18th International Conference
ENGINEERING MECHANICS 2012
Svratka, Czech Republic, May 14 – 17, 2012

pp. 585–592
Paper #326

SIMULATION OF THE BEHAVIOUR OF A 3D LINK OF A KNITTED FABRIC MADE OF NI-TI TO THE MECHANICAL LOADING

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Abstract: *The models of knitted fabrics are geometrically complicated systems. The simulations of the knitted fabrics models have to include nonlinearities in a form of the geometry, contact and in some case in a form of the material. These nonlinearities increase the computational time. One of the simplifications is the geometrical simplification. The model of the knitted fabric can be transfer from 3D to 2D model. That removes the contact. How large influence has this simplification, we can determine with a model of one link. The creation of this model and the results of the simulation for the link are described thereinafter.*

Keywords: ***shape memory alloy, knitted fabric, non-linear simulation***

1. Introduction

Technical textiles are used in many industries such as geoengineering, agroengineering, civil engineering, health service and transport facilities. The technical textiles have unique characteristics, which are the reasons, why they are tested in new fields of application. That brings new needs of testing of not only mechanical properties. One of the several possibilities of testing of the behaviour of the technical textiles to the mechanical loading is simulation by way of the finite element method. This method can be in some cases the only possibility.

In this article is described a link of a knitted fabric, which is made from Ni-Ti material. Ni-Ti is one of the materials, which is part of the shape memory alloy materials (SMA). SMAs are a unique group of materials, which has the property to recover their shape, when the temperature is increased. Further these materials are capable of absorb large elastic deformations to 10%.

Simulations of the mechanical behaviour of the Ni-Ti knitted fabrics, in which I am engaged, include nonlinearities in the form of the large deformations, contact and material. In consequence of these nonlinearities are the computational simulations of large models of the knitted fabrics time-consuming. One of the possibilities, how the time-consuming of the FEM simulations can be reduced, is a disestablishment of the contact nonlinearity. The contact nonlinearity can be removed only in the case, that the influence of the frictional forces is inconsiderable. The investigation of the influence of the frictional forces is the main aim of the simulations, which are described thereinafter.

2. Geometrical model

For a creation of a geometrical model of a 3D link of Ni-Ti knitted fabrics is used Dalidovic`s model. This model simplifies the geometry of the knitted fabrics by means of abscissas and semicircles. The shape of the Dalidovic`s geometry model of the knitted fabric is figured in Figure 1. The geometrical model, which is applied for the following simulations, is in Figure 2.

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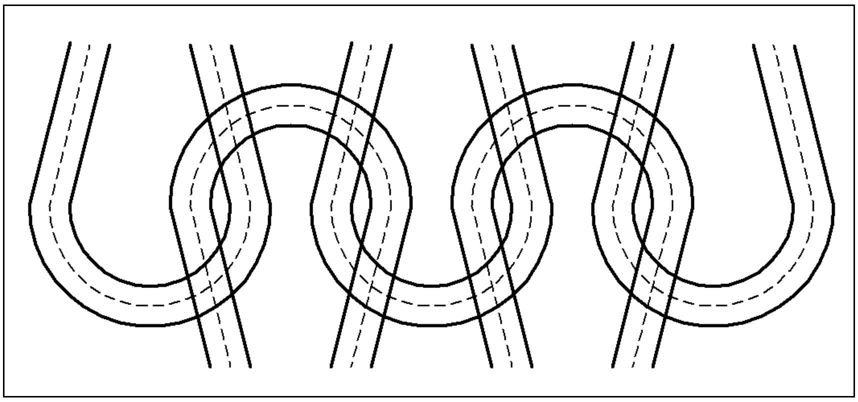

Fig. 1: Dalidovic`s model of the knitted fabrics.

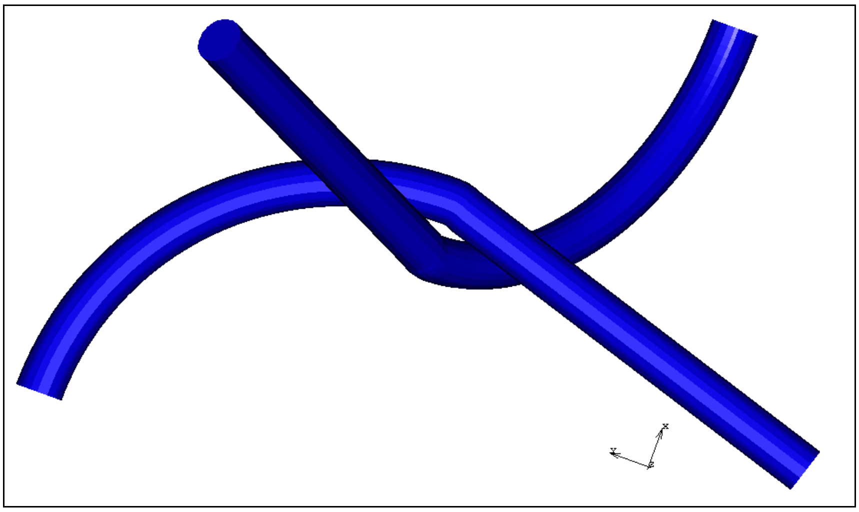

Fig. 2: Geometrical model of the 3D link of the knitted fabrics.

3. Finite element mesh

A three dimensional mesh of elements is created from 2D elements QUAD4, which are created on one of two end sections of the thin wire of the knitted fabrics. These 2D elements are applied for the creation of 3D elements. The two dimensional elements are pulled in the direction of the axis of the thin wire. As a result are 3D elements HEX8, which are an eight/node, isoparametric, arbitrary hexahedral. These linear solid elements are converted to HEX20 elements, which are represented by three-dimensional 20-node bricks with Herrmann formulation. These elements use triquadratic interpolation functions to represent the coordinates and displacements and can be used for large strain behaviour.

The both parts of the geometrical model of the knitted fabrics have an equable geometry, hence the finite element mesh of one thin wire of the knitted fabrics is used for the definition of the second thin wire. The final FE model is shown in Figure 3 and Figure 4. The parameters of the FE mesh are described in Table 1.

Tab. 1: Parameters of the finite element mesh.

Type and number of elements	Number of nodes
Element 35 – HEXA20	-
11400	53238

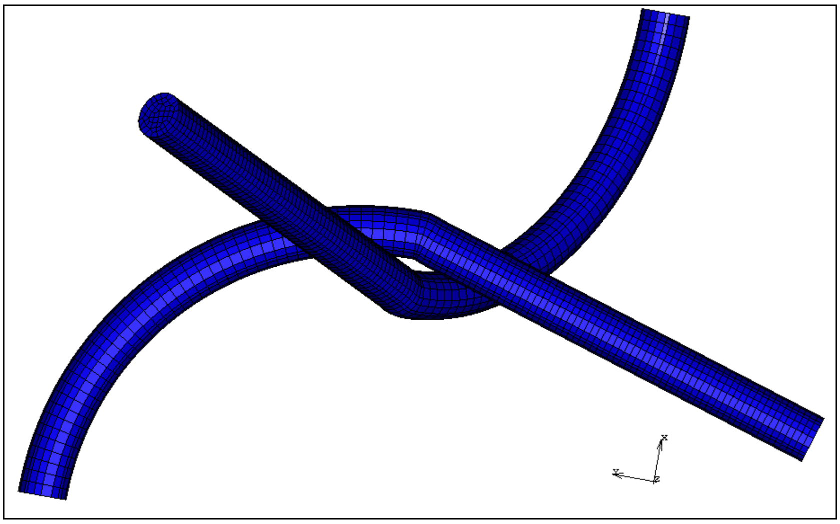

Fig. 3: Finite element mesh of the 3D link of the knitted fabrics.

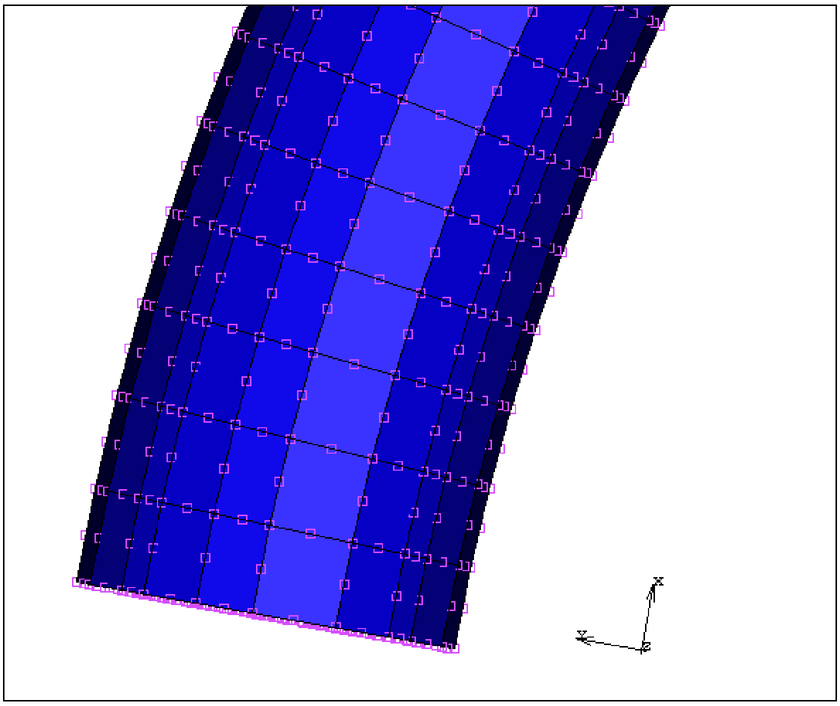

Fig. 4: A detail of the nodes of the FE mesh.

4. Boundary conditions

The influence of the friction is observed on two types of the mechanical loading. The first type of the mechanical loading is a tension of one thin wire in the lengthwise direction of the knitted fabrics. The second thin wire of the knitted fabrics is fixed in the initial position. The boundary conditions for the fixed parts of the 3D link are transformed into the direction of the thin wire as shown the Figure 5.

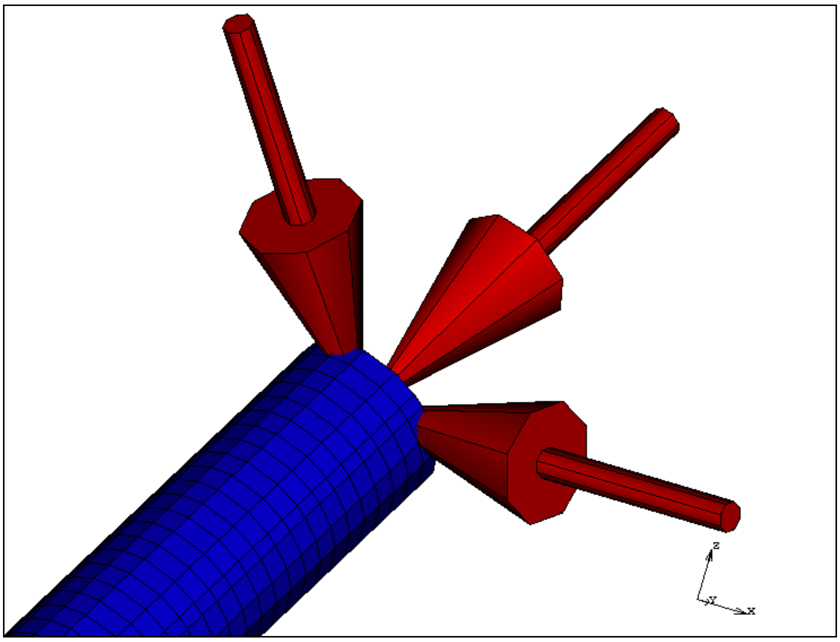

Fig. 5: The transformed boundary conditions for the fixed wire.

The second type of the simulations is a tension of one thin wire in the cross direction of the knitted fabrics. The second wire is fixed as well as in the first simulation.

The tension for the both simulations is defined by means of displacements. Maximal displacement is 0,5mm. All boundary conditions are defined on the end sections of the thin wires of the 3D link. The both type of boundary conditions are shown on Figure 6.

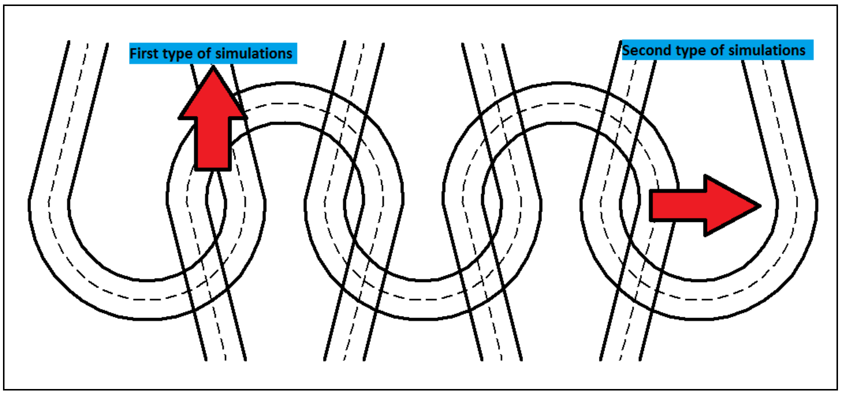

Fig. 6: The boundary conditions for both simulations.

5. Material and material model

One of the materials, which belong to SMAs, is called Nitinol (Ni-Ti). The chemical composition of Ni-Ti is 55.82 wt. % nickel (Ni). Nickel gives the fibers superelastic behaviour above 10°C. SMAs have two phases, each with a different crystal structure and therefore different properties. One of the phases is a high temperature phase called *austenite* (A) and the other is the low temperature phase called *martensite* (M). Austenite has a generally cubic crystal structure and martensite has tetragonal, orthorhombic or monoclinic crystal structure. The change from one structure to the other is called as martensitic transformation.

For the simulations of the behaviour of the 3D link of the knitted fabric is the material model defined by the help of structural material model for the shape memory alloy or more precisely Auricchio`s model. This material model is described by Helmholtz free energy.

$$\psi = \psi_{el} + \psi_{ch} + \psi_{tr} + \psi_{id} + I_{\varepsilon L} \quad (1)$$

This material model can be for tension cases replaced by trilinear material model.

6. Contact

For both simulations is for the contact between the wires of the 3D link of the knitted fabric used arctangent model, which belongs to the group of Coulomb friction models. This friction model is based on a continuously differentiable function in terms of the relative sliding velocity.

$$\sigma_t = -\mu \sigma_n \cdot \vec{t} \quad (2)$$

7. Parameters of the computations

All the variants of the simulations have the same computational parameters. A step of the simulation is set with a fixed and equally small increment. The small increment is important for a finding a contact between the thin wires of the 3D link of the knitted fabric in every step of the computation. During the simulations the large deformations rise. That is the reason, why the third part of the relation for the strain cannot be neglected.

$$\frac{\partial u_j}{\partial x_i} + \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\frac{\partial u_i}{\partial x_j} \quad (3)$$

8. Results

For both types of the simulations are used the results for the displacement 0,25mm. The maximal displacement 0,5mm is too large. Below I show the results for contact normal forces, contact friction forces, principal stresses, normal stresses and shear stresses.

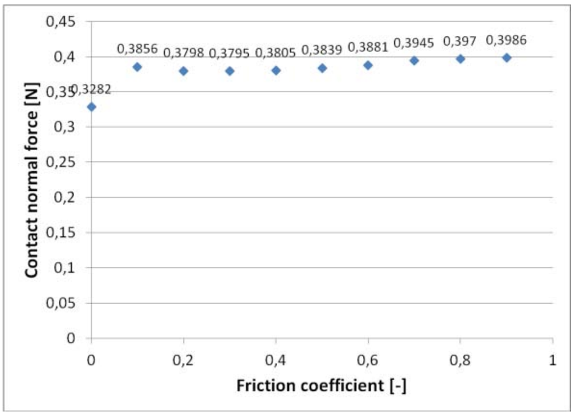

Fig. 7: The contact normal force [N] for the first type of the simulations.

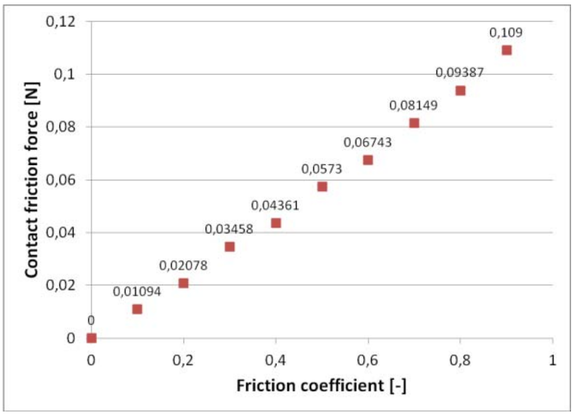

Fig. 8: The contact friction force [N] for the first type of the simulations.

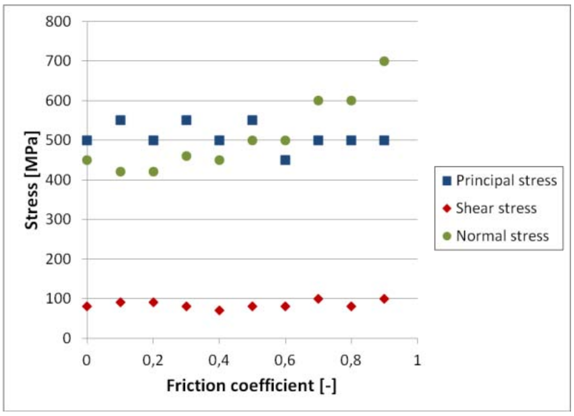

Fig. 9: The stresses [MPa] for the first type of the simulations.

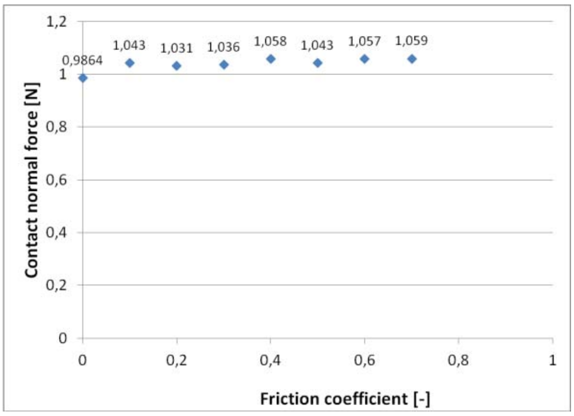

Fig. 10: The contact normal force [N] for the second type of the simulations.

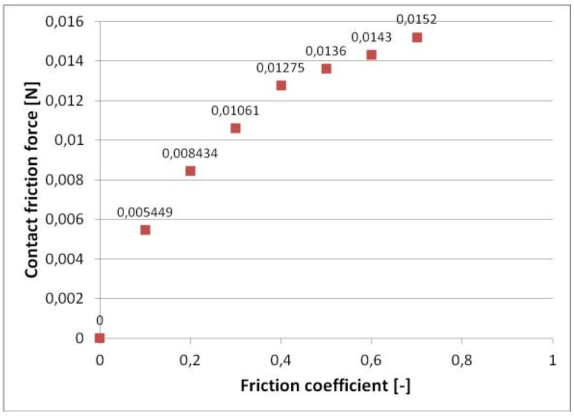

Fig. 11: The contact friction force [N] for the second type of the simulations.

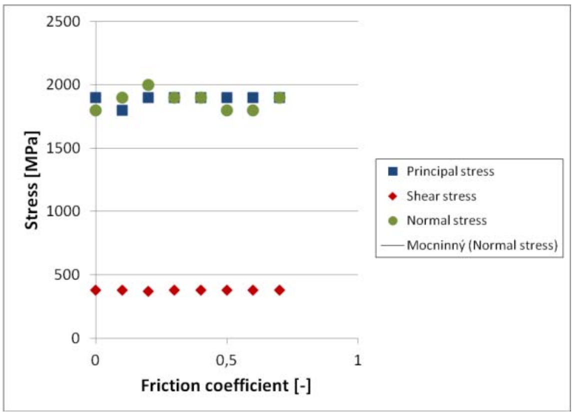

Fig. 12: The stresses [MPa] for the second type of the simulations.

The results show, that only the contact friction force changes in depending on the friction coefficient, which is given the definition of the contact friction force. The contact normal force has large changes, but only for the first type of the simulations and for large friction coefficients, which are unrealistic for our materials. Other variables are unchanging in depending on the friction coefficient.

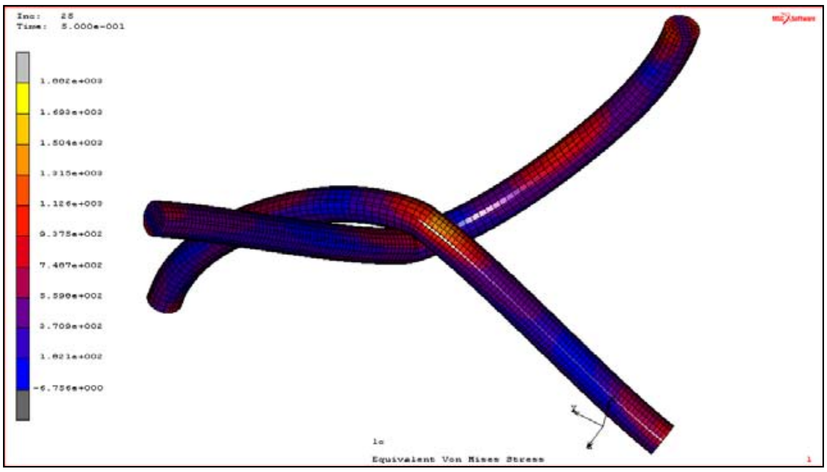

Fig. 13: Von Mises stress [MPa] for the second type of the simulations.

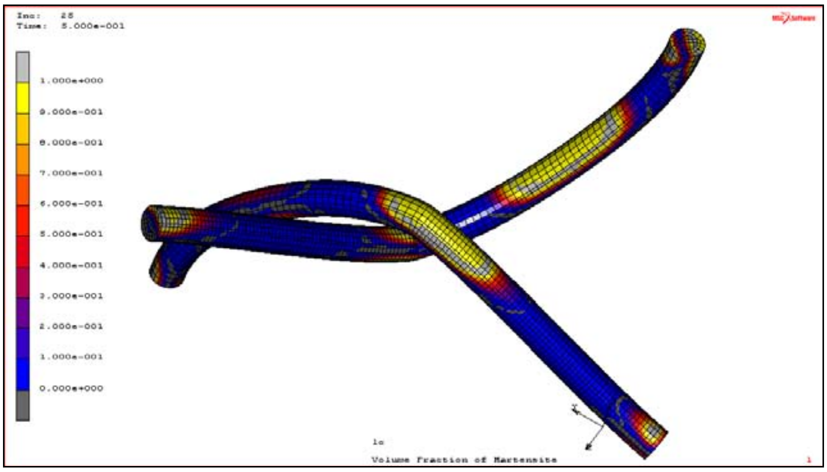

Fig. 14: The volume fraction of martensite.

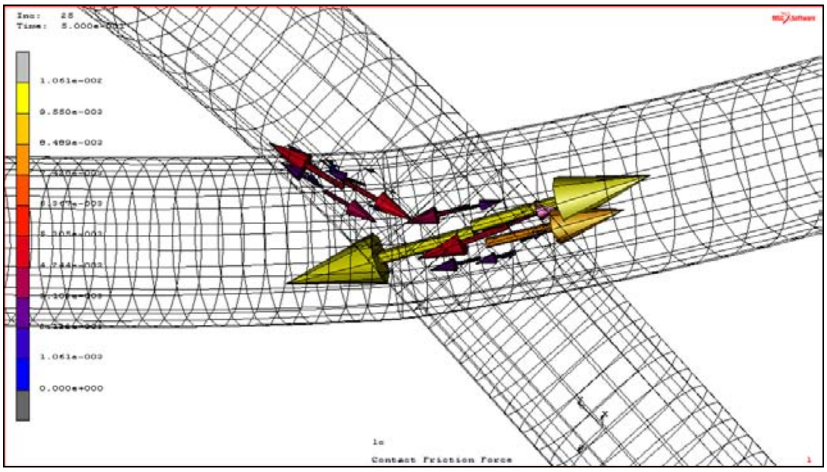

Fig. 15: The contact friction force [N].

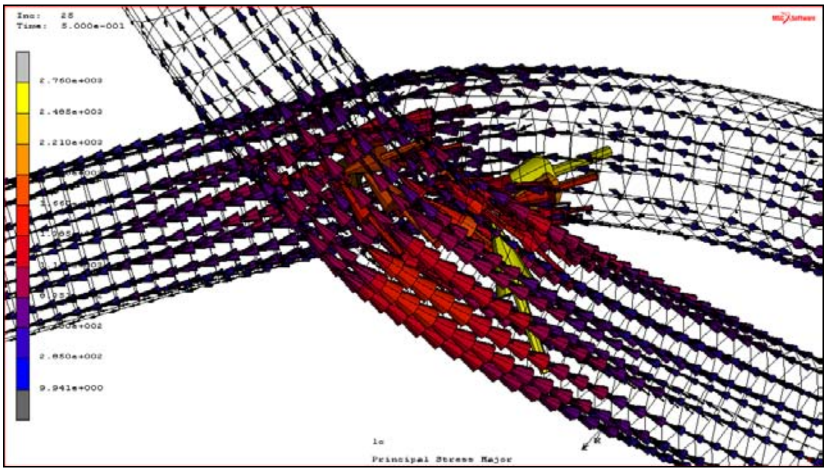

Fig. 16: The principal stress major [MPa].

9. Conclusion

The results of both simulations show, that we can the influence of the friction, if we do not research the friction or heat, which is generated from the friction. Other variables are independent on the friction coefficient. The changes of these variables are shown only for large friction coefficients. The main result of these simulations is the simplified geometrical model of the knitted fabric, which will be used for simulations of large models of the knitted fabrics.

Acknowledgement

Acknowledge the support from project SGS (Student Grant Competition) at Faculty of Mechanical Engineering at Technical university of Liberec, int. n. 2820.

References

Renkens, W. & Kyosev, Y. (2011) Geometry modeling of warp knitted fabrics with 3D form. *Textile Research journal*, 81(4), 437, pp.437-443.

Kharkova, G., Kononova, O., Krasnikovs, A., Eiduks, M., Machanovskis, E. & Dyelyitis, K. (2011) Elastic properties of cotton fabric based polymer composites. *Engineering for rural development,* pp.402-407.

Lomov, S., Moese, M., Stalmans, R., Trycinski, G., Humbeeck, J. V. & Verpoest, I. (2011) Finite element modeling of SMA textiles: superelastic behaviour. *The Journal of the Textile Institure*.

Ramakrishne, S. (1997) Characterization and modeling of the tensile properties of plain weft-knit fabric-reinforced composites. *Composite Science and Technology*, 57.

Reese, S., & Christ, D. (2008) Finite deformation pseudo-elasticity of shape memory alloys – Constitutive modeling and finite element implementation. *International Journal of Plasticity*, 24, pp.455-482.