NUMERICAL MODELLING OF TEXTILE STRUCTURES: POTENTIAL AND LIMITS

BOŇKOVÁ KAROLÍNA*

Technical University of Liberec, Department of Textiles and Structures, Studentská 2, 461 17 Liberec, Czech Republic

ABSTRACT

Numerical modelling, namely finite element modelling, is a standardised tool in many branches of engineering. In textile engineering, due to the complexity of the structure, many limitations occur in using this approach. Despite the limitations the finite element modelling of textiles has huge potential for the future. This contribution deals with FE modelling of tensile test in wale and course direction of single jersey knitted fabric. The meso level of the structure was chosen for the model, so it could be possible to track the behaviour of yarn interlacement during the simulated deformation. The virtual model was created according to parameters of single jersey knitted fabric sample, which was produced from polyester monofilament. By using monofilament instead of staple yarn, contacts between fibres in yarn could be excluded in FE model preparation. Two different computational programs were used for simulations – MSC Marc Metant for implicit computing approach and ANSYS LS-DYNA for explicit computing approach. The results from implicit and explicit solver were compared and discussed. Validation of models was done and results were included in the discussion. Due to big deformations of textiles, explicit solver appears to be more suitable for finite element modelling in textile engineering.

KEYWORDS

Finite element method; Implicit and explicit solver; Textile structures; Modelling; Tensile test; Knitted fabric.

* **Corresponding author:** Boňková K., e-mail: *karolina.bonkova@tul.cz*

INTRODUCTION

Textile structures are extremely variable which is one of the reasons why it is possible to find them in nearly every industrial sector from clothing industry, automotive to biomechanics etc. Modelling of textiles is a challenging topic for many reasons and one of them is their multi-scale structure character [1, 2]. Textile structures can be divided into three main groups – linear, planar and 3D shaped textiles. Each group can be further described on three levels – macro, meso and micro scale. Macro-scale describes overall shape of the textile, so for example if it is yarn, woven fabric or some 3D braided structure. Meso-scale investigates the core structure of the textile, how yarns are interlaced so basically it describes pattern of the yarn arrangement. Micro-scale model tracks how individual fibres are arranged around each other.

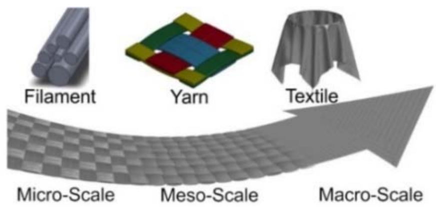

Figure 1. Representation of micro, meso and macroscale of textiles [1]

Textiles have inhomogeneous character and their mechanical behavior can be described mainly as viscoelastic. Thaks to these attributes the general geometry depiction of textile structures is complicated to desribe, because of its changeability. For example a shape of an individual staple yarn is different than the same yarn which is weaved in fabric. Many studies have beed done about this topic and in conclusion, geometry models of textile structures are always simplified at some level in comparism with the real geometry. By using computer tomography data and reconstruction of textile structure it is possible to create virtual textile model with exact geometry [3], but this method is time consuming and ususally only small part of the textile is modelled. Another aspect is, that even though we have high performance computational technology, it still is not efficient enough to capture all scales of the structure at the same time. Such model would be extremely demanding for the data and processing memory. Because of that we are able to model textiles usually on one or maximally two structural levels at the same time.

Creating virtual 3D model of textiles is first step for finite element modelling in which even more limitations occur such as description of material models, types of used elements, number of elements, contacts and more. Complex multicsale simulations are used in FE modelling of textiles, when results from one scale simulation are used as input data for another scale simulation [3]. According to work [4], the most important aspects for quality simulation on one scale with good corresponding results are:

- a realistic geometric model of textile structure,
- realistic boundary conditions,
- a realistic contact surface between yarns without penetration,
- physically measured yarn mechanical data used as input for material model.

Most of the studies which include FE modelling of textiles are oriented on woven fabrics which are commonly used as a reinforcement in textile composites [5]. Work of [6] studied optimization of geometrical model of knitted structures designated as an input for FE modelling. Similarly work [5] investigated mechanical behavior of knitted textiles and their geometrical modifications. Unfortunately neither of these works have FE models validated by experiment.

EXPERIMENTAL

Materials and methods

PERLON Polyester monofilament of diameter 0.1 mm was used to produce single jersey knitted fabric. Tensile test of monofilament was done to obtain information about its mechanical properties (Instron 4411, testing length 250 mm, testing speed 500 mm/min, 10 tested samples). Average tensile strength was 734 MPa and average modulus was 1950 MPa.

Single jersey knitted fabric was manufactured using Shima Seiki SRY 123LP machine with gauge G14. Relaxed fabric had 32 loops/50 mm in course direction and 98 loops/100 mm in wale direction so geometry of a single loop could be described by width 1.56 mm and height 1.02 mm.

Table 1. Parameters used for generating of geometry – models of single jersey knitted fabric samples

	Model for wale direction	Model for course direction
Number of courses	49	15
Number of wales	10	32
Loop width [mm]	1.56	
Loop height [mm]	1.02	
Monofile diameter [mm]	0.1	
Element length for export [mm]	0.2	

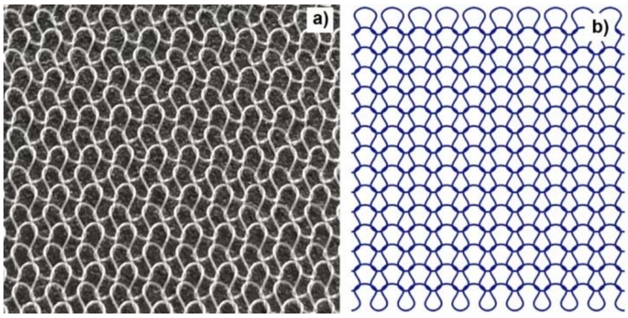

Figure 2. a) Single jersey knitted fabric from polyester monofilament, b) 3D virtual model of the textile

Preparation of FE models

Two computational solvers were used – MSC Marc Metant (implicit solver) and ANSYS LS-DYNA (explicit solver). Two models were prepared, tensile test of virtual sample in course and tensile test of virtual sample in wale direction. In both softwares the same input geometry, material properties, boundary conditions, computational method and job results were set. Since programs offer different settings, models differed a little bit in used element and contact description but both were chosen as similar as possible.

a) Geometry

The geometry of the single jersey fabric was prepared in program TexMind WeftKnitting3D. Two models were prepared – one as a sample for tensile test in course direction and second as a sample for tensile test in wale direction. As an input information for the program, parameters shown in Table 1 were used.

b) Meshing, material and contact

Beam elements were used. Beam had circular cross-section with diameter 0.1 mm. Average element length was 0.2 mm. In MSC Marc Metant element type 52 (Euler-Bernoulli beam) was used and in ANSYS LS-DYNA beam formulation 1 (Hughes-Liu) was chosen.

Linear elastic material model was chosen and described with values of modulus E = 1950 MPa, Poisson's ratio μ = 0.3 and density ρ = 1365 kg/m^3.

In MSC Marc Metant, beam to beam touching contact was chosen. Friction coefficient was set to value 0.1.

In ANSYS LS-DYNA, automatic general contact was chosen. Static and dynamic friction coefficient were set to value 0.1.

c) Boundary conditions and job results

In both tensile tests edge nodes were disabled in every degree of freedom on one side (symbolized by cross) – this side represented static clamp of tensile testing machine. Other edge nodes were allowed in every rotational degree of freedom, one sliding degree of freedom in one direction and two remaining directions were disabled (symbolized by arrow). This side of model represented the edge of sample fixed in moving clamps of tensile testing machine. In LS-DYNA boundary conditions were applied directly on the nodes, in MCS Marc nodes were connected to one Rigid body element on each side.

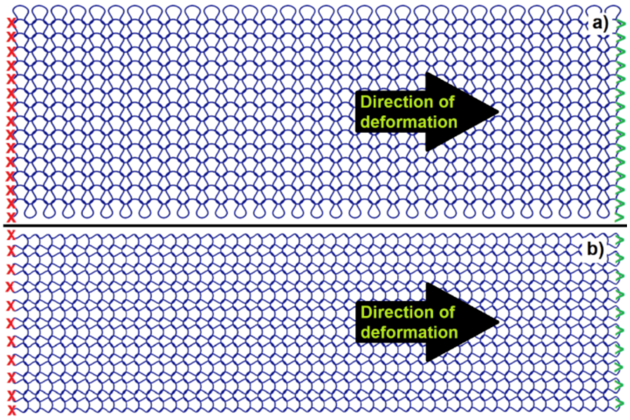

Figure 3. Boundary conditions a) course direction, b) wale direction

In both tests (tensile test in course and wale direction) models were elongated by 15 mm. Tests were controlled by displacement of destined nodes.

Displacement and reaction force were monitored as results of simulations.

Validation

For validation ADMET MTESTQuattro (TM) machine with 10lb head was used. For each direction (course, wale) 10 samples were prepared and tested. One sample had 90x15 mm dimensions for comfortable fixation to the clamps. The machine set up and sample can be seen in Figure 4. Clamps had coarse surface, so during testing there was no problem with slipping of the sample from the clamps. Testing length was 50 mm and testing speed was 40 mm/min.

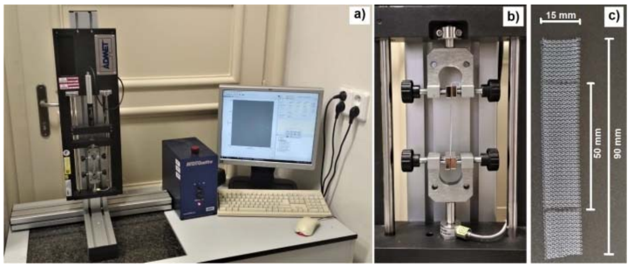

Figure 4. a) Testing machine setup, b) fixed sample in clamps, c) sample dimensions

RESULTS AND DISCUSSION

Table 1. Results of tensile tests – validation experiment and simulations

	Tensile test in wale direction		Tensile test in course direction	
	Displacement [mm]	**Force [N]**	**Displacement [mm]**	**Force [N]**
Validation Experiment	15	0.57	15	0.37
			7.83	0.67
MSC Marc Metant	15	2.96	15	0.04
ANSYS LS-DYNA	15	1.09	15	0.38
			29.5	0.65

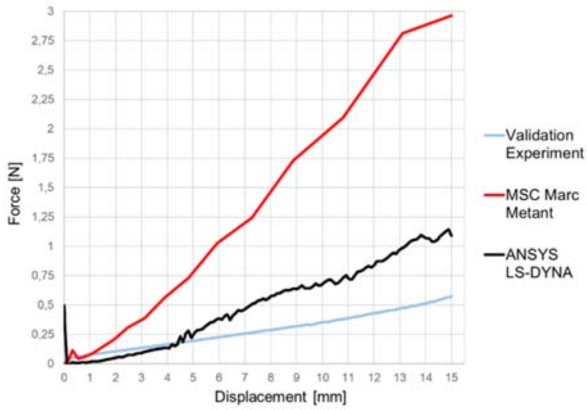

Figure 5. Comparison of tensile curves computed in MSC Marc, LS-DYNA and from validation experiment – testing in wale direction

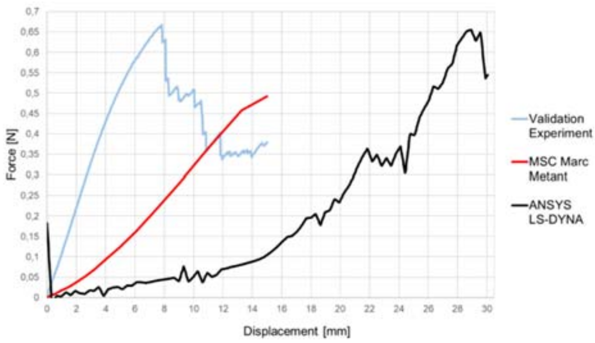

Figure 7. Comparison of tensile curves computed in MSC Marc, LS-DYNA and from validation experiment – testing in course direction

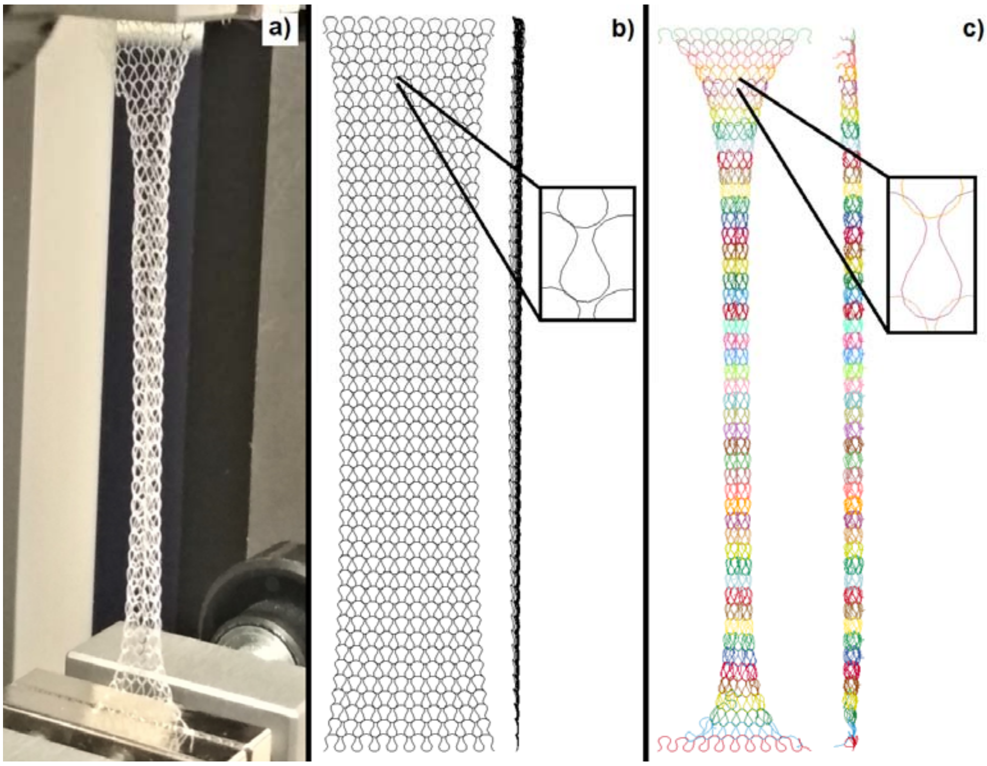

Figure 6. Visual comparison of deformed samples: a) validation experiment, b) MSC Marc simulation, c) LS-DYNA simulation – testing in wale direction

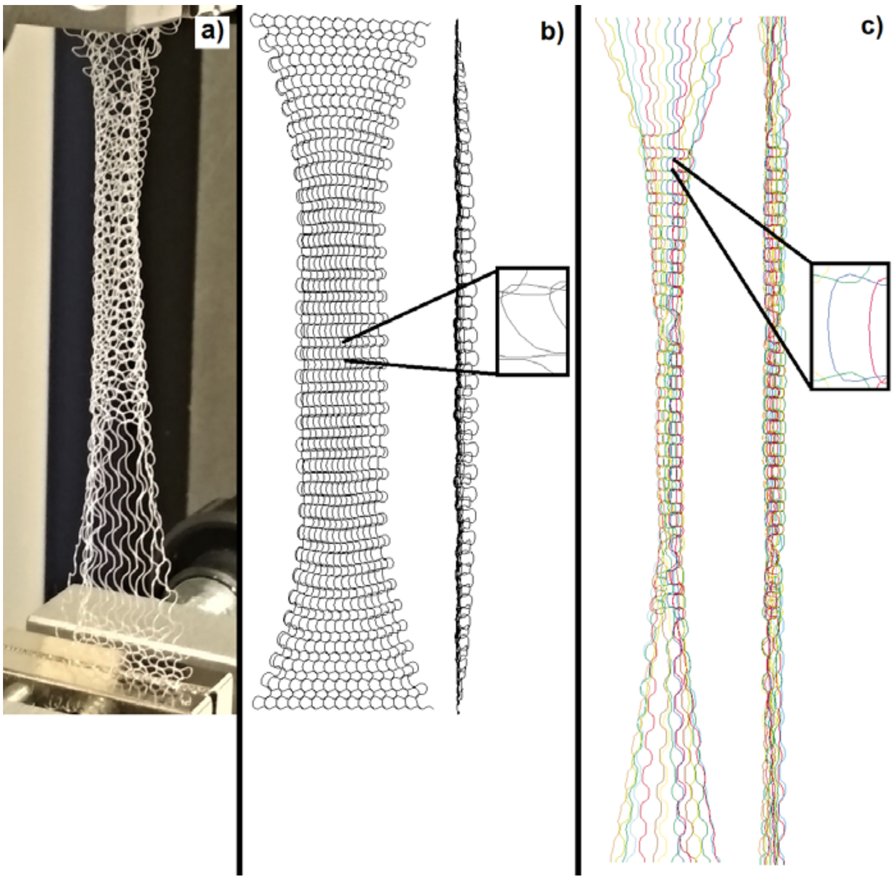

Figure 8. Visual comparison of deformed samples: a) validation experiment, b) MSC Marc simulation, c) LS-DYNA simulation – testing in course direction

Tensile test in wale direction: In Figure 6 c) it can be seen, that LS-DYNA visual representation of deformed sample corresponds with the real deformed sample very well. The elongated model sample is curled, narrow only in area of boundary conditions (same as nearby clamps) and some of the edge loops are pulled out. In LS-Dyna model no penetration of beams occurred. On the other hand, MSC Marc model after deformation is mainly narrow, minimally curled on the edges and the edge loops mostly remained in the initial shape. During the simulation there were even problems with penetration of the beams thorough all settings which supposed to prohibit that. From results we can see, that the MSC Marc model is not applicable and that the implicit solver with mentioned settings is not usable. In Figure 5 comparison of tensile curves in wale direction is shown. MSC Marc's result curve is extremely up dimensioned in comparison with the validation experiment. LS-DYNA's result curve is more accurate but the predicted value of the reaction force is still nearly twice bigger than the experimental value.

Tensile test in course direction: As it can be seen in Figure 8 a), the real sample at elongation of 15 mm is damaged by many pulled out loops. Neither model was able to simulate this at 15 mm elongation. Both models were visually compact and none of the loops were pulled out. Due to this, both simulations were repeated but with the elongation of 30 mm. The MSC Marc model was not able to simulate the slippage of the loops even with the higher deformation and plus beam penetrations occurred again. On the other hand, LS-DYNA model accurately predicted the slippage of loops during the higher deformation, even with the curled edges of the model which are appearing also in the real specimen. Again, the model did not have any penetrations of beams. In Figure 7 comparison of tensile curves in course direction is shown. Both simulated result curves are under dimensioned in comparison with the experimental curve, however the LS-DYNA's result curve with the 15 mm offset from the origin of the coordinate system, with some instabilities, is getting closer to the experimental curve and at its end it has nearly the same value of reaction force. LS-DYNA's value of reaction force is 0.65 N and the experimental value is 0.67 N.

Usually single jersey fabric is more elastic in course direction. Ratio of number of loops in a course is 1.5 times bigger than in a wale of the manufactured fabric. Due to that, experimental results from tensile tests show that the fabric is more rigid in course direction and more elastic in wale direction. After relaxation of the fabric, original width of the loop 1.81 mm shrank to 1.56 mm. Inner forces of the monofilament are certainly influenced by the shrinkage and FE model is not capable to predict these forces just from the input geometry model, which affects the results. As it can be seen in Figure 2, due to the bending stiffness of the monofilament, knitted fabric loops are not in a narrow position as it is in the case of the generated geometry model. There is also a difference between loop length even though that the geometry model was generated according to real parameters of the fabric. Average measured loop length is 4.62 mm and the modelled loop length is 3.93 mm. These geometric differences have influence on the results. Also simplified material model and friction model affect the simulated results.

CONCLUSIONS

Two finite element models of single jersey knitted fabric were prepared in computational software MSC Marc Metant with implicit solver and in computational software ANSYS LS-DYNA with explicit solver. Tensile test in a course and in a wale direction were simulated in both programs with as similar settings as possible. Validation of the models was done using ADMET MTESTQuattro machine which has great sensitivity so the experimental results have good accuracy. It appears that MSC Marc was not able to provide good results even with complex settings and penetrations of beams occurred during the simulations. ANSYS LS-DYNA performed great visual simulations of deformations of modelled samples which corresponded very well with real deformation of the specimen during the validation experiment. Simulated tensile curves were less corresponding with the experiments however that is influenced by the simplified geometry of the knitted fabric and simplified material model. In this case it can be said that the explicit solver is more suitable for modelling of textile mechanical deformations. For future simulations, more accurate input geometry, more complex material model as for example linear piecewise material should be used and analyzed. Also, inner forces of the yarn after the relaxation of the knitted fabric should be considered and incorporated in FE simulations. Finite element modelling of mechanical behavior of textile structures is possible but experimental validation is necessary. FE simulations can be highly inaccurate without validation and models like that can be very misleading for the research.

Acknowledgements: *This contribution was written at the Technical University of Liberec, Textile Faculty with the support of Student Grant Competition (project SGS-2022-6062 "Textile replacements designated for the chest wall reinforcement after bone defects"), which financially supported finite element course in computing program ANSYS LS-DYNA.*

REFERENCES

1. Döbrich, O., Gereke, T., Cherif, Ch. (2015). Textile and Composite Modelling on a nearMicro-scale: Possibilities and Benefits. 10th European LS-DYNA Conference 2015, Würzburg, Germany [online 17.10.2022] https://www.dynalook.com/conferences/10th-european-ls-dyna-conference/4%20Materials%20II%20-%20Endless%20Fibers/01-Doebrich-TechnicalUnivDresden-P.pdf
2. Komeili, M., & Milani, A. S. (2011). Finite Element Modeling of Woven Fabric Composites at Meso-Level under Combined Loading Modes. In (Ed.), Advances in Modern Woven Fabrics Technology. IntechOpen. https://doi.org/10.5772/17333
3. Sodhani, D., Reese, S., Jockenhövel, S., Mela, P., Stapleton, S. E. (2018) Multi-scale modelling and simulation of a highly deformable embedded biomedical textile mesh composite, Composites Part B: Engineering, 143. 113-131. https://doi.org/10.1016/j.compositesb.2018.01.010.
4. Lin, H., Clifford, M., Long, A., Lee, K., Guo, N. (2012). A finite element approach to the modelling of fabric mechanics and its application to virtual fabric design and testing. Journal of The Textile Institute, 103. 1-14. https://doi.org/10.1080/00405000.2012.660755.
5. Liu, D., Christe, D., Shakibajahromi, B., Knittel, Ch., Castaneda, N., Breen, D., Dion, G., Kontsos, A. (2017) On the role of material architecture in the mechanical behavior of knitted textiles, International Journal of Solids and Structures, 109.101-111. https://doi.org/10.1016/j.ijsolstr.2017.01.011.
6. Wadekar, P., Perumal, V., Dion, G., Kontsos, A., Breen, D. (2020). An optimized yarn-level geometric model for Finite Element Analysis of weft-knitted fabrics. Computer Aided Geometric Design, vol. 80, https://doi.org/10.1016/j.cagd.2020.101883.