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Simulation of The Behaviour of A Knitted Structure Made of Ni-Ti Wires to The Mechanical Loading.

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Abstract: This article describes the response of the knitted fabric to the mechanical loading. The knitted fabric is made of the nitinol material, which belongs to the group of shape memory alloys. There are described two simulations, which show the behavior of this structure in the unidirectional stretching and in the bending by a punch. The FE simulations are compared with experimental measurements on the real knitted fabric.

Keywords: shape memory alloy, stretching, bending, NiTi, finite element method

1. Introduction

The aim of this article is a description of response of the knitted fabric to the mechanical loading. There are summarized two cases of the mechanical loading. The first one is uniaxial tension. This tension is done in one direction of the knitted fabric and the second direction is fixed at the same time. The second case is the bending of the knitted fabric by a punch. Both cases were done experimentally. The second step is to prepare simulations, which are based on the FEM.

The knitted fabric is made from NiTi wires. This material belongs to a group of materials called Shape memory alloys.

2. Shape memory alloys

Shape memory alloys (SMAs) are researched for last few decades. SMAs are a unique group of materials, which has the property to recover their shape when the temperature is increased. These materials are able to recover under high applied loads too. These special characteristics are the reason, why SMAs are used foe sensing and actuation, impact absorption and vibration damping applications.

SMAs are used in many areas of industrial such as automotive, biomedical and other. It is used for medical stents medical superelastic tools, permanent screw-jacks, flexible antennae, single-outlet combination tap assembly, superelastic spectacle frame and reinforcements in shoes, clothes and garments.

One of materials, which belong to SMAs, is called Nitinol (NiTi), which was discovered 1963. Studied NiTi knitted fabric were made of commercially available drawn NiTi fibres Fort Wayne Metals Ltd. of the chemical composition 55.82 wt. % nickel (Ni). The knitted fabric is shown on **Figure 1** Nickel giving the fibres superelastic behaviour above 10^{o}C. The knitted fabric was made of NiTi fibers of diameter 0.2mm, which had been previously treated by cold drawing. The Nitinol has the reversible deformation 6%.

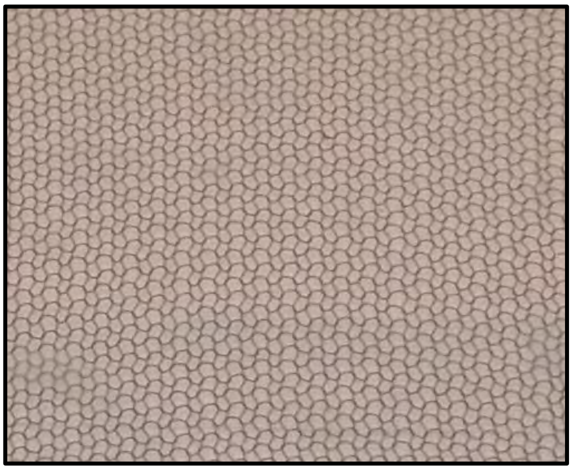

Figure 1. The knitted fabric for our experiments.

SMAs have two phases, each with a different crystal structure and therefore different properties. One is the high temperature phase called *austenite* (A) and the other is the low temperature phase caller *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. Each martensitic crystal formed can have a different orientation direction, which is called a *variant*. The assembly of martensitic variants can exist in two forms. The first one is known as *twinned* martensite (M^t), which is formed by a combination of self-accommodated martensitic vatiants. The second form is called *detwinned* or reoriented martensite, in which a specific variant is dominant (M^d). Properties of SMAs are described in detail in [1].

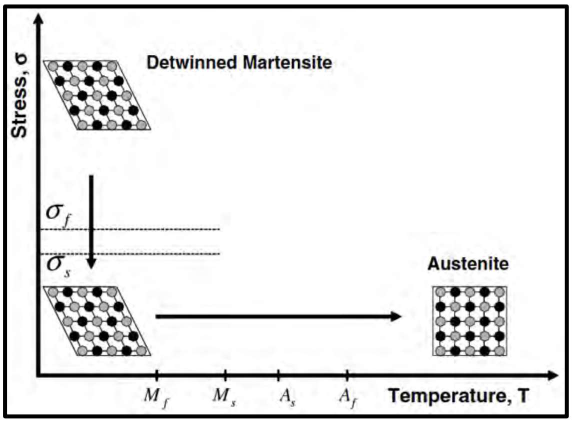

Figure 2. Schematic of the shape memory effect in stress – temperature diagram [1].

On this place is described only one property, which is used in these simulations. This behaviour is called *pseudoelastic effect*. This effect is induced by applying a sufficiently high mechanical load to the material in the austenitic phase. The final structure of this load is fully detwinned martensite, which is created from austenite. The pseudoelastic effect is shown in stress – temperature diagram on **Figure 3** and in stress – strain diagram on **Figure 4**.

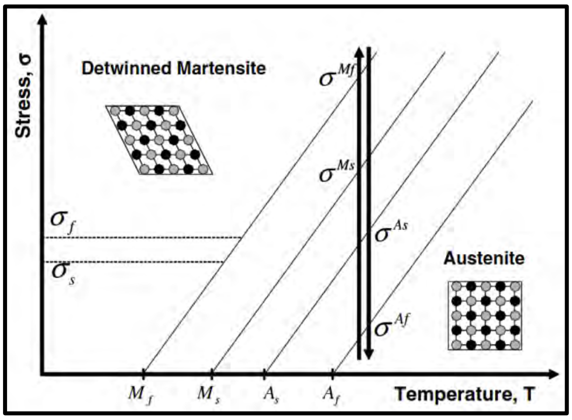

Figure 3. A pseudoelastic loading path [1].

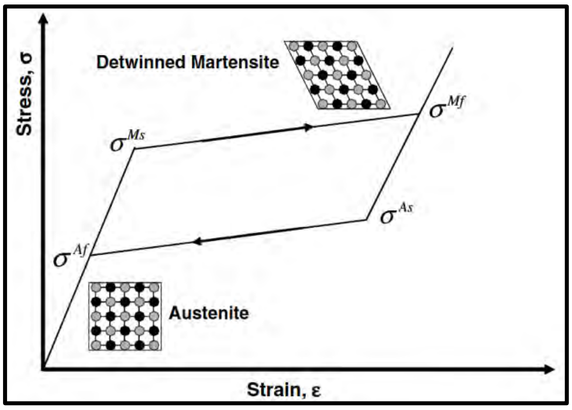

Figure 4. Schematic of a pseudoelastic stress – strain diagram [1].

3. Description of the models

COMSOL Multiphysics is used for simulations. For both cases is needed Structural Mechanics Module. Both models have the same geometry and the same material too. Previous simulations showed that it is not necessary to prepare a three dimension CAD model of the knitted fabric, because the knots of the knitted fabric can be neglected. It means that the geometry is constructed as a plane model. The knitted fabric has a periodic structure so there can be constructed only the part of the model, which is repeated. This repeated part is shown in the **Figure 5**. The dimensions of the cell, which is repeated, are written in the table below.

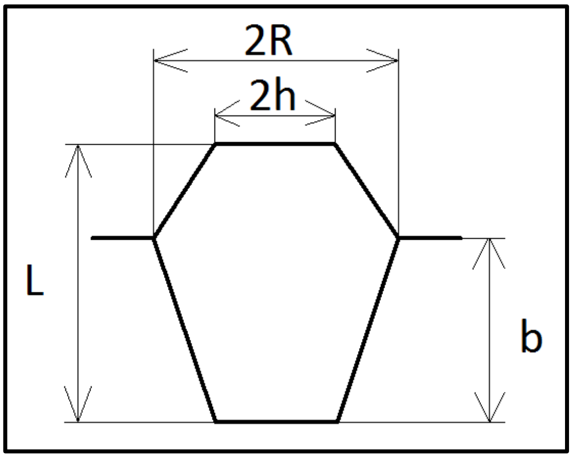

Figure 5. The simplified cell of the knitted fabric.

The cell is copied in two directions. The cell consists of curves and points too. The points are important for definition of the boundary conditions in the second case. The full geometry model is shown in the **Figure 6**.

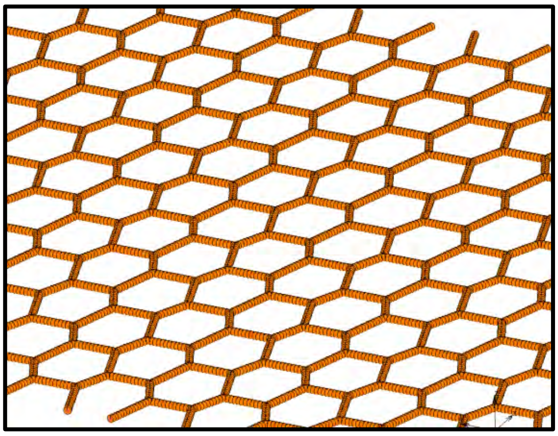

Figure 6. The geometry model of the knitted fabric.

The material for the simulations in COMSOL Multiphysics is defined as a linear isotropic material, because there were done simulations with Auricchio material model [2]. This material model is a material model for SMAs. The results of these simulations shown, that the structure of the knitted fabric is during the experiments in the austenite phase (**Figure 7**). That the reason, why these first simulations in COMSOL Multiphysics are defined with the linear isotropic material.

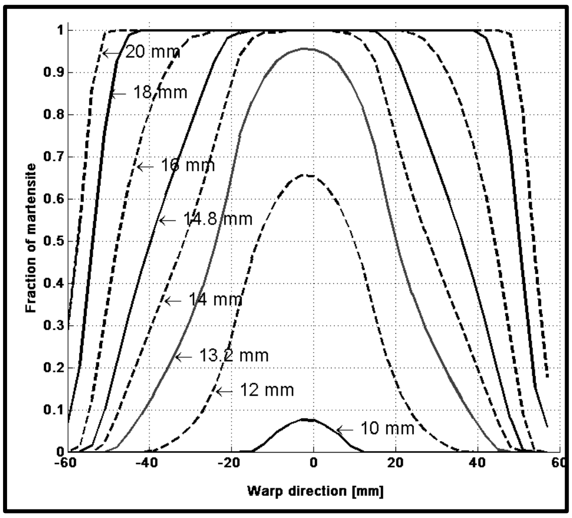

Figure 7. The fraction of martensite during last simulations.

Material parameters are determined with the method, which is shown on **Figure 8**. Methods for determination all parameters are described [1].

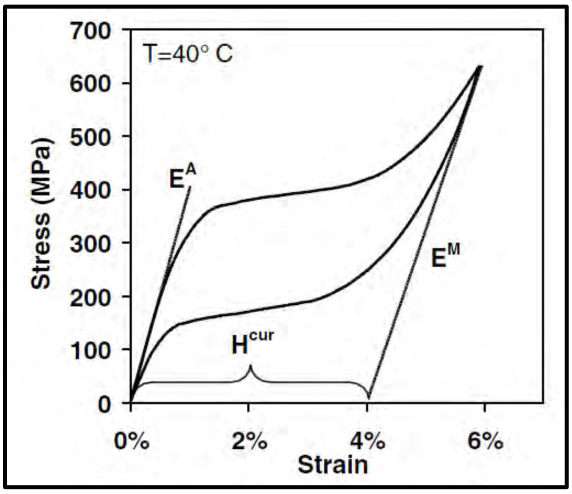

Figure 8. Young´s moduli of SMAs [1].

Results of the tested knitted fabric are shown on **Figure 9** and the parameters of the knitted fabric are written in **Table 1**.

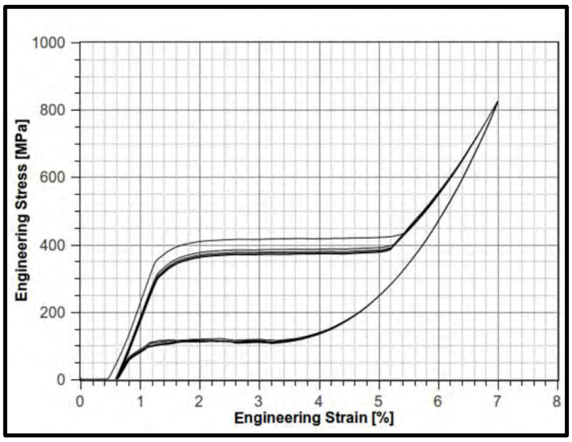

Figure 9. The results of the tested knitted fabric.

Table 1. Material parameters.

Parameter	Value
E_A	53 600 MPa
E_M	21 100 MPa
ν_A	0.3
ν_M	0.3

The boundary conditions for the first case are simple. Two opposed sides have defined displacement in one direction and the second opposed sides have fixed perpendicular direction on the displacement direction.

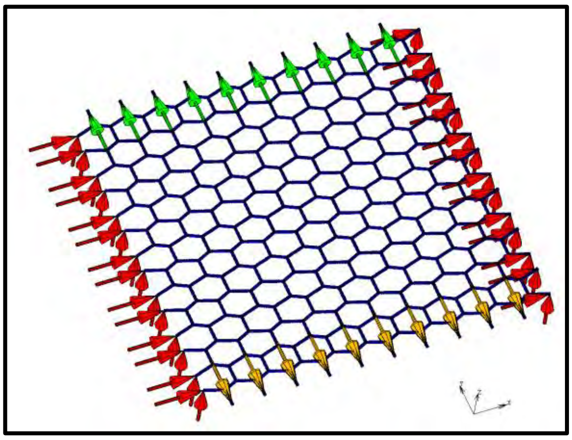

Figure 10. Boundary conditions for the tension simulation.

The second simulation has fixed all degrees of freedom. The bending of the knitted fabric by the punch is replaced by described displacements. That is the way how to do the simulation without contact, which is not possible with beam elements. The contact between the punch and the knitted fabric is defined with the displacements for a circle in the middle of the knitted fabric. The displacements have a shape of a half sphere.

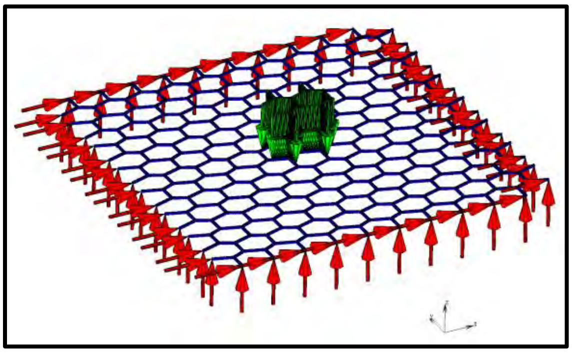

Figure 11. Boundary conditions for the bending simulation.

4. Results

The results of the tension simulation shows, that the material has great response to the mechanical loading. The bending moments and torsion moments are inconsiderable.

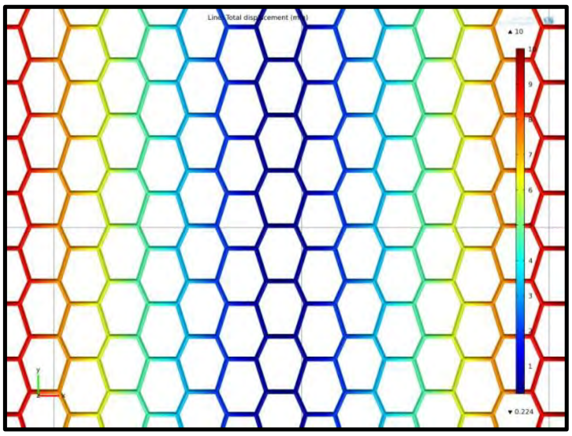

Figure 12. Total displacement of the knitted fabric for the tension simulation.

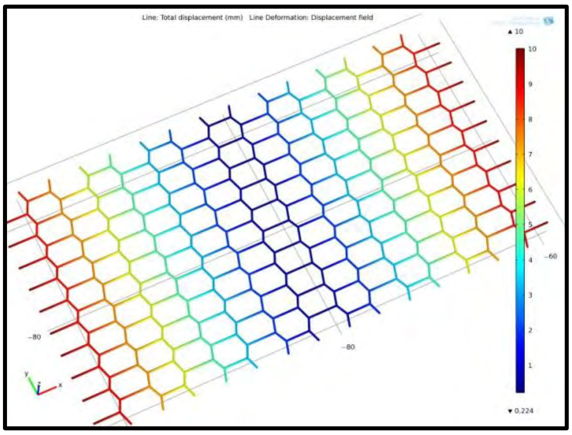

Figure 13. Total displacement of the knitted fabric for the tension simulation.

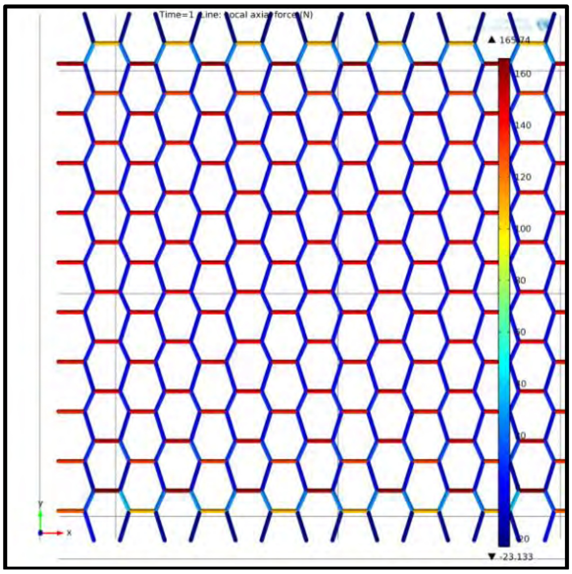

Figure 14. Axial force for the tension simulation.

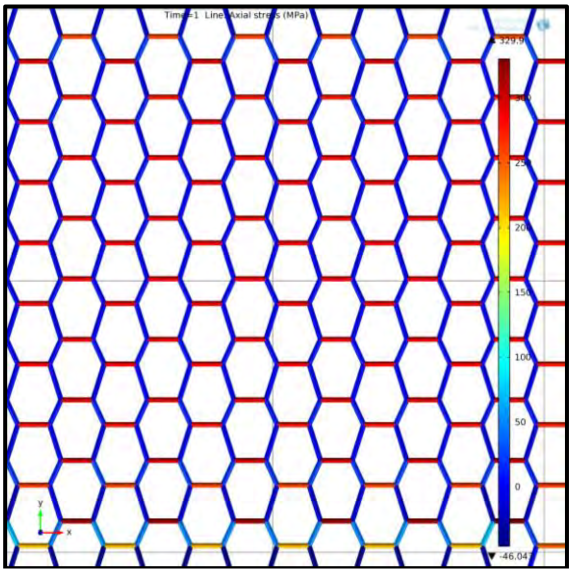

Figure 15. Axial stress for the tension simulation.

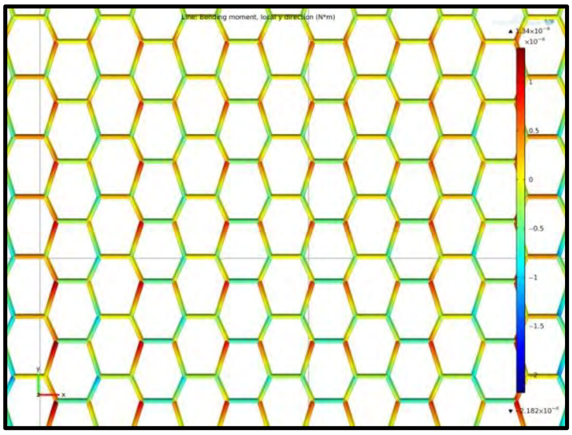

Figure 16. Bending moment of the local y direction for the tension simulation.

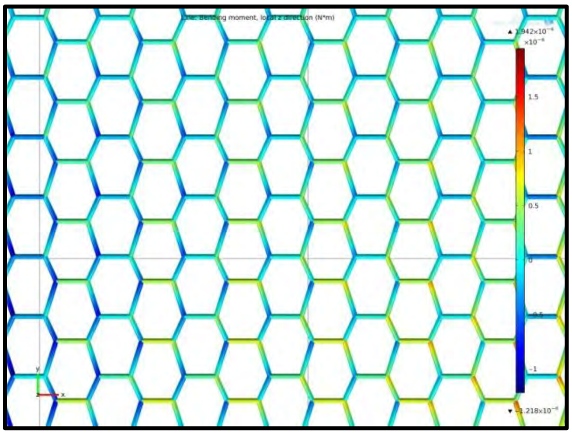

Figure 17. Bending moment of the local z direction for the tension simulation.

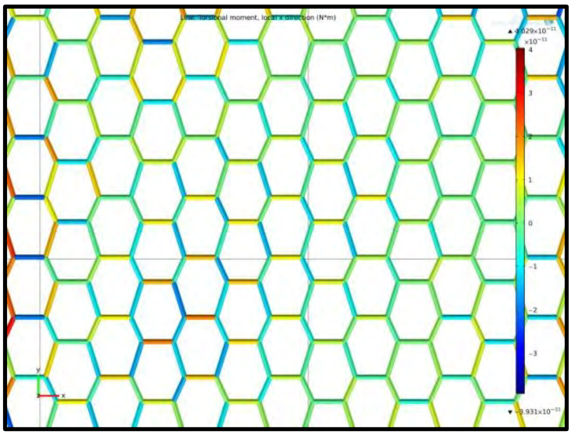

Figure 18. Torsion moment of the local x direction for the tension simulation.

The second simulation shows the response of the knitted fabric to the bending by the punch. The structure is still in the austenite phase, which is shown from the stress visualization. The bending and torsion moments are not inconsiderable as in the first case.

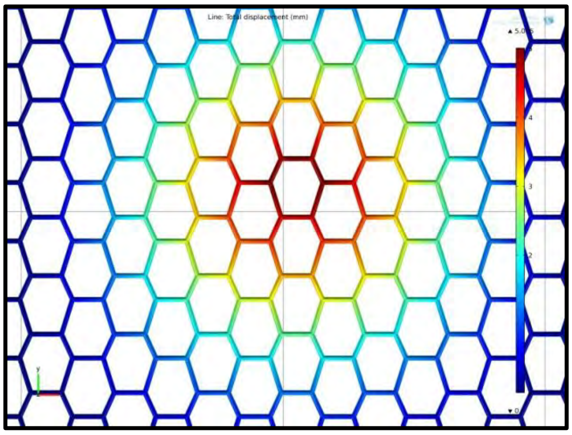

Figure 19. Total displacement for the bending simulation.

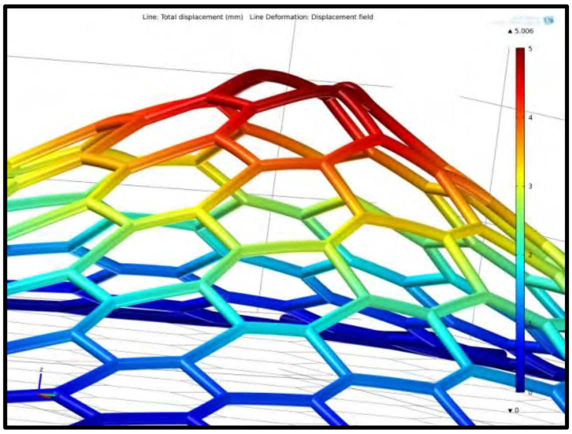

Figure 20. Total displacement for the bending simulation.

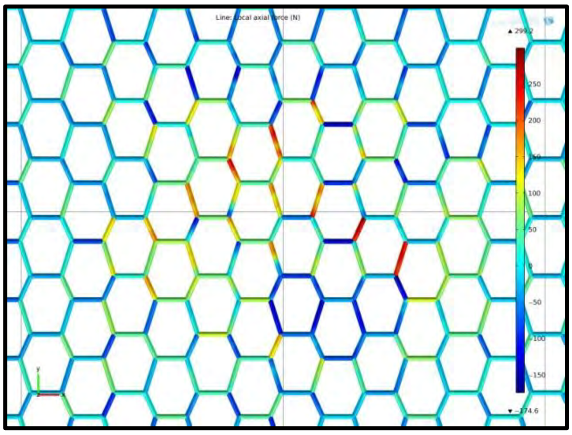

Figure 21. Axial forces for the bending simulation.

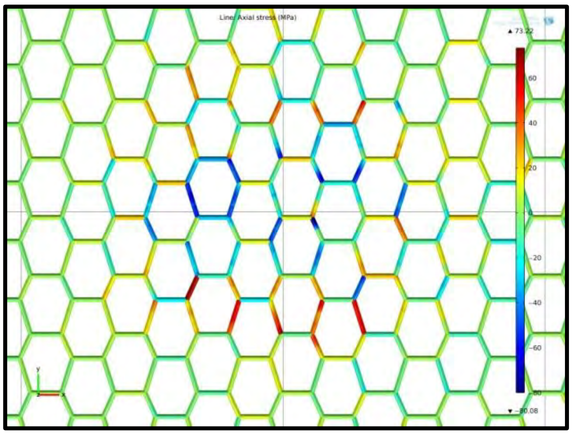

Figure 22. Axial stress for the bending simulation.

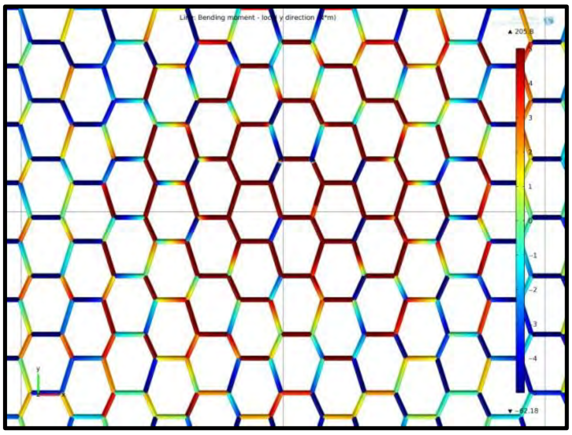

Figure 23. Bending moment of the local y direction for the bending simulation.

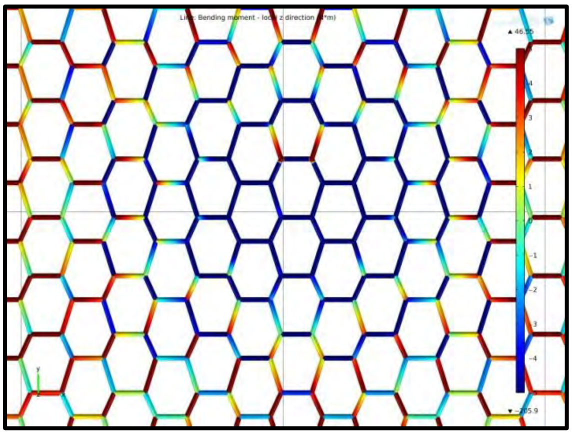

Figure 24. Bending moment of the local z direction for the bending simulation.

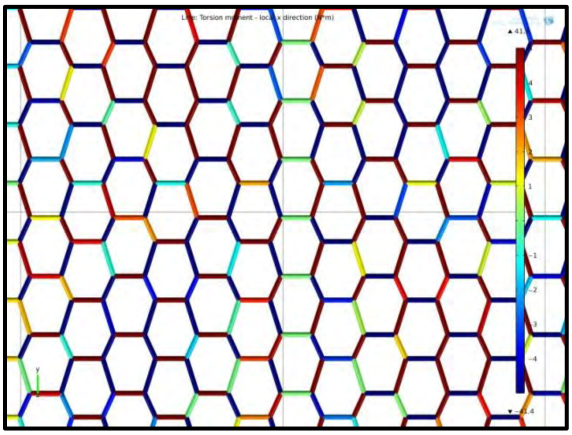

Figure 25. Torsion moment for the bending simulation.

5. Conclusions

The last simulations showed that out tests are still in the austenite phase. That is the reason, why we can replace the material model for SMAs with the linear isotropic material model. That simplifies the next simulations. The results of the axial forces and the axial stress for the tension simulation are interesting. The other results (bending and torsion moments, …) are inconsiderable. The results for the bending simulation are more interesting even the distribution of the quantities is not regular and accurate. It is caused by irregular defining of the displacements, which are defined to the points on the knitted fabric. These points do not have the regular distribution in the circle of the punch.

6. References

1. Lagoudas, Shape memory alloys, *Book title*, Springer

2. MSC manual – theory and user information, *Book title*, MSC.Software

3. Auricchio, A robust integration algorithm for a finite strain shape memory alloy superelastic model, *Int. J. Plasticity*

7. Acknowledgements

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