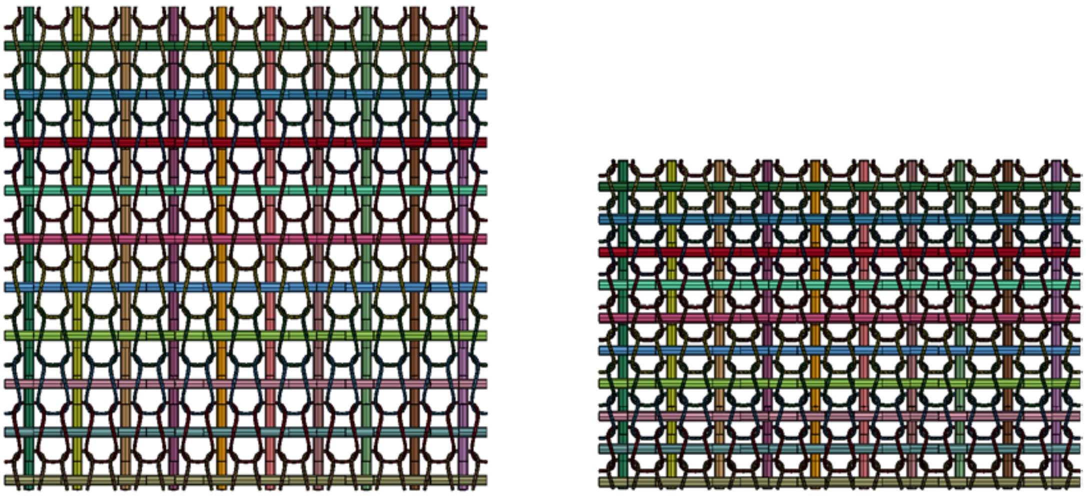
Figure 2. (a) Cantilever test machine (b) Tensile machine with picture frame 200 x 200mm

Table 2. Overhang length of the two fabric variants according to DIN 53362

	Warp direction right side	**Warp direction left side**	**Weft direction right side**	**Weft direction left side**
Variant 1	219 mm	124 mm	137 mm	165 mm
Variant 2	190 mm	164 mm	191 mm	199 mm

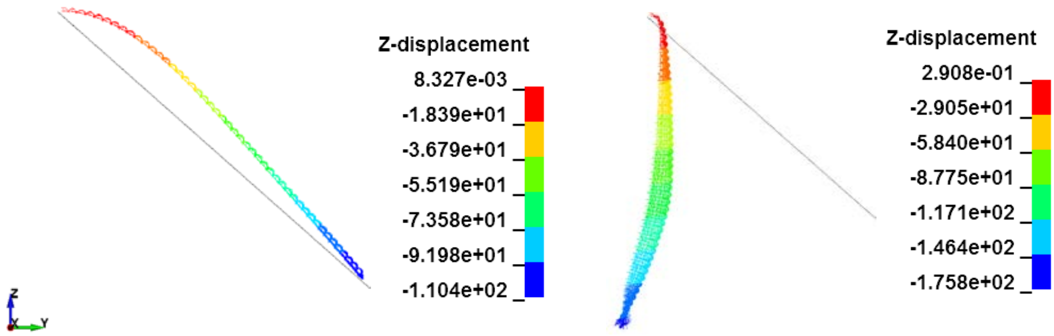
3. MODELLING AND SIMULATION

The modelling method of the biaxial reinforced weft-knitted fabrics was presented earlier [6]. A chain of beam elements are used to represent for the yarn. This simplification allows to investigate further phenomena such as interaction between yarns in structure, yarn slippage, gap formation at a reasonable cost. However, the contact accuracy is suffered due to the assumption that yarn cross-section is round and incompressible.
The results gained while making use of the model with the fabric parameters according to Table 1 are shown in Figure 3. These models agreed well with the optical comparison of the real fabrics presented in Figure 1. The bending stiffness of the textile model was calibrated through setting the bending stiffness of the beam element and validated by a simulation of the cantilever bending test as shown in Figure 4. As the used weft knitted fabrics exhibits an unsymmetrical layup, the bending stiffness is different on each side of the fabrics At the other hand, the contact force between knitting yarns and reinforcing yarns also contribute to a difference of bending stiffness along each direction of reinforcing yarns. By manipulating the bending stiffness of the current models, only the difference of bending stiffness in each direction of reinforcing yarn can be simulated. Due to the simplification of the yarn cross-section, the influence of the fabric side cannot be taken into account. The wrinkling behaviour of textile under compression stress agrees with the conclusion of Boisse et al. [2], namely the size of the wrinkles increases along with the bending rigidity as shown in Figure 5 and Figure 6. The results from the picture frame test simulation also agree very well with the scanned data during the experiment. The wrinkle size in the experiment and simulation are compared in Figure 7 and Figure 8. The shear resistance of the fabric models were calibrated through the friction parameter between beam elements. However, due the simplification of the yarn cross-section, a perfect agreement between simulation and experiment is hard to achieve as shown in Figure 9.



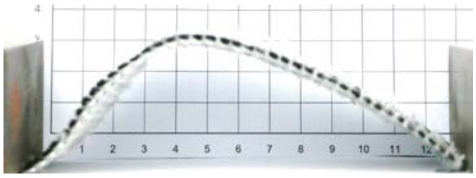
(a) (b)

Figure 3. Comparison of the meso-scale models of the two fabric variants: (a) Variant 1 (b) Variant 2

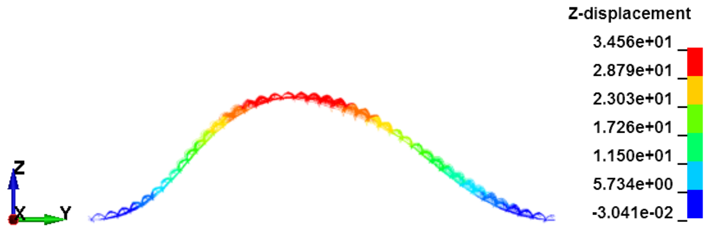


(a) (b)

Figure 4. Simulation of cantilever test of textile: (a) correct bending rigidity (b) lower bending rigidity

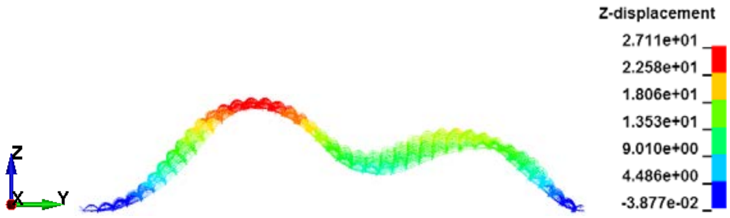


(a) z_{max} = 35 mm (axis offset 5 mm from the ground)



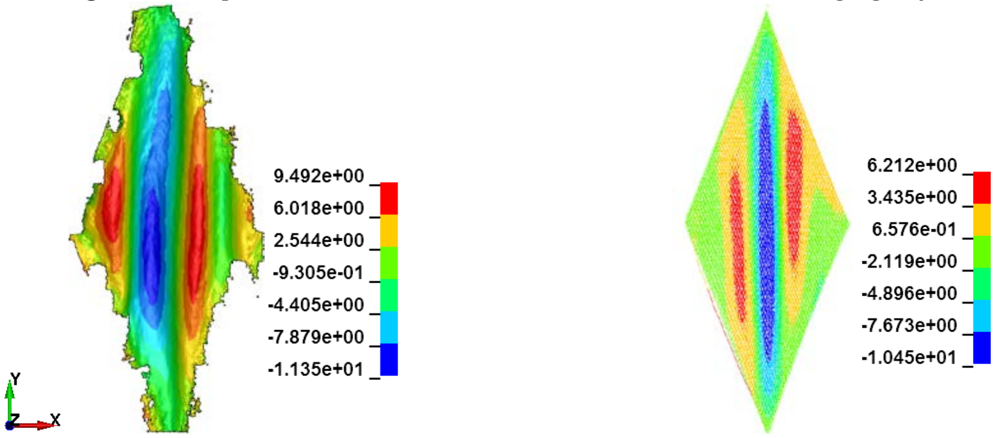
(b) z_{max} = 34.6 mm

Figure 5. Compressive deformation of textile: (a) Real fabrics variant 1 (b) Equivalent model of variant 1



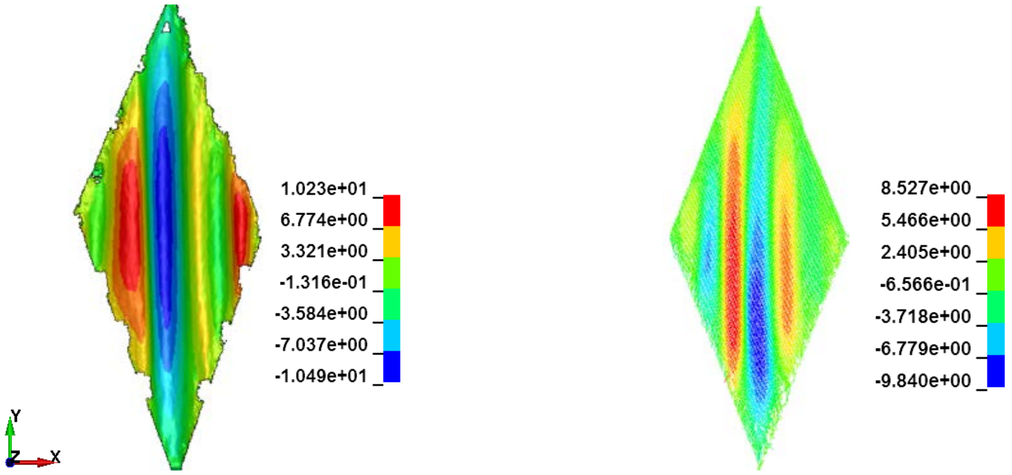
z_{max} = 27.1 mm

Figure 6. Compressive deformation of textile models with lower bending rigidity



(a) z_{max} = 9.5 mm z_{min} = -11.4 mm (b) z_{max} = 6.2 mm z_{min} = -10.5 mm

Figure 7. Optical comparison of the wrinkle size of fabrics variant 1 (a) Experiment (b) Simulation



(a) z_{max} = 10.2 mm z_{min} = -10.5 mm (b) z_{max} = 8.5 mm z_{min} = -9.8 mm

Figure 8. Optical comparison of the wrinkle size of fabrics variant 2 (a) Experiment (b) Simulation

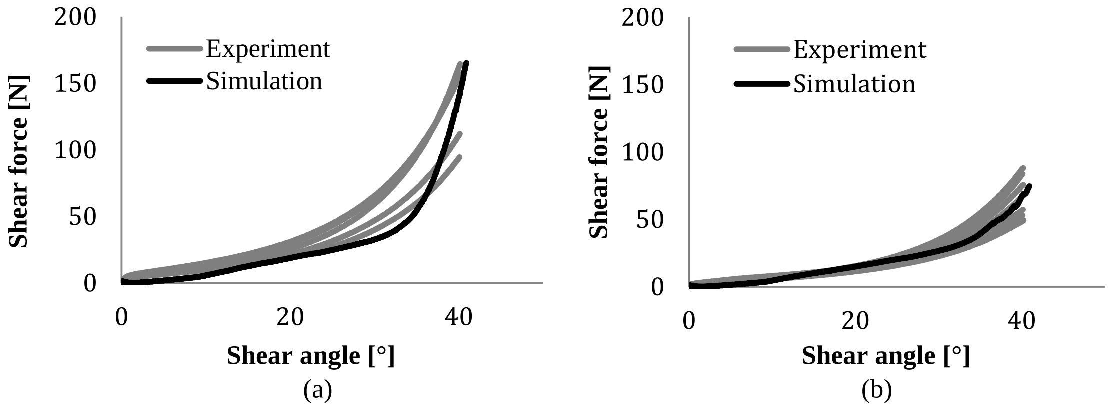


Figure 9. Comparison of shear force – shear angle curve between simulation and experiment of (a) Variant 1 and (b) Variant 2

4. CONCLUSION

The meso-scale modelling methods with beam elements was extensively used to simulate the bending and shear behaviour of two variants of the biaxial reinforced weft-knitted fabrics. The results show very good agreement between experimental data and simulations. The validated models are suitable for further investigations of the forming process, namely they can be used for forming simulation of 2D textile to 3D preforms.

5. REFERENCES

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Acknowledgements

The „Saxon Alliance for Material- and Resource-Efficient Technologies“ (AMARETO, 100291445) is funded by the European Union (European Regional Development Fund) and the Free State of Saxony.

The computations were performed partly on an HPC system at the Center for Information Services and High Performance Computing (ZIH) at TU Dresden.